NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

USING MODEL-BASED SYSTEMS ENGINEERING TO IMPROVE PROCESS MANAGEMENT IN THE DOD

by

Gustin W. Paras

September 2022

Thesis Advisor:	Warren Vaneman
Second Reader:	Ronald R. Carlson

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC, 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** September 2022	**3. REPORT TYPE AND DATES COVERED** Master's thesis	
4. TITLE AND SUBTITLE USING MODEL-BASED SYSTEMS ENGINEERING TO IMPROVE PROCESS MANAGEMENT IN THE DOD			**5. FUNDING NUMBERS**
6. AUTHOR(S) Gustin W. Paras			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.			**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

Every engineering organization within the DOD relies on documented processes, but few have access to modern process-management resources to assist in the development and the sustainment of their processes. This thesis proposes leveraging existing systems-engineering resources to offer the DOD's engineering workforce a modern digital process-management solution. The thesis begins with a literature review of existing process-management techniques and uses this research, along with model-based systems engineering (MBSE) practices, to tailor an existing systems engineering methodology for digital process management. The MBSE process-management methodology proposed in this thesis provides the DOD engineering workforce with increased collaborative, modeling, traceability, and simulation capabilities over the traditional process-management practices in use.

The effectiveness of the MBSE process-management methodology presented in this thesis was demonstrated through a case study conducted on a DOD process used to accept critical safety items for DOD use. Through the application of the MBSE process-management methodology, performance improvement goals set at the beginning of the case study by the process stakeholders were met and exceeded. Based on the results of the case study, it is the recommendation of this thesis that MBSE practices, already prevalent within the DOD engineer workforce, be utilized to improve process management within DOD engineering organizations.

14. SUBJECT TERMS model-based systems engineering, MBSE, process improvement, process management, business process management			**15. NUMBER OF PAGES** 165
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

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USING MODEL-BASED SYSTEMS ENGINEERING TO IMPROVE PROCESS MANAGEMENT IN THE DOD

Gustin W. Paras
Civilian, Department of the Navy
BSME, Virginia Polytechnic Institute and State University, 2015

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
September 2022

Approved by: Warren Vaneman
Advisor

Ronald R. Carlson
Second Reader

Oleg A. Yakimenko
Chair, Department of Systems Engineering

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LIST OF ACRONYMS AND ABBREVIATIONS

BPI	Business Process Improvement
BPM	Business Process Management
BPMN	Business Process Model and Notation
BPR	Business Process Reengineering
BVA	business value-adding
CCA	Clinger Cohen Act
DOD	Department of Defense
GAO	Government Accountability Office
LML	Life cycle Modeling Language
MBSE	model-based systems engineering
NVA	non-value adding
SIMILAR	State, investigate, model, integrate, launch, assess, reevaluate
SysML	Systems Modeling Language
UML	Unified Modeling Language
VA	value-adding
WAWF	Wide Area Workflow

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EXECUTIVE SUMMARY

This thesis proposes a model-based system engineering (MBSE) process management methodology for use within Department of Defense (DOD) engineering organizations and demonstrates the methodology's ability to facilitate digital process improvement through a case study using a DOD engineering process.

As the largest engineering organization in the world with over two million employees, and a leader in the development and the acquisition of advance defense systems, the DOD must maintain modern and efficient processes to complete its mission (U.S. Department of Defense 2022). This need for high performing processes has been repeatedly recognized over the years and is addressed within the DOD by multiple continuous process improvement documents detailing the application of process reengineering, Just-In-Time, Lean, and Six Sigma (DAU n.d; Department of Defense 2008; United States Government Accountability Office 2015). While the lessons detailed in the DOD's continuous process improvement documents are applicable to the DOD engineering workforce, process management within industry has advanced far more rapidly with digital process management methodologies and tools becoming the standard.

While the DOD has yet to explore the advantages offered by modern process management techniques, the DOD has adopted and pushed best practices and modern tools from the field of systems engineering. If a process is viewed as a system consisting of several interacting subsystems, the systems engineering resources and tools available to the DOD workforce can be leveraged and used in unison with process management research to offer a digital process management solution. Guided by the four research questions shown below, this thesis explores the capability of MBSE to offer a digital process management solution to the DOD engineering workforce.

- How can the systems engineering process be applied to an engineering organization’s processes to facilitate both the improvement and long-term management of the process?
- How can MBSE languages be used to model a DOD organization’s structure and process flow?
- What process management best practices from industry can be leveraged to improve a systems engineering approach to process management?
- How can MBSE simulation capabilities be used to quantify process performance throughout the process life cycle?

The SIMILAR systems engineering process, shown in Figure ES-1, provided the basic activity flow for the MBSE process management methodology (Bahill and Gissing 1998). Within each step of the SIMILAR process, MBSE activities were integrated with best practices from the field of Business Process Management (BPM), and Business Process Reengineering (BPR) to tailor the generic systems engineering methodology for process management. The MBSE process management methodology relies heavily on an MBSE software’s modeling, simulation, and requirements traceability capability to construct and validate process models and uses known process management analysis techniques and best practices to guide process improvement. The collaboration capabilities of an MBSE software are used throughout the methodology to facilitate the construction and the validation of models, and technical information transfer to stakeholders.

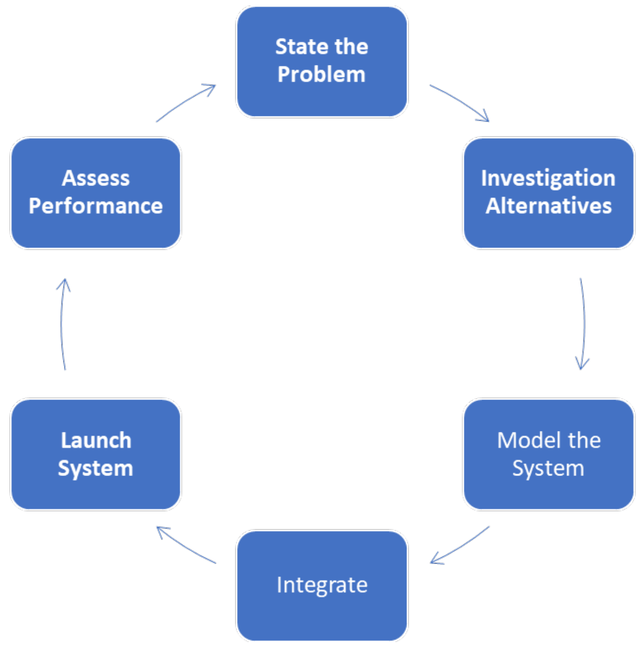

Figure ES-1. The SIMILAR systems engineering process. Adapted from Bahill and Gissing (1998).

A case study using a DOD engineering process was conducted to demonstrate the effectiveness of the MBSE process management methodology at generating process improvements. The case study, which applied the MBSE process management methodology to a DOD engineering process used to accept critical safety items for DOD use, resulted in a 24.5% improvement in the subject process's simulated duration performance. The duration improvement generated by the methodology met the duration performance improvement goal of 20% set at the beginning of the case study, confirming the MBSE process management methodology could facilitate digital process improvement.

Further research is needed to confirm the hypothesis of the thesis, that MBSE can offer a long-term digital process management solution. The case study conducted in support of this research executed one iteration of a continuous MBSE process management methodology. While this single iteration of the process generated positive results, additional research should examine the challenges and the ability of MBSE to support process management through a process' entire life cycle, which could span several years.

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ACKNOWLEDGMENTS

I would like to thank my advisors, Dr. Warren Vaneman and Prof. Ron Carlson, whose guidance over the past year has been invaluable. Your encouragement during this process and periodic distraction from my thesis to discuss current sports news made this process far more enjoyable.

To my boss, Ed, thank you for telling me on day one to finish my master's degree, and reminding me every year after that, that I had to finish.

Last and most importantly to my wife, Leslie, thank you for supporting me over the past two years of classes, meetings, and late nights working on my degree. I could not do this without your support, and I am grateful for your patience through this entire process. It took much longer than planned to get my master's, but you never stopped pushing me to finish (or restart and finish). I am excited to be wrapping up this chapter and starting our family together.

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I. INTRODUCTION

The purpose of this thesis is to develop a model-based systems engineering (MBSE) methodology for process management and to demonstrate the methodology's effectiveness when used as a process management solution for the Department of Defense's (DOD) engineering workforce. The research conducted for this thesis aims to address the gap in the DOD's process management resources through the utilization of MBSE, a resource being widely pushed within the DOD's engineering workforce.

As the largest employer in the world with over two million employees (U.S. Department of Defense 2022), and as a leader in the development and the acquisition of dozens of advance defense systems, the management of engineering process within the DOD is a significant undertaking. The difficulty of managing DOD processes is compounded by the lack of process management standardization within the DOD, and the continuously increasing complexity of defense systems and their support systems. This thesis proposes an MBSE solution to address deficiencies within the DOD's process management guidance for the engineering workforce. This will be achieved through the completion of two primary objectives: 1) create a model-based systems engineering process management methodology utilizing prior research from the fields of Systems Engineering and Business Process Management, and 2) demonstrate the effectiveness of an MBSE process management methodology through a case study on a known DOD system.

A. BACKGROUND

> Every good process eventually becomes a bad process, unless continuously adapted and improved to keep up with the ever-changing landscape of customer needs, technology and competition. (Dumas et al. 2013)

Engineering organizations within the DOD rely on documented processes to complete work and support the capabilities needed by the warfighter. These processes vary greatly in scope and complexity, but all share the common need to be maintained and adapted as the DOD and the environment the DOD operates in evolves. Across the DOD a lack of modern process management training, resources, and tools has resulted in the poor maintenance of existing engineering processes and has led to significant inefficiencies in engineering processes over time. While the mission to support the war fighter requires the DOD to act and deliver resources to the fleet faster than ever, the legacy processes that guide the DOD's engineering workforce introduce inefficiencies that negatively impact both schedule and cost performance.

The need to maintain and improve processes within the DOD has been repeatedly recognized over the last several decades. In the 1996 the Clinger Cohen Act (CCA) highlighted several issues with the adoption of information technology (IT) within existing DOD processes (DAU n.d.). One year later, in 1997, the Government Accountability Office (GOA) released the Business Process Reengineering Assessment Guide to address the process inefficiencies identified through the CCA and to help redesign workflow within DOD organizations. In the early 2000s, the DOD added to its process management efforts through the introduction of the Continuous Process Improvement (CPI) program. Since the introduction of these process management resources, numerous GAO reports have again identified issues within the DOD's processes. GAO reports published in 2012, 2013, and 2015 have discussed existing problems and inefficiencies within the DOD's business systems modernization effort and identified applications of business process reengineering within the DOD that have yet to be complete (GAO-12-685, GAO-13-685, and GAO-15-627 respectively). Additionally, GAO report GAO-15-192, published in 2015, identified the need to streamline decision making processes within the DOD's weapons acquisition process due to the large amount of time DOD acquisition programs spend on unnecessary or low value steps. There are numerous additional reports that detail process inefficiencies within the DOD but examining specific processes across the DOD is outside the scope of this thesis. The referenced reports are documented to establish the continuous need for process maintenance and improvement within the DOD. Processes can become inefficient over time, and often become bogged down when new technologies are added to processes or oversight changes. Even at the lowest level processes, the DOD workforce must be equipped to conduct the needed process maintenance.

Department of Defense specific process development, and process improvement guides have been generated in response to the numerous reports detailing process inefficiencies within the DOD. As of January 2022, the DOD-wide guidance for process development and process improvement are DOD Directive (DoDD) 5010.42, "DOD-Wide Continuous Process Improvement (CPI)/Lean Six Sigma (LSS) Program" dated May 15, 2008, DOD Instruction (DoDI) 5010.43, "Implementation and Management of the DOD-Wide Continuous Process Improvement/Lean Six Sigma (CPI/LSS) Program" dated July 17, 2009, and The DOD Business Process Reengineering Assessment Guidance dated September 28, 2012. These publications provide a structure for the implementation of process reengineering, Just-In-Time, Lean, and Six Sigma, but do not provide a detailed structure for continuous process management and do not detail the use of current digital process management tools. The DOD has no current organization wide standard for how processes should be maintained over time, and commonly does not make digital process management tools available to the engineering workforce. As a result, the advancement of process management within the DOD's engineering activities has not paralleled that of industry and academia. Within industry, collaborative digital process management tools are available, and their use is backed by research in academic fields like Business Process Reengineering (BPR), Business Process Management (BPM), and the sub-fields of BPM like Business Process Improvement (BMI). Within the DOD, the management of process is far less sophisticated, with organizations having minimal guidance and relying on generic office software solutions.

While the DOD's process management resources lack detail and direction regarding modern digital process management techniques, an underlying lesson reiterated several times through DOD process improvement literature is that process improvement cannot be limited to only the material covered by DOD documentation. According to the DOD's CPI plan, a requirement for the success of any process improvement effort within the DOD is:

> Staying receptive to new CPI concepts and tools as they might evolve and become applicable, while avoiding becoming locked in on a single school of thought that precludes other useful approaches and perspectives. (Department of Defense 2008, 2-5)

1. Process Management within the DOD

Within the DOD engineering workforce most processes are recorded and controlled through the management of non-model-based process documentation. This documentation commonly is in the form of written out procedures, flowcharts, hierarchy charts, or a combination of these items. The primary goal of this process documentation is to provide a detailed explanation of the steps and the sequence required to complete a task. Often DOD engineering process documents meet this top-level requirement and provide the necessary information to complete a task, but commonly the processes are recorded in a manner that prevents easy maintenance or rapid adaptability. Department of Defense process documentation rarely records the requirements driving a process and varies significantly in format and detail between organizations, with images of flowcharts and written out procedures being the most common formats. These issues are exacerbated by the fact that many commands within the DOD rely on generic, non-collaborative office software solutions (Microsoft PowerPoint or Vizio) when developing or managing processes and do not have standards guiding the development or maintenance of said processes. These process documentation and management issues results in: inconsistencies between organization processes and process documentation, a lack of traceability between process requirements and a process, and inefficiencies in processes.

Figure 1 shows the process documentation for an in-service engineer process within a DOD command. This documentation, which is similar in detail to several others process documents used across the DOD command, shows the top-level workflow for an in-service engineer with the decomposed workflow of a single sub process. While the documentation does show the necessary steps to complete the task of interest and the chronological order of the steps from one perspective, the resolution of the process is very low, no requirement details are captured for the processes, and minimal details are provided elaborating on the purpose of each step. Because of this, before any maintenance can be performed on the process (assessing, altering, removing, or adding steps) the requirements of the process will have to be determined along with any intermediate steps and details. This can be a challenging and time-consuming task, especially with legacy processes where the originator is no longer available as a resource. Additionally, in the case of the example documentation shown in Figure 1, the process was documented via flowcharts that were saved as PDF images and cannot be quickly modified. To make any updates to the flow charts, copies of the process documentation would have to be remanufactured prior to any modification. This increases the time investment that must be made to maintain the process, and it introduces the chance of errors between copies of the documentation.

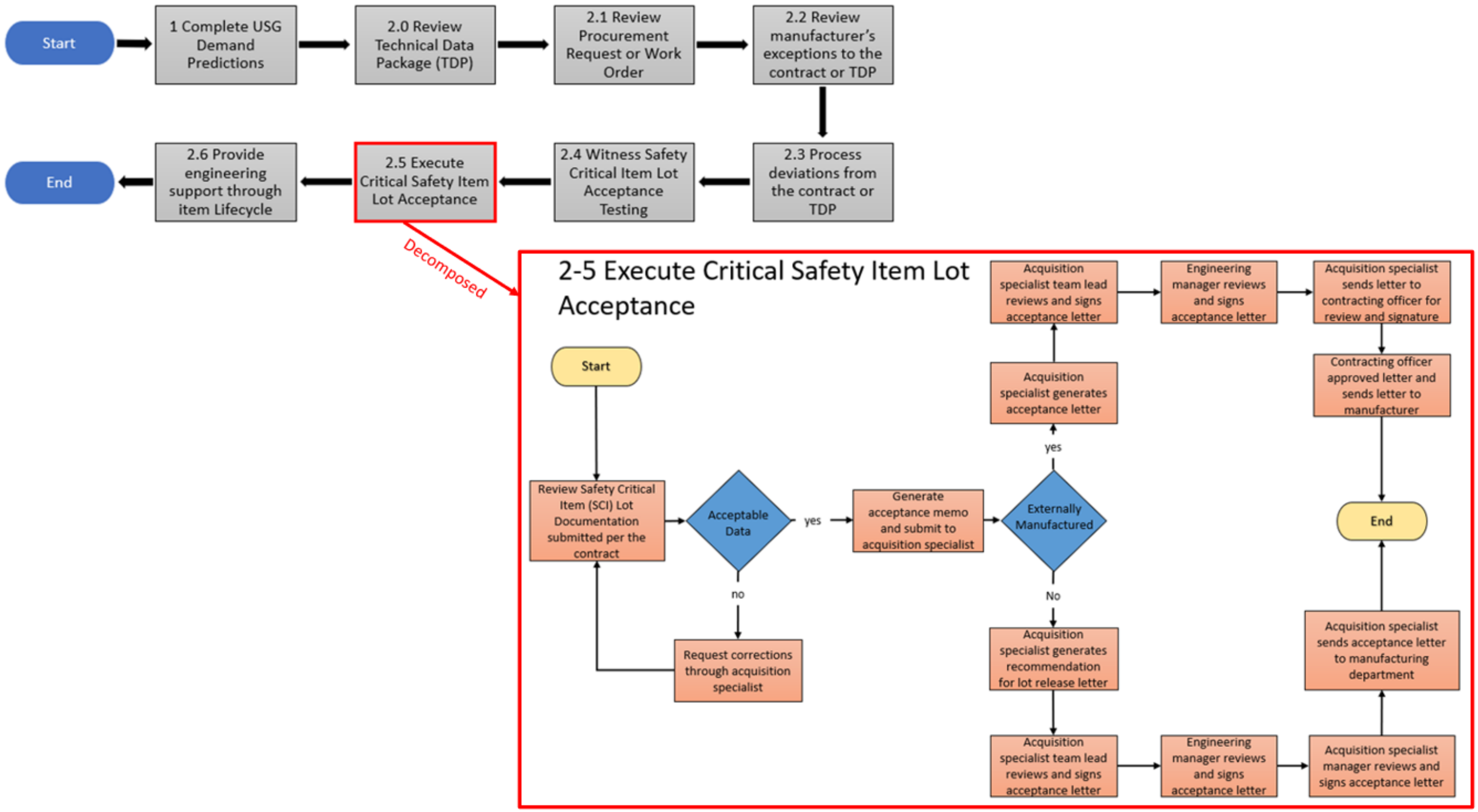


Figure 1. Example DOD process documentation for an in-service engineering group.

In addition to traceability issues, process documentation like that shown in Figure 1 provides very little assistance when trying to improve a process. No throughput, cost, or duration data is captured in the process documentation, and multiple tasks are consolidated into single steps resulting in extremely low resolution. Furthermore, the various actors involved in the process are not clearly defined along with the interactions between them. Given this documentation, any effective attempt at process improvement can only be made by someone with extensive experience with the process, and even then, there is a high chance of bias preventing the best solution. Even if all required process information was readily available, most DOD engineering organizations are not provided tools or guidance on how to analyze and simulate the operation of a process which allows for the identification of issues like bottle necks, non-value adding steps, and inefficient process flows.

2. A Systems Engineering Approach

Prior to the development of an MBSE methodology for process management, two questions must be addressed: 1) can systems engineering practices and principles be applied to a process, and 2) why not used an existing process management solution?

The definitions for both a system and a process shown below give us an insight into the first question.

> A system is an arrangement of parts or elements that together exhibit behavior or meaning that the individual constituents do not. (INCOSE 2019)
>
> A process is a collection of inter-related events, activities and decision points that involve a number of actors and objects, and that collectively lead to an outcome that is of value to at least one customer. (Dumas et al. 2013, 5)

While the definition for a system and process do slightly differ, both a process and a system consist of components integrating in a specific way to produce an outcome that could not be generated by any single actor or action. Based on these definitions, a process is a type of system where the elements are events, activities, and decision points. Additionally, as with any system, a process has stakeholders driving requirements and in turn the design of the system. Two types of stakeholders, actors and objects performing the process, are identified right in the definition of a process.

The second concern that must be addressed is why the DOD engineering workforce does not use an existing process management technique and tool commercially available, why “reinvent the wheel”? The answer here comes down to resource limitations within DOD organizations. The implementation of a commercially available process management system would have a high investment cost that DOD leadership has not been willing to accept. Not only do commercially available process management products often have relatively high subscription or licensing costs, but the implementation of a DOD-wide process management training program, and the act of securing a commercial software for DOD use carry high costs and a logistical challenge. Systems engineering training, resources and MBSE tools on the other hand are being widely pushed in the DOD’s engineering workforce, and often as the one-size-fits-all solution to problems, including those outside the traditional scope of systems engineering. Within several DOD commands UML, SysML, and LML MBSE tools are available with ongoing efforts to implement the tools across the organization.

The application of a systems engineering approach to the DOD’s process management problem is only part of the solution proposed by this thesis. The use of an MBSE tool to apply a systems engineering methodology is equally as important. Collaborative business process management software has become one of the most accepted methods to improve the chance of success for a business process management program in industry (Vuksic, Brkic and Tomicic-Pupek 2018). For the methodology developed for this thesis, an MBSE software is utilized in place of a business process management software and offers many of the same capabilities critical to the success of a process management effort. Like many digital business process management systems, an MBSE solution to process management will allow for the collaborative development, refinement, and management of a process (system of interest) in a digital modeling environment. The digital environment offered by an MBSE software resolves the issue of inconsistent and inaccessible process documentation by allowing processes to be developed and maintained as a collaborative digital model instead of the paper-based diagrams and documents traditionally used. Additionally, the use of MBSE allows for the modeling of relationships and structures that are difficult to capture with traditional paper-based process documentation approaches. Within an MBSE environment, organization structures can be modeled along with the relationships between each actor. MBSE tools are also capable of managing requirements traceability within the digital environment and have simulation capabilities that can be used to test process performance and quantify process improvement.

B. RESEARCH QUESTIONS

The background provided in this chapter details the current state of process management within the DOD and the motivation for the thesis. Based on the issues outlines in the background this thesis will aim to address the following research questions:

1. How can the systems engineering process be applied to an engineering organization's processes to facilitate both the improvement and long-term management of the process?
2. How can MBSE languages be used to model a DOD organization's structure and process flow?
3. What process management best practices from industry can be leveraged to improve a systems engineering approach to process management?
4. How can MBSE simulation capabilities be used to quantify process performance throughout the process life cycle?

C. ORGANIZATION

The thesis will be structured as follows:

Chapter II contains the results of a literature review that investigated process management best practices and tools utilized within industry. Chapter II also presents the results of an investigation into the various modeling languages and tools used within the systems engineering domain and the business process management domain to identify how systems engineering resources can be utilized to offer a process management solution.

Chapter III proposed a generic methodology for an MBSE approach to process management. The best practices and tools identified in chapter two were integrated into a systems engineering methodology in this chapter to provide a tailor MBSE solution for process management.

Chapter IV presents the results of a case study that applied the MBSE process management methodology to a DOD process.

Chapter V presents the conclusion of the research conducted and recommendations for further follow-on research.

II. LITERATURE REVIEW

A literature review was conducted on process management best practices identified by both industry and academia. The goal of this research was to identify both the lessons and tools previously recognized as effective for process management so they could be leveraged to tailor an MBSE methodology. Research was also conducted into the digital tools and modeling languages used for both process management and MBSE to identify the capabilities needed for a process management effort, and how the capabilities could be met using an MBSE approach.

A. PROCESS MANAGEMENT IN INDUSTRY

The constant need for higher performing organizations across all industry has driven the development of multiple disciplines dedicated to the improvement of business processes and operations. These fields include Business Process Reengineering (BPR), Business Process Management (BPM), and the sub-fields of BPM like Business Process Improvement (BMI). Each of these fields revolve around process thinking (Dumas et al. 2013), and aim to improve the way organizations operate through the implementation of a methodology that modifies a process's current state to eliminate inefficiencies and improve the utilization of resources. While the goal to improve the operation of an organization is similar among each of these fields of study, the methodology implemented for each is unique. The scope of this section of the literature review will be limited to the BPM, and BPR. There are several subfields of BPM that could add value to this review, but a holistic approach to business process management will include components from these sub-fields and therefore a review of BPM should address the critical characteristics that will be of value to the methodology developed for this thesis.

1. Business Process Management (BPM)

BPM is a field of study focusing on the continuous process of overseeing and managing how work is completed within an organization to improve processes and assure the organization is meeting the needs of the critical stakeholders (Dumas et al. 2013). BPM aims to provide the tools, principles, and structure needed to manage an organization's processes through the entire process life cycle (Dumas et al. 2013). Under a BPM effort, an organization will employ the BPM process and utilize any combination of modeling, measurement, automation, and controls to discover, analyze, redesign, and monitor business processes (Dumas et al. 2013). Unlike some business process improvement methodologies, BPM is a continuous effort focused on the continual sustainment and refinement of a process over its life cycle. BPM will be a primary focal point for this literature review since the goals of BPM align with the goals of the methodology being developed for this thesis.

Several variations of the BPM process flow exist, but most can be summarized by the following steps identified in the Guide to Business Process Management Common Body of Knowledge:

1. Planning
2. Analysis
3. Design and Modeling
4. Implementation
5. Monitoring and Control
6. Refinement. (Association of Business Process Management Professionals 2009)

One variation of the BPM process taken from the Fundaments of Business Process Management is shown below in Figure 2. This variation is unique because it pulls the process identification step out of the cyclical BPM process and uses it as an external starting point. Despite this unique feature, the BPM process shown in Figure 2 still aligns with the generic BPM steps.

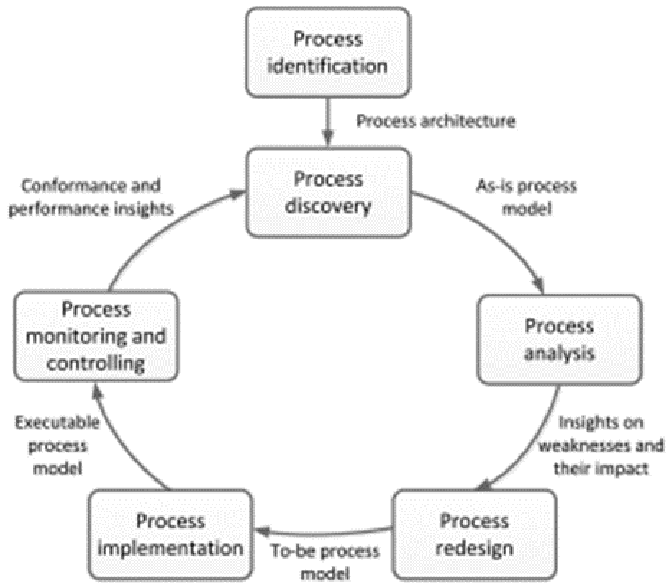


Figure 2. The fundamentals of business process management BPM process. Source: Dumas et al. (2013).

Since the target audience for the methodology developed for this thesis is the DOD's engineering workforce, it is critical to note the BPM process mirrors a basic system engineering design process, and furthermore, the scientific process. This phenomenon of multiple processes across multiple disciplines following almost identical steps was first observed by Bahill and Gissing (1998), who identified similarities in more than one dozen well known processes from diverse technical and non-technical fields. From their research, Bahill and Gissing concluded that human thinking drove the structure of the general problem-solving process and as a result they developed the SIMILAR systems engineering process which captured the generic structure they had observed. Bahill and Gissing's research is important to this thesis because it supports the argument that the BPM process is not unique and is a revision of the generic systems engineering process. Table 1 shows a comparison of the BPM process, and several other technical processes which include the SIMILAR Systems engineering process and the scientific method. As observed by Bahill and Gissing these processes are nearly identical at the resolution presented. This supports the hypothesis of this thesis that the target audiences' existing knowledge of engineering can be used to provide the structure for a process management methodology.

Table 1. A comparison of the generic BPM process and various engineering processes.

Business Process Management	“Planning”	“Analysis”	“Design and Modeling”	“Implementation”	“Monitoring and Control”		“Refinement”	(Association of Business Process Management Professionals 2009)
Business Process Reengineering	“Fundamental Rethinking”	“Hunt for Reengineering Opportunities”	“Model the Business Processes”	“Relocate work Across Organizational Boundaries”	“Radical Redesign”	“Achieve Dramatic Improvements”		(Hammer and Champy, Reengineering the Corporation: A Manifesto for Business revolution 1993)
“SIMILAR Systems Engineering Process”	“State the Problem”	“Investigation Alternatives”	“Model the System”	“Integrate”	“Launch System”	“Assess Performance”	“Re-evaluate”	(Bahill and Gissing 1998)
Systems Engineering Activities	“Definition of Need and Conceptual Design’	“Preliminary Design”	“Detailed Design and Development”	“Production and Constructions”	“Utilization and Support”		“Phase-out and Disposal”	(Blanchard and Fabrycky 2011)
Scientific Process	“Ask a Question”	“Perform Background Research”	“Propose a Hypothesis”	“Test the Hypothesis”	“Analyze the Test Data and Draw Conclusion”		“Reiterate”	(Reading Rockets 2019)

Beyond the top-level structure similarities between the BPM process and the systems engineering process, the processes also utilize many of the same principles when examined in greater detail. Both BPM and the systems engineering process have a requirement to define system boundaries early in the process, and a requirement to establish performance metrics based on stakeholder requirements. There are dozens of additional similarities between the two processes that could be identified but discussing each one individually is unimportant for this thesis. The assumption moving forward is the similarities between BPM and systems engineering can be leveraged for an engineering specific process management methodology allowing a focus to be placed on identifying the unique BPM characteristics that are critical to the success of a process management effort.

Both systems engineering and BPM are more than just sciences, there is an artistic component to both (Dumas et al. 2013; Maier and Rechtin 2009). This is to say that within both BPM and systems engineering, there are many processes and steps where there exists no one correct path or solution. In these scenarios, quantitative requirements and measures alone are often inadequate to reach the best solution. The actions and decisions of an individual in these moments are instead made based on a set of personal lessons gathered through experience. In an interest to progress the fields of study, academics in the fields of systems engineering and BPM have worked to document these lessons and principles previously learned. The lessons, or heuristics gathered from BPM will be a key focal point for this thesis. The assumption has been made that the audiences will have their own set of systems engineering heuristics, but they will have minimal knowledge of BPM specific heuristics, and therefore minimal guidance in the art of process management.

Table 2 provides a list of analysis tools recognized by experts in the field of process management as valuable for a process management effort. These tools are not unique to BPM but given the target audience's minimal experience with process management, it is worth identifying the tools as applicable to a process management effort. The engineering audience targeted by this project will have broad experience with analysis tools, identifying which of these analysis tools can effectively be applied to a process management effort will reduce the total time required to conduct a process management effort by downsizing the available toolset. Each of these tools might not be applicable to every process, instead the goal is to identify multiple tools that a process owner can select from when conducting a process management effort.

Table 2. Process management analysis tools.

1	Value-Added Analysis	Value Classification – Identify if a step is: - “Value-adding (VA): This is a step that produces value or satisfaction vis-à-vis of the customer. When determining whether or not a step is value-adding, it may help to ask the following question: Would the customer be willing to pay for this activity?” (Dumas et al. 2013, 187) - “Business value-adding (BVA): The step is necessary or useful for the business to run smoothly, or it is required due to the regulatory environment of the business.” (Dumas et al. 2013, 187) - “Non-value adding (NVA): The step does not fall into any of the other two categories.” (Dumas et al. 2013, 187) Waste Elimination – Eliminate or minimize non-value-added steps. Ask “what is the minimum amount of work required in order to perform the process to the customers satisfaction.” (Dumas et al. 2013, 190)
2	Root Cause Analysis	“Part of the job of a [process owner] is to identify and to document the issues that plague a process. To this end, [a process owner] will typically gather data from multiple sources and will interview several stakeholders.” (Dumas et al. 2013, 190) With this information, any number of root cause analysis techniques can be utilized to identify the cause of problems identified by the stakeholders. Example techniques are the fishbone analysis method and the five why method.
	Sensitivity Analysis	A sensitivity analysis (also known as a “what if” analysis) tries to determine the outcome of changes to the parameters or to the activities in a process (Association of Business Process Management Professionals 2009). A sensitivity analysis will help a process owner understand the responsiveness of the process to internal and external change.

The analysis tools identified in Table 2 will allow a process owner to understand the issues within a process and how a process reacts to manipulation. While this understanding is critical to a process management effort, once a process is understood, the process owner must be able to improve the process. Since there is no one way to improve every process, this process modification or redesign effort is guided by experience. Table 3 identifies several BPM best practices that have been documented by experts in the field of BPM. For the target audience, these best practices or heuristics will supplement the lack of experience managing processes and provide known approaches to improve a process's performance. Like the tools listed in Table 2, the heuristics identified in Table 3 are not applicable to every process and are instead meant to equip a process owner with general set of known effective methods to select from.

Table 3. BPM best practices.

Number	Lesson/Heuristic
1	"Reduce the number of contacts with customers and third parties" (Reijers and Mansar 2005).
2	"Eliminate unnecessary tasks from a business process" (Reijers and Mansar 2005).
3	Consider the division of a general task into two or more alternative tasks' or 'consider the integration of two or more alternative tasks into one general task" (Reijers and Mansar 2005).
4	"Combine small tasks into composite tasks and divide large tasks into workable smaller tasks' (Reijers and Mansar 2005).
5	"Move tasks to more appropriate places' (Reijers and Mansar 2005)
6	"Order knockouts in an increasing order of effort and in a decreasing order of termination probability' (Reijers and Mansar 2005).
7	"Consider whether tasks may be executed in parallel' (Reijers and Mansar 2005).
8	"Design business processes for typical orders and isolate exceptional orders from normal flow' (Reijers and Mansar 2005).
9	"Avoid assignment of task responsibilities to people from different functional units' (Reijers and Mansar 2005).
10	"Minimize the number of departments, groups and persons involved in a business process' (Reijers and Mansar 2005).
11	"Appoint one person as responsible for the handling of each type of order in relevant processes' (Reijers and Mansar 2005).
12	"Consider making resources more specialized or more generalist' (Reijers and Mansar 2005).
13	"Give workers most of the decision-making authority and reduce middle management' (Reijers and Mansar 2005).

Number	Lesson/Heuristic
14	“Check the completeness and correctness of incoming materials and check the output before it is sent to customers’ (Reijers and Mansar 2005).
15	“Consider automating tasks’ (Reijers and Mansar 2005).
16	“Try to elevate physical constraints in a business process by applying new technology’ (Reijers and Mansar 2005).
17	“Instead of determining information oneself, use results of a trusted party’ (Reijers and Mansar 2005).
18	“Consider a standardized interface with customers and partners” (Reijers and Mansar 2005).

2. Business Process Reengineering (BPR)

Business Process Reengineering is a process improvement approach that calls for the complete redesign of an organization’s entire process to achieve significant improvements in an organization’s performance. BPR operates on the assumption that the process of interest is fundamentally inefficient, and any effort to incrementally change the process will result in minimal performance improvements (GAO Accounting and Information Management Division 1997). A BPR effort regularly involves redesigning processes at an organization level, and it starts with an organization defining its mission and priorities. A BPR effort requires extensive labor to complete, so understanding an organization’s mission and the gaps between an organizations current state and desired state are critical prior to committing the resources to conduct such an effort. The product of a BPR effort is the implementation of a completely new process built around an organization’s mission and resources.

Unlike other process improvement approaches, a BPR effort cannot be performed independently by a process owner. Heavy involvement from leadership throughout the entire process is critical for success (GAO Accounting and Information Management Division 1997). This scale of organization and process redesign is outside the scope of this project since this thesis aims to provide engineering process owners with a tool to manage and improve their own processes. While the scope of BPR effort is significantly greater than the methodology proposed in this thesis, principles from BPR provide valuable guidance for any process management effort.

Michael Hammer, a professor at the Massachusetts Institute of Technology who initially introduced the concept of process reengineering, observed that when organizations invested in new technology, often the processes involved were not redesigning around the technology. Instead, the new technology was forced to fit over the existing processes, resulting in sub-optimal performance. This observation can easily be extended to DOD engineering processes today, many of which have adopted dozens of new technologies like email, computer aided design, and IT databases with minimal redesign. While Hammer's solution to these sub-optimal processes, process reengineering, is more dramatic than the solution developed for this thesis, the principles at the center of Hammer's proposed solution are valuable. In "Reengineering Work: Don't Automate, Obliterate" Hammer states:

> We cannot achieve breakthroughs in performance by cutting fat or automating existing processes. Rather, we must challenge old assumptions and shed the old rules that made the business underperform in the first place. (Hammer 1990, 6)

The necessity to challenge old assumptions and rules is a key component that will be carried throughout this thesis. All too often in organizations, the justification for a process is "We've Always Done It This Way," This thinking demonstrates a lack of understanding of a process's requirements, and regularly leads to processes with many non-value adding or antiquated steps. When managing a process, the stakeholders, their needs, and their requirements need to be understood. If a process or step is not supporting a stakeholder requirement, or a requirement can be supported in a better way, change needs to occur.

Within the field of systems engineering documenting and understanding stakeholder needs is a fundamental step critical to the success of any effort. While the system's engineering approach to process management should include this fundamental step, it is worth reiterating the importance even within the field of BPR. The success of any effort to improve a process is dependent on an understanding of the requirements driving the process and the function the process must perform.

The second principle that will be pulled from Hammer and the field of BPR is:

> "Put the decision point where the work is performed, and build control into the process." (Hammer 1990, 15)

Within the DOD, organizations and as a result processes, have become risk adverse with many processes being slowed by several levels of oversite, and decision authority being held at the top of organizations (Schultz 2022). While Hammer statement isn't explicitly intended to target this oversite and bureaucracy within DOD processes, the performance of many DOD processes would be greatly improved by lowering decision authority to the same level that work is performed at. This isn't to say that all oversite should or even can be removed, but redundant oversite, and decision points pushed up the management hierarchy without a strict requirement demanding so, should be reviewed, and eliminated when possible. Not only do unnecessary levels of authority and oversite introduce additional steps within a process that drain resources, but single point decision authorities within an organization can often become bottlenecks for workflow. While this principle aims to address a common decision authority problem within processes, it does tie closely with the first principle from Hammer to challenge current assumptions and rules. The existence of oversite or high-level approvals in a process's current state does not mean there is a strict requirement supporting it, or that it is the best way for workflow to be structured.

There is a great deal that can be learned from the field of BPR and the success and failures in the field. For this thesis, a basic understanding of the motivation for BPR, and key relevant principles will be adequate. The principles identified in this section will be integrated into the systems engineering process management methodology developed for this project.

B. PROCESS MODELING AND ANALYSIS

1. Modeling Languages

Process modeling is a critical component of any process management effort. Process models are graphical representations of processes that are used across nearly every stage of the process management effort and provide valuable insight into how a process functions. According to Eriksson and Penker (2000) process models are created for any of six reasons:

1. To better understand the key mechanisms of an existing business
2. To act as the basis for the creation of suitable information systems that supports the business
3. To facilitate improvements to the current business
4. To show the structure of an innovated business
5. To experiment a new business concept or to study an alternate business concept
6. To identify outsourcing opportunities. (Eriksson and Penker 2000)

Process models can be as simple as hand drawn flowcharts, or as complex as digital models which contain process characteristics like throughput, duration, or cost. The sophistication of process models depend on the complexity of the process of interested, the goals of the process management effort, and the resources available to a process owner during a process management effort. At the most basic level, a process model should accurately represent the process of interest and allow a process owner to see the workflow for the purpose of analysis. More sophisticated process models will include information on the organization's goals and structure, and process performance data to allow more detailed analysis.

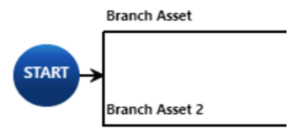
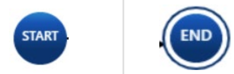
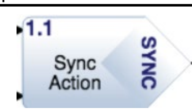
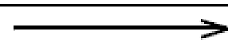
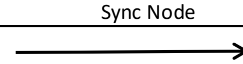
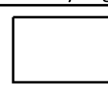
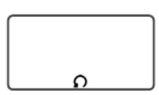
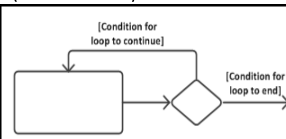
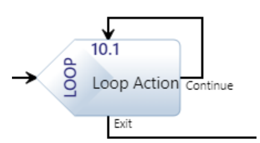
Within the field of BPM, a unique process modeling language, Business Process Model and Notation (BPMN), was developed to support the standardized construction of accurate process models. BPMN is a process focused, graphical modeling language that was developed with the primary goal of being easy to understand for a wide range of stakeholders (OMG 2011). Today, BPMN has become the standard within industry for process modeling (Association of Business Process Management Professionals 2009). While BPMN is the industry standard for process modeling, the motivation for this thesis is a BPM resource limitation which includes the limited availability of BPMN resources. Multiple other modeling languages far more common within the DOD's engineering workforce like Systems Modeling Language (SysML), Unified Modeling Language (UML), and Life cycle Modeling Language (LML) can be used to model processes. Each of these modeling languages has the capability to model a process flow as well an organization's structure and the requirements driving a process. The following section investigates the ability to use SysML, UML, and LML for process modeling since these languages are becoming increasingly available to the DOD engineering workforce through MBSE efforts.

Studies have investigated the difference in process modeling performance of BPMN and other modeling languages like UML (Venera 2012; Eriksson and Penker 2000). When comparing UML and BPMN specifically, the only notable difference repeatedly identified across multiple studies is the existence of more complex business process specific modeling components within BPMN that can only be modeled using multiple simple components in the UML language (Venera 2012). This presents an additional complexity when modeling certain processes using UML but does not prevent UML's use as a process modeling tool. The literature review conducted as part of this thesis was unable to identify any process that couldn't be modeled in LML, UML, or SysML.

Since one of the primary goals of BPMN is to be easy to understand, multiple studies have investigated the ability of stakeholders unfamiliar with modeling languages to understand process models. All studies found as part of the literature review concluded that stakeholders were able to understand process models in UML and BPMN with comparable ease (Venera 2012; Borges et al. 2008).

Research was conducted into the performance of LML and SysML to model processes, but very little information on the topic exists since LML and SysML were developed far more recently than UML. With that said, SysML is an extension of the UML language with activity diagrams being the primary process modeling tool in both UML and SysML. This means that the performance of SysML to model a process should be comparable to UML. Unlike SysML, LML is a unique modeling language. Within LML the tool used to model a process is an action diagram. While the action diagram is unique to the LML language with its own set of elements, the capability of an action diagram is similar to the activity diagram. Based on this similarity, the assumption has been made that LML will be comparable to UML and SysML in its ability to model a process. Table 4 shows a comparison of the basic elements available when modeling a process in BPMN, UML, SysML, and LML to further elaborate on the capability of each language to model a process.

Table 4. A comparison of BPMN, UML/SysML, and LML basic elements. Adapted from Venera (2012).

Process Elements	BMPN	UML/SysML	LML
Participants to the process	Pool 	Swimlane 	Branch Asset 
Process start and end points	 Start Event End Event	 Initial Node Final Node	 Start Node End Node
	"Note: In a process with more participants, BPMN uses a start event and an end event for the parts of the process corresponding to each participant, while UML, [SysML and LML] use only one initial node and one final node for the entire process" (Venera 2012).		
Activities performed by participants	 Task Object	 Action Node	 Action Node
An process element that represents a specific time expendeture.	 Timer Event	 Time Event	 An action node can be used to perform a time event
A modeling element that synchronizes (combines) parallel flows	 Parallel Gateway	 Join Node	 Sync Node
Process flow elements	 Sequence Flow	 Activity Edge	 Action Flow
Objects and data within a process	 Data Object	 Object Node	 Input/Output and Resource
"Elements of the business process that are represented in BPMN using one symbol and in UML, [and SysML] using a group of symbols" (Venera 2012).			
Activities that repeat sequentially or loop	 Activity Looping	 Action Node and Decision Node	 Loop Action

2. Process Modeling Tools

The various modeling languages previously discussed provide the ability to model a process. Equally as important as the modeling languages available are the tools used to implement and analyze such models. Within industry modeling software suites that utilize BPMN known as business process management software have become one of the most widely accepted means to ensure the success of a process management effort (Vuksic, Brkic and Tomicic-Pupek 2018). This is due to the capabilities, beyond modeling, delivered by the software solutions that reduce the time and effort to manage and design a process. Many of the leading BPM software solutions include the ability to capture organization structures and goals, and provide the capability to simulation processes and conduct social computing. These capabilities allow a process owner to trace a process to its requirements, to validate process models through simulation and exposure to all critical stakeholders, and to simulate process revisions prior to implementation.

Within the DOD's engineering workforce, many processes exist with a high enough complexity to warrant the use of a digital process management solution. Since BPM software solutions are rarely available to the DOD engineering workforce, it is the hypothesis of this thesis that MBSE software can be effectively used in their place. While MBSE software suites are not specifically designed for process management, they provide a collaborative digital environment where both an organization and the organization's processes can be modeled, and their performance simulated, generating data for a variety of performance metrics like cost, process duration, and resource utilization.

The capability requirements for a process management software will vary based on the organization investigating a process management effort, but often these requirements look similar. Examples of requirements or capabilities used during the select of BPM software from multiple sources are:

- "Process models have to be easy to understand because many employees were involved in the process modelling phase and we wanted them to understand the models of business processes without additional training." (Štemberger, Bosilj-Vukšić, and Jaklić 2009, 92)

- “The tool should be user friendly and process models should be easy to design.” (Štemberger, Bosilj-Vukšić, and Jaklić 2009, 92)

- “The BPM tool should provide the functions needed to dynamically analyses the processes.” (Štemberger, Bosilj-Vukšić, and Jaklić 2009, 92).

- “The tool should have the ability to express all elements of an enterprise architecture model (e.g., organizational diagram).” (Štemberger, Bosilj-Vukšić, and Jaklić 2009, 92).

- “Software should enable the user operates it and control it easily and efficiently. Allowing a friendly interaction with the user.” (Rocha et al. 2013, 493)

- “Capability of the system to keep your operation online on the server of the provider, minimizing possibility of interruption of service applications” (Rocha et al. 2013, 494)

- “BPM software should provide support for teamwork, communication and collaboration.” (VUGEC, STJEPIĆ, and SUŠAC 2019, 553)

While this is not an exhaustive list of possible process management requirements or capabilities, MBSE software can meet all identified requirements and often deliver many of the same capabilities as a BPM software. Research has indicated that UML and BPMN are comparable in the ability to be understood by interested stakeholders (Venera 2012). Additionally, most MBSE software options offer both simulation and analysis capabilities, and cloud support for remote access. Beyond the software capabilities offered by most MBSE options, MBSE software tools have a wealth of both free and professional training resources available to users. The one area MBSE can lack is in its ability to offer an easy-to-use interface (OMG Standards Developement Orginization 2015). This is in part due to the modeling languages employed by MBSE software and the increasing complexity of development projects across all industries (Finberg 2021). While usability is a metric that most MBSE software designers are working to improve, the process management effort explored through this research only employs a small portion of the capabilities of MBSE software and therefore should reduce the complexity and in turn improve usability.

III. METHODOLOGY

In this chapter, the process improvement and process management best practices identified during the literature review will be integrated with an MBSE problem solving approach to provide an MBSE process management solution tailored to the DOD engineering workforce. The goal of this chapter is to provide a generic framework for process owners familiar with MBSE to improve and manage their processes over the process life cycle.

The methodology developed for this thesis is based on the SIMILAR systems engineering process shown in Figure 3 which consists of the following six steps: State the Problem, Investigate Alternatives, Model the System, Integrate, Launch the System, Assess Performance, and then Re-evaluate (Bahill and Gissing 1998). As discussed in the previous chapter, the SIMILAR process was developed as a generic systems engineering process that captured characteristics of the problem-solving process that organically occurred across a diverse range of technical and non-technical fields (Bahill and Gissing 1998). The SIMILAR process was selected for this methodology over several other variations of the systems engineering process because it offers one of the more generic interpretations of the systems engineering process. This allows the process to easily conform to the problem at hand, process management.

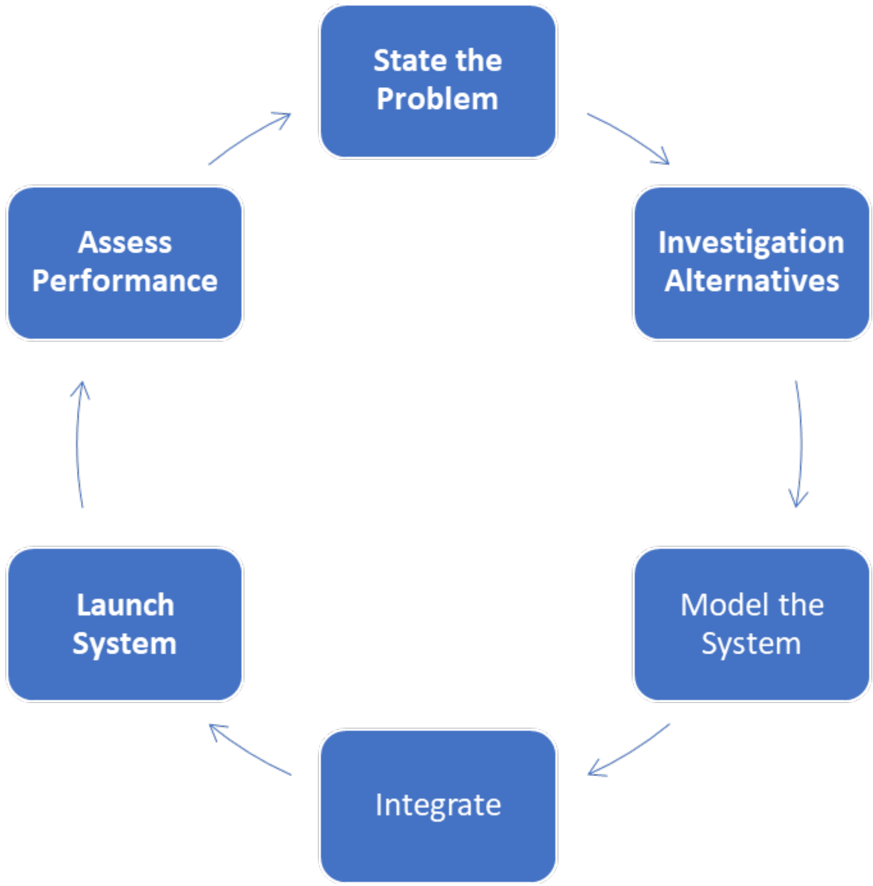


Figure 3. The SIMILAR systems engineering process. Adapted from Bahill and Gissing (1998).

Prior to beginning a process management effort, it is critical to assess the MBSE resources available within an organization and decide on the modeling language and software that will be used for the process management effort. The methodology detailed in this section can be executed using most of the commercially available MBSE tools, but there are factors that need to be considered when making the selection. Process management is a continuous effort that does not stop after a process is improved the first time. The MBSE tool selection should reflect this by selecting a tool that will be supported by the manufacturers and the purchasing organization through the subject process's complete life cycle. One of the advantages of a digital model-based process management tool is the improved traceability, and continuity offered over the traditional document-based approach. A tool that will not be supported throughout the process life cycle could lead to the elimination of this advantage and unplanned rework. The second consideration when selecting an MBSE tool is accessibility within an organization. The capability to facilitate social computer or collaboration is another significant advantage offered by a digital model-based process management solution. Selecting an MBSE tool that an organization has a limited access to will deteriorate this advantage by increasing the difficulty of collaboration among the critical stakeholders. While the implementation of any model-based digital management tool could improve process management through an increase in capabilities, investing a relatively short amount of time to assess the available digital resources can greatly improve the longer-term effectiveness of a process management effort.

The remainder of this chapter will expand on the activities within each step of the systems engineering process necessary to complete a process management effort. An expanded view of the process is shown below in Figure 4. Generic systems engineering activities used in the methodology are not discussed in detail since the target audience is provided extensive resources on systems engineering through the defense acquisition workforce. The chapter will focus on the unique activities added to the generic systems engineering methodology to address process management and will detail where to utilize MBSE tools.

The scope of this methodology will be limited by the variation in how MBSE tools enter, store, and present data. The variability of how MBSE tools function make it unreasonable within the scope of this thesis for the methodology to include detailed procedures for generating or loading specific information into individual MBSE tools. Instead, the methodology will detail the general use of MBSE capabilities widely available through most MBSE tools.

Figure 4. The expanded MBSE process management methodology.

1. State the Problem

The first step of this methodology consists of several activities that revolve around developing an understanding of the process of interest, and the requirements driving the process. The activities required during this step include:

- Defining the existing process of interest
- Defining the purpose of the process management effort
- Identifying the stakeholders
- Documenting the requirements of the process
- Modeling the process of interest in its current state along with the structure of the organization executing the process.

The problem definition process outlined above should be familiar to the engineering workforce within the DOD since it employs activities vital to nearly every engineering design process.

The characteristic of this methodology that differs from the traditional engineering process's problem definition approach is the inclusion of modeling. In the case of a process, the system of interest is often an abstract and sometimes undocumented sequence of activities executed by varying entities within an organization. It is critical to build a model of the process in its current state at the start of a process management effort to effectively define the system of interest and to develop a clear understanding of the system in its current state. The process model should be developed using an MBSE tool and the associated modeling language. It should include the structure of the organization with relationships between the organization's entities and the process. At this stage, the model developed by the process owner should be a copy of an existing process and the executing organization's structure. In the event the process owner is not familiar with the process of interests, the following steps from the Fundamentals of Business Process Management are recommended as a systematic approach to modeling the process:

1. Identify the process boundaries
2. Identify activities and events
3. Identify resources and their handovers
4. Identify the control flow
5. Identify additional elements (Dumas et al. 2013, 167)

Avoiding bias when modeling the as-is process is important, so it is critical to collaborate with stakeholders during this process and validate that the model accurately represents the system of interest. Beyond acting as a tool to define the process of interest, the as-is model developed during this stage of the process management effort will provide structure for modeling, analysis, and simulation activities conducted later in the process management effort. Figure 5 shows an example process model, and the data entry for a single action, E15.9.1 Generate Lot Release Form. The data entry module shown in Figure 5 depicts some of the relationships the action has with other entities within the model. The relationships specifically shown for action E15.9.1 in Figure 5 are a "performs by" relationship with the engineer who executes the action, and a "decomposes" relationship with the next higher model level, E1.9 Issue Lot Acceptance Letter. Additional relationships to other entities like requirements can also be created and displayed using the relationship module.

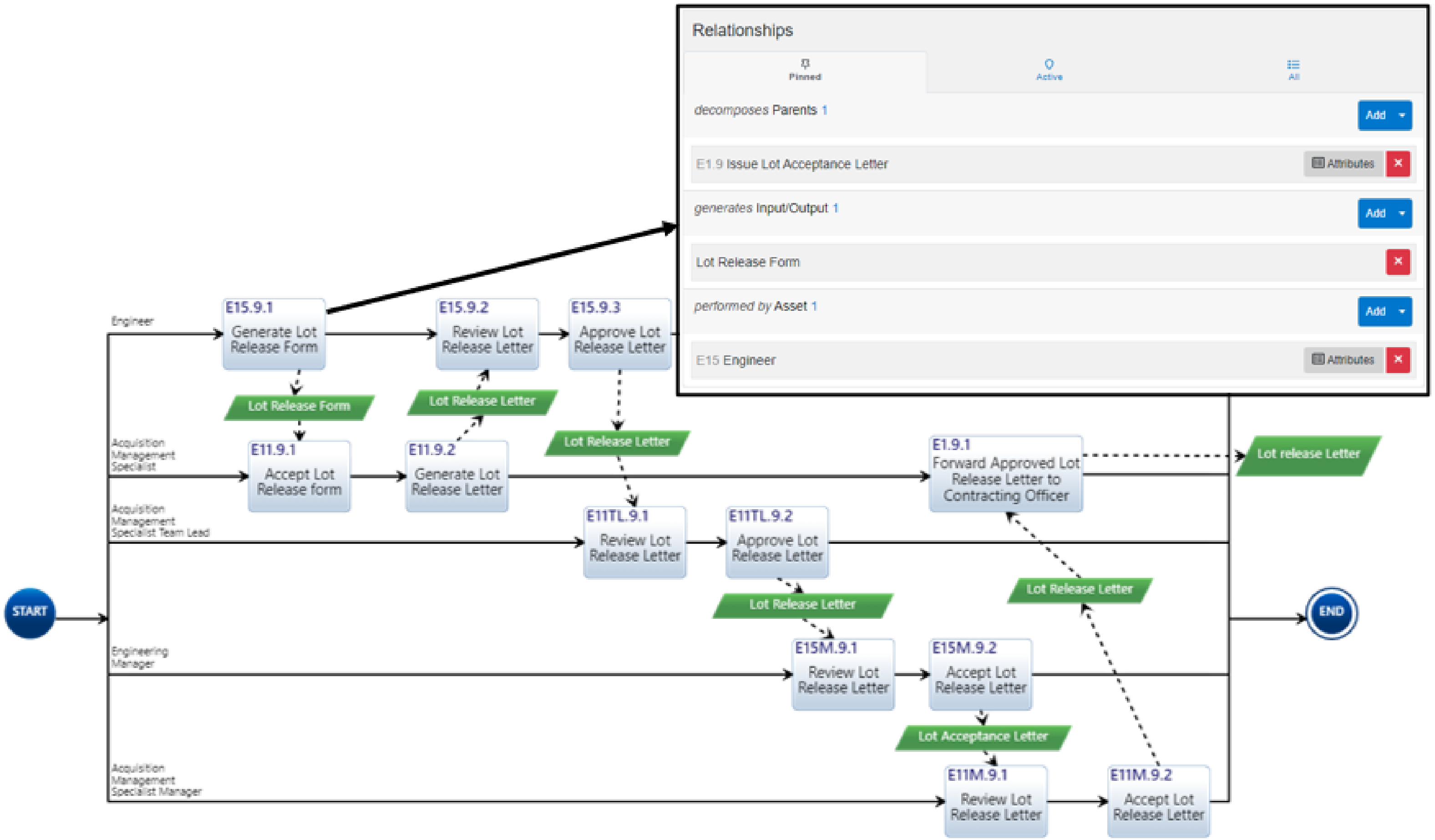


Figure 5. An example process model and the data entry for a single action showing the relationship between the stakeholder and the action.

One of the advantages of using an MBSE tool for process management is the ability to document and model all details relevant to a system in a single, digital environment. To realize this advantage, it is important to include all relevant process and organizational information within the same digital environment as the process model. This means that all data items developed during this stage should be generated in or uploaded to the MBSE tool of choice. Figures 6 and 7 below show examples how requirements and stakeholders can be captured in an MBSE environment. The views shown in Figures 6 and 7 are from the MBSE tool Innoslate, but other MBSE have similar capabilities.

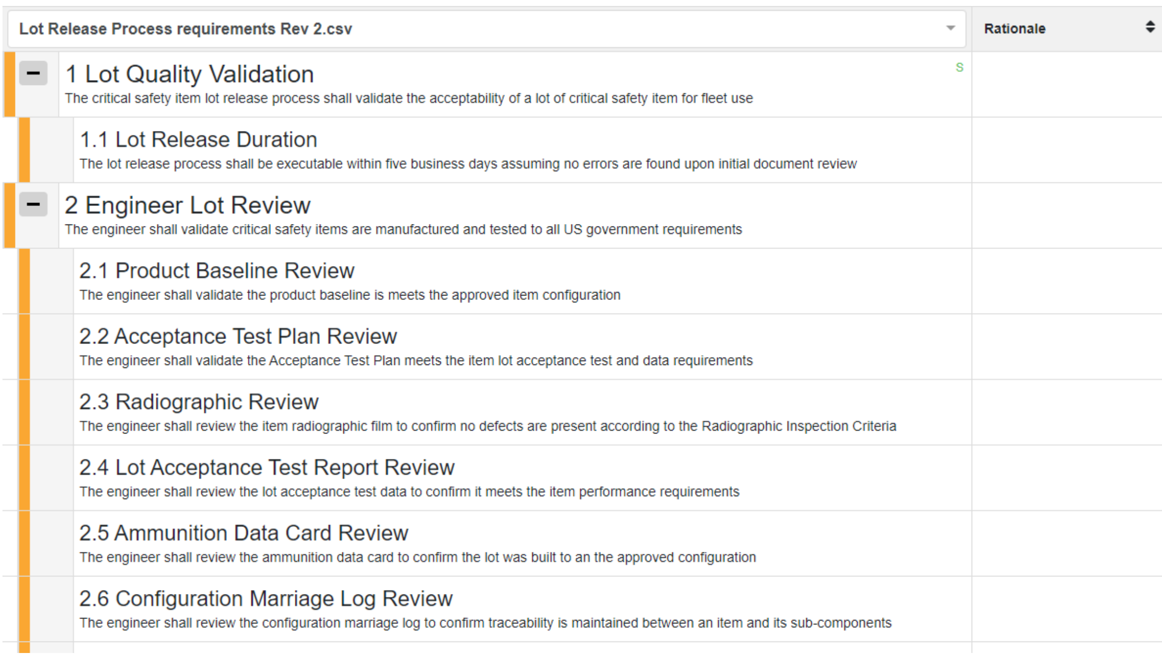


Figure 6. Process requirements recorded in Innsolate.

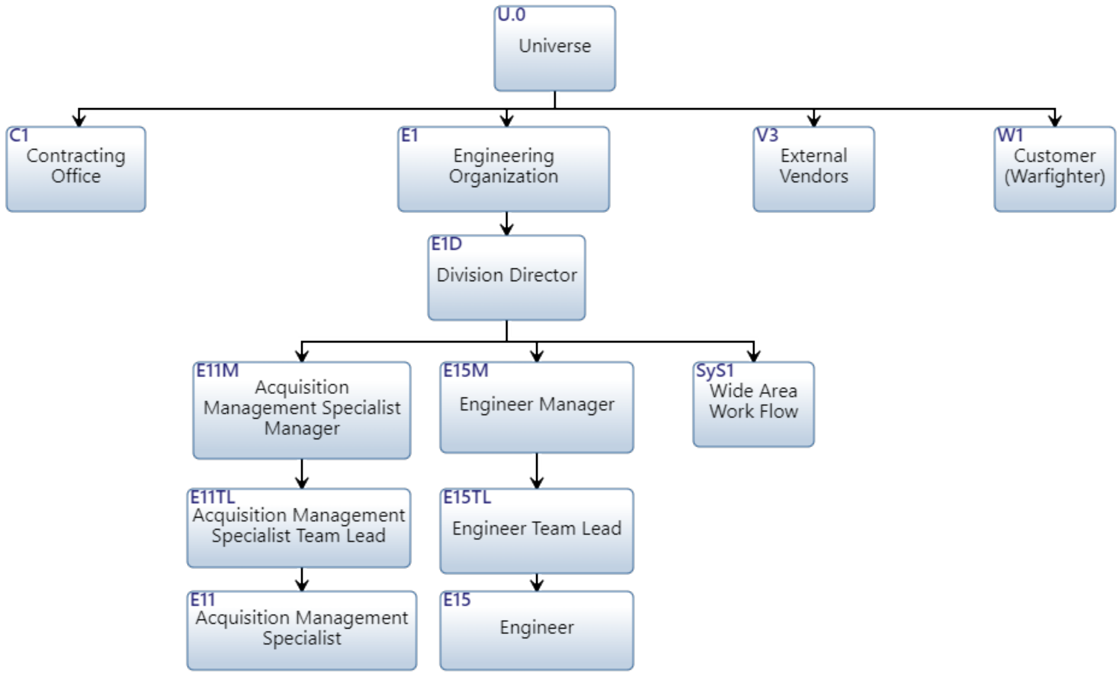


Figure 7. A process stakeholder hierarchy diagram.

2. Investigate Alternatives

The Investigate Alternative stage of a process management methodology will consist of several activities focused on the identification of process problems, and the investigation of solutions or changes that could improve the process. Often process owners or stakeholders will already be aware of problems with a process prior to this stage of the methodology, but rarely will the root causes of the problems be known, or the extent of inefficiencies within a process be understood. During this stage of the process management methodology, stakeholders will approach the process systematically to complete the following activities:

- Identify current process short comings using quantifiable performance metrics where possible.
- Investigate the causes of the problems identified within the current process

- Prioritize the process problems according to the requirements and the organization goals

- Investigate solutions to the current process shortcomings, utilizing process management heuristics for reference

An analysis of the process of interest will start with a comparison of the as-is process against and the process requirements. This should include an assessment of the process's performance, in areas like cost, resource consumption, and schedule, against requirements-based metrics. This analysis of process performance against requirements-based metrics will rely on existing data collected on the process, and simulation data generated from the digital model built in the MBSE environment. The engineering workforce of the DOD is extensively familiar with this type of analysis as it is a cornerstone of the engineering process employed for DOD programs. Less familiar to the target audience will be the non-quantifiable analysis techniques used to identify problems with a process. A list of known techniques for process analysis is shown on Table 2. As stated in the literature review, there is no single correct way to analyze a process, so the methods employed by the process owner will be based on the process of interest and the process owner's experience. Table 5 below shows an example Value-Added Analysis, one of the process analysis approaches identified in the literature review.

Table 5. An example value-added analysis.

Step Number	Process Step	Actor/ Entity	Step Label (VA, BVA, or NVA)	Value Added Process Time (hours)	Non-Value Added Time (hours)	Explanation
SyS.1.	Accept Configuration Baseline Submission	Wide Area Workflow System	BVA	0.05	0	Satisfies requirement 5.1: technical documents shall be submitted to wide area workflow.
E11.1.1	Download Configuration Baseline from WAWF	Acquisition Specialist	NVA	0	3.1	There is no requirement for the acquisition specialist to download the configuration baseline. The acquisition specialist does not review or process the configuration baseline.

Step Number	Process Step	Actor/ Entity	Step Label (VA, BVA, or NVA)	Value Added Process Time (hours)	Non-Value Added Time (hours)	Explanation
E11.1.2	Forward Configuration Baseline to Engineer	Acquisition Specialist	NVA	0	0.1	There is no requirement for the acquisition specialist to provide the configuration baseline to the engineer. The acquisition management specialist does not review or process the configuration baseline.
E15.1.1	Review Configuration Baseline	Engineer	VA	2	3	Satisfies Requirement 2.1: The engineer shall review the configuration baseline

Value-Added Analysis Key	
Value-adding (VA)	"Value-adding (VA): This is a step that produces value or satisfaction vis-à-vis of the customer. When determining whether or not a step is value-adding, it may help to ask the following question: Would the customer be willing to pay for this activity?" (Dumas et al. 2013, 187)
Business value-adding (BVA)	"The step is necessary or useful for the business to run smoothly, or it is required due to the regulatory environment of the business." (Dumas et al. 2013, 187)
Non-value adding (NVA)	"The step does not fall into any of the other two categories." (Dumas et al. 2013, 187)

Along with the identification of problems within a process, process owners must also determine the root cause for problems. The process analysis tools listed in Table 2 of Chapter II once again can be used for this purpose. Examples of how the tools from Table 2 can be used to identify root causes are: Value-Added Analysis can identify too many non-value processes that might be leading to unacceptable cost or schedule performance, and a root cause analysis, or an experience examination analysis can help identify the cause of functional problems like bottlenecks.

The output of the process analysis activity should be a list of performance or functional deficiencies with the current process along with the root cause identified for each issue. There are several tools that can be employed to document process issues, but to avoid increasing the scope of this thesis only one method, the Issue Register, will be detailed. The issue register method of documenting process deficiencies is recommended for process management in the Fundamentals of Business Process Management and is a table or list including any combination of the following data items for each known process issue:

- “Name of the issue – This name should be kept short, typically two–five words, and should be understandable by all stakeholders in the process.” (Dumas et al. 2013, 199)
- “Issue Description – A short description of the issue, typically one–three sentences, focused on the issue itself as opposed to its consequences or impact, which are described separately.” (Dumas et al. 2013, 199)
- “Issue Priority – A number (1, 2, 3, . . .) stating how important this issue is relative to other issues. Note that multiple issues can have the same priority number.” (Dumas et al. 2013, 199) Issue priority will often be established based on the impact of the issue and the needs of the stakeholders.
- “Assumptions (or input data). Any data used or assumptions made in the estimation of the impact of the issue, such as for example number of times a given negative outcome occurs, or estimated loss per occurrence of a negative outcome.” (Dumas et al. 2013, 199)
- Impact – A description of the qualitative or quantitative impact of the issue. Examples of quantitative impacts are time loss, or revenue lost. Examples of qualitative impacts are changes to “customer satisfaction, employee satisfaction, long-term supplier relationships, [or a] company’s reputation” (Dumas et al. 2013, 199).
- Root Cause – The factor or characteristic that caused a process issue. Often identified through the use of a root cause analysis.

An example issue register is shown in Table 6.

Table 6. An example issue register.

Name	Issue Description	Issue Priority	Assumptions	Qualitative Impact	Quantitative Impact
Documentation Errors	Technical documents are submitted with errors that result in unplanned rework.	2	The quantitative impact is calculated for a single document error.	Shifting delivery dates cause issues for the manufacturer and customer Increased storage cost at manufacturer	Approximately 15 business hours
Excessive downtime	A high number of handoffs between entities results in excessive downtime	1	Email is the primary form of information transfer. Downtime was estimated using the average email response time in a workplace.	Excessive downtime results in increase delivery time to the customer	Approximately 3 hours of downtime per handoff

The last activity of the Investigate Alternatives stage is to identify potential solutions to the problems documented on the issue register. This activity will involve brainstorming process changes that will improve or eliminate the known issues. To guide this activity, a list of process improvement heuristics is available in Table 3. These heuristics along with the analysis tools already discussed should equip the DOD engineering workforce with the knowledge to systematically identify problems within a process and to generate potential solutions. The output of this activity should be a list of possible solutions to the various documented problems with a focus on the highest priority problems.

3. Model the System

Once a process analysis is complete and a process owner has a documented list of process issues and potential solutions, the process owner enters the modeling stage of the process management methodology. During this stage of the process management methodology, an MBSE tool's modeling and simulation capabilities will be used to model and test the list of potential solutions to identify the solution or combination of solutions that best meet the stakeholder needs. The system modeling stage will consist of the following activities:

- Analyze the solutions identified during the previous step
- Determine the feasibility of a solution within the organization of interest and use the as-is model to determine the impact a change may cause to the process
- Use available modeling and simulation resources to identify any undesirable emergent behaviors resulting from proposed solutions
- Determine which solutions can be combined to best meet the process requirements and organization goals.
- Construct a model of the improved process and its relationship to the organization

The as-is process model will be the foundation for this stage of the process management methodology. As possible solutions are determined to be feasible through an analysis against the process requirements, the process owner will integrate the solutions into a copy of the as-is process model to simulate the changes in both process structure and process performance a solution may cause. Since DOD processes vary significantly there is no one systematic approach that can be applied to the redesign of a process. The redesign of a process should target the highest priority process deficiencies first, but will rely on the process owner's knowledge and experience, and the trial and error of multiple possible solution combinations to develop an improved process. An example of a how an MBSE process model can simulate performance metrics is shown in Figure 8, which depicts the Innoslate simulation output for process duration performance.

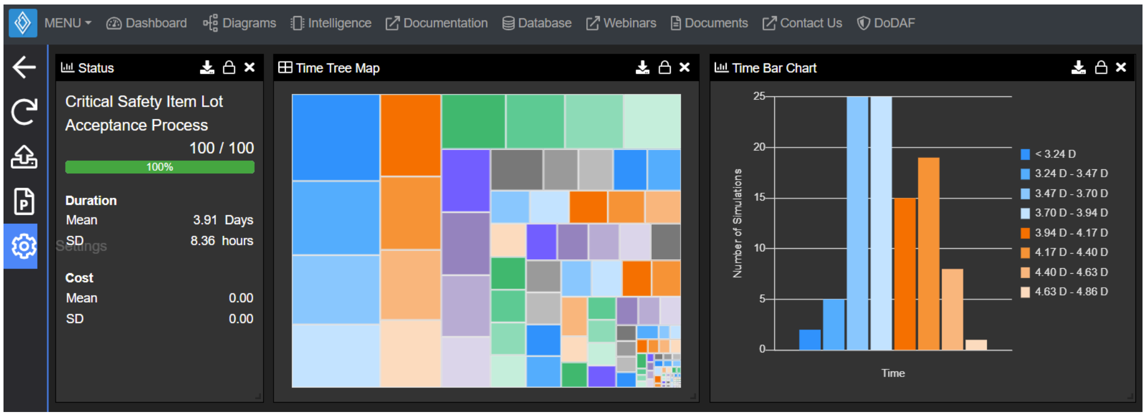


Figure 8. An example of Innsolate's Monet Carlo simulation dashboard.

The final product of the modeling stage of the process management methodology will be a redesigned model, integrating any number of the identified process improvements that lead to a process that best meets the customer's need.

4. Integration

The Integration stage of the process management methodology focuses on validating that a redesigned process meets all stakeholders needs and can be integrated into an organization without any unintentional consequences The activities completed during the integration stage of the process management methodology are:

- Have the improved process model reviewed by critical stakeholders with a focus on the users of the process.
- Assess the comments and concerns of critical stakeholders, prioritizing the changes required to integrate the improved process into the organization.
- Model any additional changes required to integrate the improved process into the organization assessing the impact of each change.

- Generate an updated process model with process improvements and the necessary changes from the stakeholders.

While the use of an MBSE tool for process management should allow greater stakeholder involvement in the management of a process throughout the entire life cycle, its necessary to have stakeholders, especially those executing a process review the redesigned process and its simulated performance prior to the process implementation. The stakeholder review should be conducted through the MBSE tool used to model the process with direction provided to stakeholders on the purpose of the review. At this stage, the stakeholders' review should be focused on how the process will integrate into the organization and not necessarily the performance of the process.

In the event stakeholders identify issues with the redesigned process, the process owner should assess the problem using the analysis tools and heuristics previously discussed, and modify the process as necessary. If the process is modified, the process owner should repeat the integration stage of the process management methodology to make sure the changes do not cause any unintended issues for the stakeholders.

The output of the integration step should be a redesigned process model that has been reviewed by the stakeholders, and approved by the stakeholders that directly interface with the process and its output.

5. Launch the System

Once a redesigned process is developed and validated as acceptable through simulation and a stakeholder review, the focus of the process management effort shifts to launching the new process within the organization. The activities required to launch a redesigned process will be specific to each process and each organization, so for this stage of the process management methodology no specific procedure will be defined. Instead, potential activities and consideration will be identified to help guide a process owner. Activities that could be part of the launch the system stage are:

- The acquisition of approval for the improved process from governing organizations or personal. This will require marketing the improved process to stakeholders using simulation data generated during the process management effort.

- The generation of formal process documentation for an organization that can be distributed to each stakeholder. Process documentation will vary based on the organization, but the goal should be to use a product of the MBSE software as process documentation.

- Briefing all stakeholders executing the process on the organizational and position changes associated with the redesigned process. The MBSE software used for the process management effort should be utilized during process briefs to avoid the rework associated with generating a presentation, and to allow stakeholders to interface with all aspects of the improve process model.

- The development of any process support systems required for the improved process (database or automation). The activities required to develop or procure a process support system, like a database, are outside the scope of this thesis, but it is critical to capture the activity during the launch stage of the methodology since the need for new support systems can result from a process management effort.

- The implement of mechanisms to monitor process performance. Performance monitoring mechanisms should be designed during the prior stages of the process management effort. During the launch stage, the infrastructure or steps required to track metrics of interest should be put into service within the organization.

The list of system launch activities presented above is not exhaustive. The wide variability in both organizations and processes will prevent any one launch procedure for working for all process management efforts. The characteristic that should be present during the launch stage of all MBSE process management efforts is the utilization of the model developed in the MBSE environment for communication with stakeholders. While the traditional presentation approach to communication is widely relied on in the DOD, the utilization of MBSE to communicate and transfer information provides several advantages. Within the MBSE environment, stakeholders are able to interface with organization models and process models in their entirety at the stakeholders desired speed. This allows a stakeholder to choose the appropriate level of detail to familiarize themselves with and allows the stakeholder to navigate the process model in a manner of their choice. Additionally, by using the model already developed in the MBSE environment, the rework associated with the generation of new design presentations is eliminated, and any configuration control issues that could result from generation of multiple design documents are eliminated.

The procedure used during the launch the system stage of the methodology will vary significantly based on the process of interested, and the organization executing the process management effort. With that said, all MBSE process management efforts should maximize the use of the MBSE environment when communicating process information for the implementation of a redesigned process within an organization

6. Assess Performance

The MBSE process management methodology detailed in this chapter is a continuous and iterative approach to process management that is not complete until a process is taken out of service at the end of its useful life. As with any system, a process needs to be continuously monitored to make sure it is operating efficiently and meeting the customers' needs. To do this, process performance data must be continuously logged and reviewed regularly by the process owner. In the event that process performance fails to meet the needs of the customer or issues with the process arise, the process owner must repeat the MBSE process management methodology to identify the process deficiencies and implement process improvements.

The collection of process performance data for a process should be both documented and controlled within an organization along with the criteria for assessing the performance data. Process performance metrics already defined during the design of a process, or the redesign of a legacy process set the benchmark for process performance.

Examples of these process performance metrics are resource and schedule limitations defined during the initial stages of the process management process. Data should be gathered for all process performance characteristics for which there is a requirement.

The frequency of performance assessments for a process will depend on the process of interest, the organization, and the metrics collected on the process, but should be defined during the process management effort. Performance assessment can range significantly from daily to yearly, but the frequency should be defined prior to process launch.

The output of the assess performance stage of the methodology is an analysis of the process performance compared against the performance criteria defined for the process of interest. Based on the analysis, a decision must be made to continue with the process operating as-is because the process meets performance requirements, or to reenter the start of the process management methodology due to process performance deficiencies. The assess performance stage of the methodology is continuous and is repeated for a process at the scheduled frequency until a process fails to meet the performance required. When that happens, the performance failures identified during the assess performance stage feed into the start of the process management methodology as a new problem.

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IV. DOD CASE STUDY

The previous chapter detailed a generic methodology for process management using an MBSE approach. This chapter applies the process management methodology to an engineering organization within the DOD as a case study to demonstrate the effectiveness of an MBSE process management methodology at improving performance. The process used for the case study is the lot acceptance process for DOD sustainment orders of critical safety items. The process selected for the case study is used to support dozens of contracts supporting the sustainment orders for thousands of critical safety items each year. In recent years, the process has come under scrutiny from stakeholders demanding a reduction in process duration with no loss in output quality.

Due to the limited scope of the thesis, the process of interest will not be integrated or launched into the subject organization and real performance data will not be available for assessment. The case study will walk through all steps of the process management methodology until the system integration step. The success of the methodology will be assessed based on the change in the simulated duration performance, the primary focus of this process management effort.

A. BACKGROUND

The process selected for the case study is the lot acceptance process used by an engineering organization within the DOD to accept critical safety items for DOD applications. The goal of this process is to: validate a lot, or batch, of critical safety items meet all U.S. government requirements and will perform as designed when deployed to the fleet, and to send a contractually meaningful acceptance signal to the manufacturer. These goals are met through the review and approval of several production traceability documents, the completion of in-process and end item testing, and the submission of a letter from the contracting officer to an external vendor accepting each lot of product for DOD use. The customer supported by this process is the DOD, who uses the critical safety items in systems supporting the warfighter. Variations of this process have been in use within the DOD for several decades with minimal change. A representative example of the current process documentation used for the critical safety item lot acceptance process is shown in Figures 9 through 12. The scope of this case study is limited to a single variation of the lot acceptance process used for critical safety items manufactured and tested by external vendors. Since the process documentation shown in these figures is meant to cover all variations of the process, the specific steps and variations that will be examined during the case study have been outlined in red.

Figure 9 depicts the top-level process that must be completed by an engineering organization for sustainment of critical safety items within DOD. The case study detailed in this chapter will only examine the portion of this process involved with the acceptance of externally manufactured critical safety items for DOD use. As highlighted in the figure, the steps that will be examined in further detail are 2–4, witness critical safety item acceptance testing, and 2–5, execute critical safety item lot acceptance. For the purpose of the case study, the assumption has been made that all prior logistical, and contractual activities are complete.

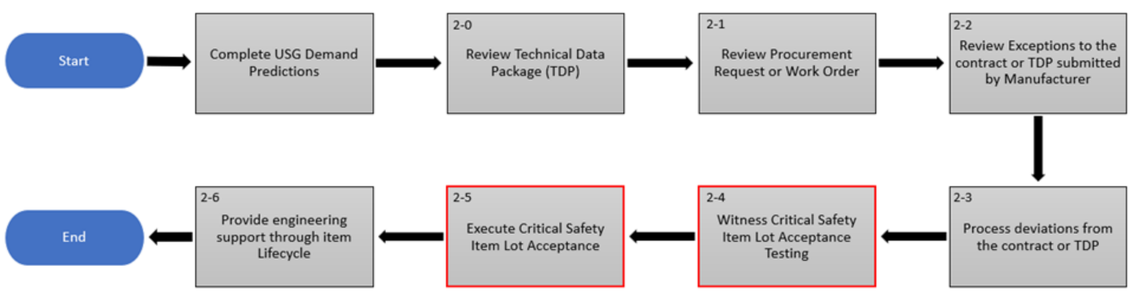

Figure 9. Critical safety item engineering sustainment process flowchart.

Figures 10 and 11 depict the decomposed process for step 2–4, witness lot acceptance testing of a critical safety item. Most of the process shown in Figure 10 is not relevant to this case study since only the process supporting externally lot acceptance tested items was considered. This resulted in the process of interest flowing to the "no" branch of the first decision node, Tested In-House, and then to step 3–2, offsite test witness, bypassing the majority of the 2–4 process. Figure 11 shows the decomposition of step 3–2, offsite test witness, and depicts the actions required to witness lot acceptance testing at an external vendor's facility. The case study conducted in this chapter was completed for a scenario where the function of test witnessing was delegated to an on-site government representative, which is shown in the flowchart.

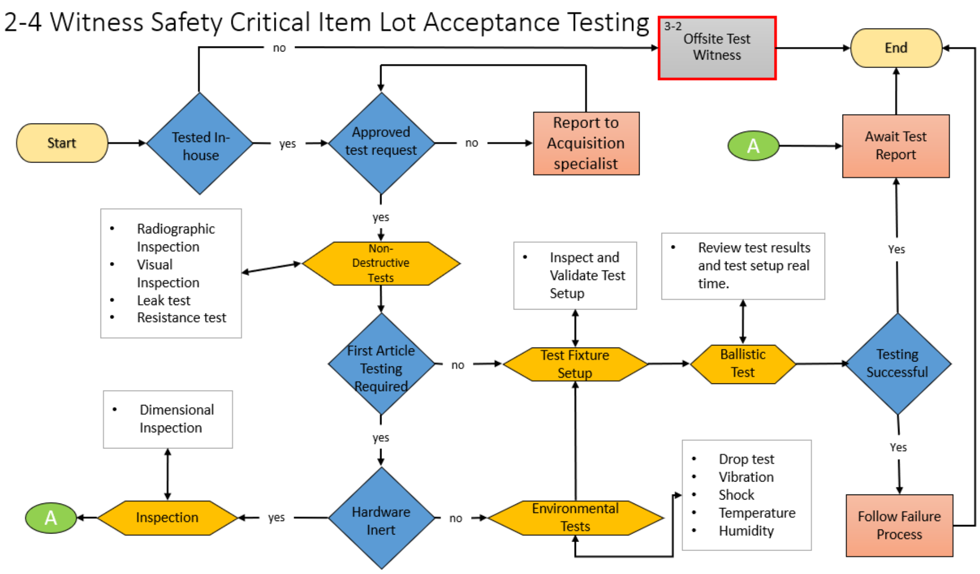

Figure 10. The flowchart for step 2–4, witness critical safety item lot acceptance testing.

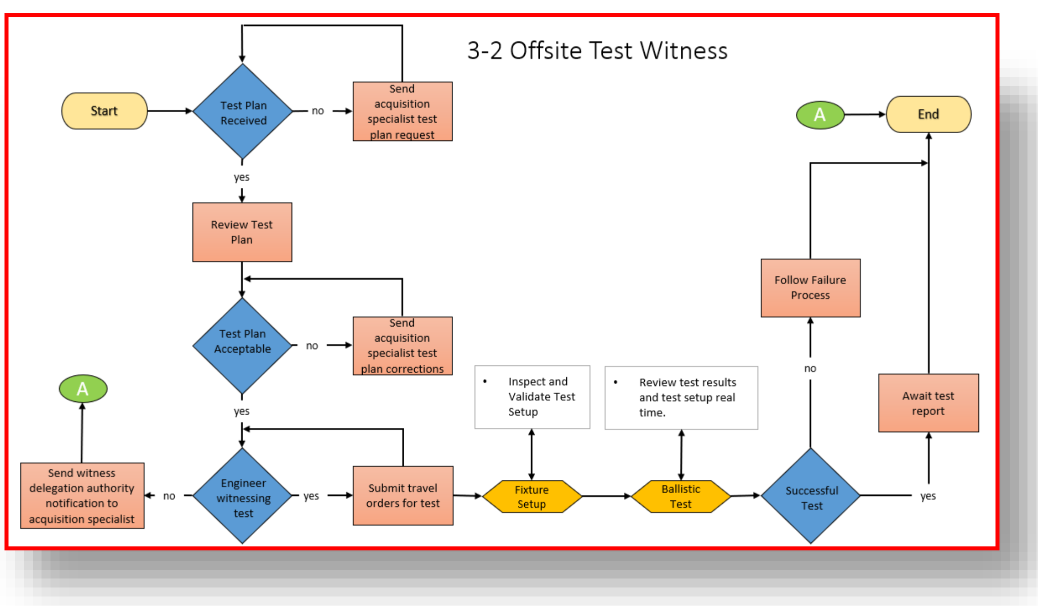

Figure 11. The flowchart for step 3–2, witnessing a critical safety item test at an offsite vendor.

Figure 12 shows the decomposition of step 2.5, executing critical safety item lot acceptance, and is meant to show the steps required to accept a lot of critical safety items for use by the DOD. Figures 11 and 12 represent the lowest level of decomposition available for the subject process.

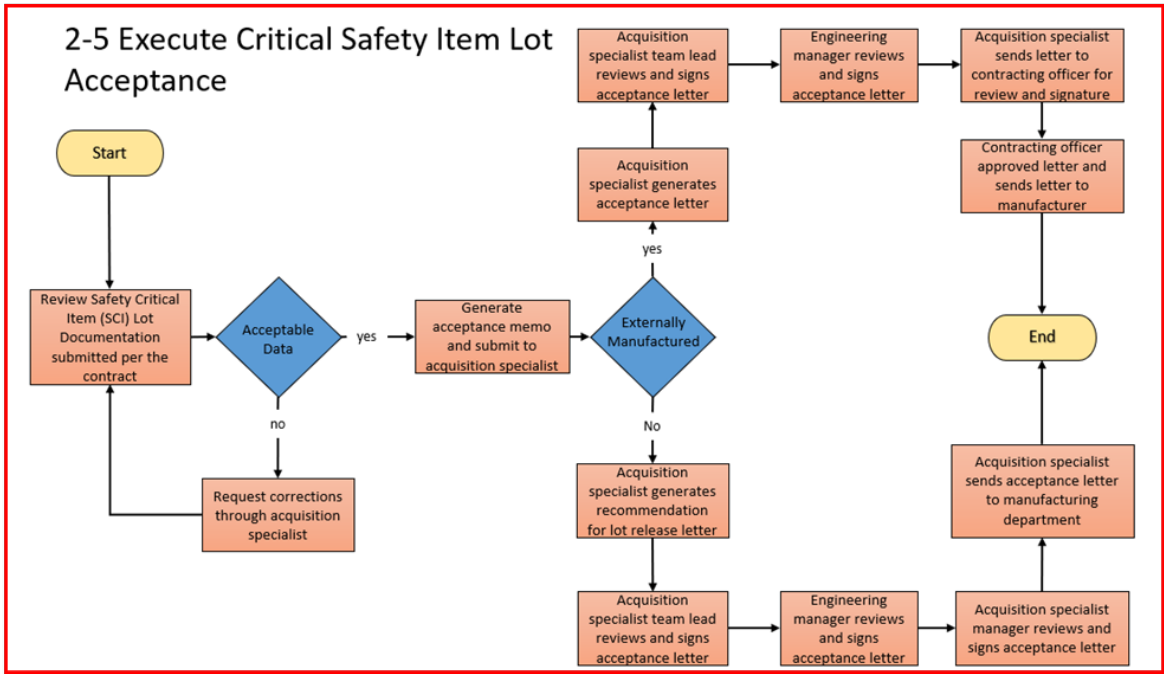

Figure 12. Step 2.5, acceptance of a lot of critical safety item.

The process documentation shown in Figures 9 through 12 is meant to capture the steps and interactions required to release a lot of critical safety items for DOD fleet use. Unfortunately, the documentation shows the process at a very low resolution, often missing steps completely, and does not provide any details on the organization or the requirements driving the process. While the target audience of the process documentation shown is the engineers executing the process, many of the steps and interactions critical to an engineer's function were left out of the documentation.

Beyond the accuracy issues associated with the process documentation shown in Figures 9 through 12, the process for accepting critical safety items recently came under scrutiny from the customer who stated the time to accept a lot of critical safety items was excessive. Initial attempts to reduce the duration of the acceptance process came from the organization's management who reduced the allowable time for lot acceptance from 30 business days to 15 business days without any examination or change to the process workflow. This attempt to reduce duration of the lot acceptance process had minimal success since it failed to address the characteristics that drive the process duration.

B. CASE STUDY

The primary goal of the process management case study was to demonstrate the effectiveness of the MBSE process management methodology defined in the previous chapter. This was completed by applying the process management methodology to the critical safety item lot acceptance process, depicted in Figures 9 through 12, with the goal to reduce duration. Innoslate, a cloud-based MBSE tool, was used to support this case study.

The case study was conducted from the perspective of the process owner, the engineering organization executing the critical safety item lot acceptance process. External entities like the contracting officer, and the manufacturing vendor were included in the process model as required for the case study, but minimal changes could be made to their actions, or outputs because they are outside the control of the process owner.

1. State the Problem

With the process of interest previously identified as the critical safety item lot acceptance process, the first steps of the MBSE process management methodology employed for the case study involved identifying the goals of the process management effort, defining the process of interest and its requirements, and modeling the as-is process in an MBSE environment.

The primary goal identified for the process management effort was: Reduce the process time required to accept a lot of critical safety items for DOD use by at least 20%. This goal came directly from the customer, who repeatedly requested a reduction in the total delivery time of critical safety items over the last several years. The primary purpose for a duration reduction in the lot acceptance process was to improve the DOD's mission readiness by delivery product to the end user faster. A secondary benefit would be a reduction in the duration product must be stored at the manufacturer's facility, which would result in a decrease in the total procurement cost.

A secondary goal of the process management effort internal to the DOD engineering organization was: Improve documentation of the critical safety item lot acceptance process to support training and process control within the organization. This goal came from the organization executing the process who observed inadequacies with the current process documentation shown in Figures 9 through 12. The current process documentation could not act as a stand-alone document due to inadequate detail on the subject process, and inaccuracies between the documented process and the actual process. Improved process documentation was desired by the organization since it would improve the organization's ability to train its workforce and manage its processes.

With the goals of the process management effort understood, the focus of the effort shifted to documenting the requirements of the subject process. Documentation of the requirements started with the identification of the relevant stakeholders and their needs. For a process, this will often include any entities or individuals executing the process, the customer of the process, and any entity inputting product or data into the process. For the critical safety item lot acceptance process, the critical stakeholders were identified using the hierarchy diagram shown in Figure 13. The hierarchy diagram shows each stakeholder identified within the scope of this process management effort and their relationship to one another.

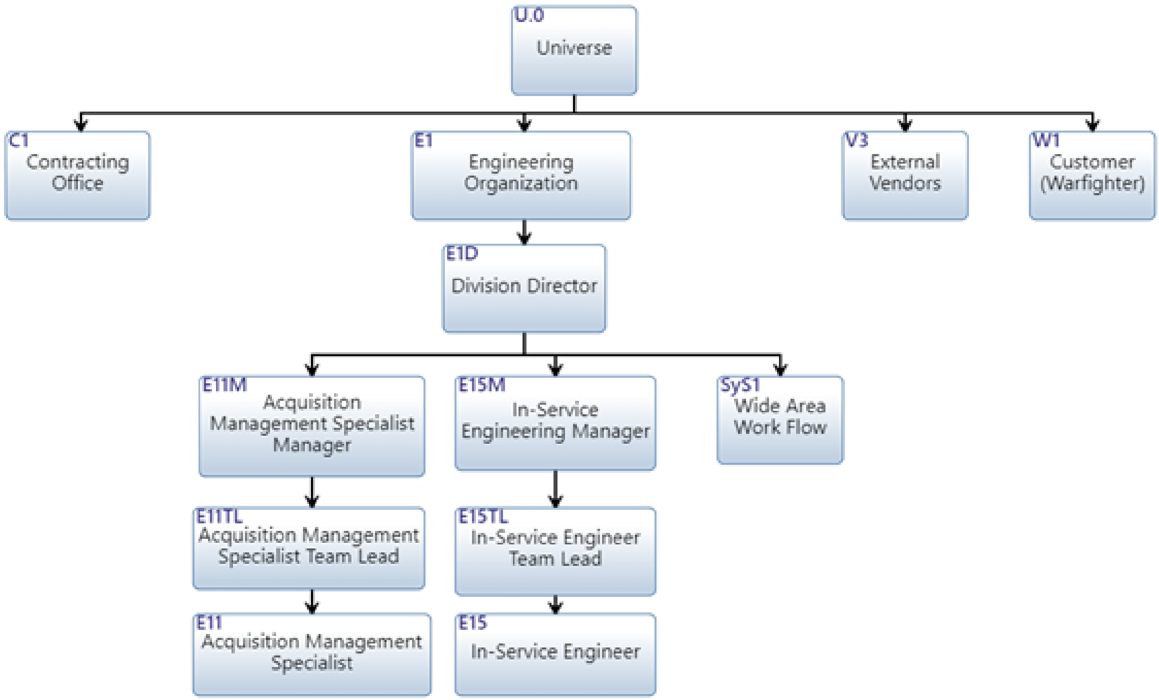

Figure 13. Critical safety item lot acceptance process stakeholders.

From the list of stakeholders, lot acceptance process needs and requirements were generated. During this stage, it was important to avoid looking to the existing process to generate requirements. As stated by Michael Hammer, the only way to achieve significant improvement is to challenge old assumptions and shed old rules. The easiest way to do this when generating process requirements was to avoid looking to the existing process that could be weighed down with non-value-added activities or obsolete requirements. The output of the requirements definition step should be a list of the requirements a process must meet. Table 7 shows the list of requirements generated for the critical safety item lot acceptance process. The requirements in Table 7 were primarily developed from the needs of the customer, the DOD, but do consider the needs of the stakeholders executing the process, and any legal requirements the process must meet.

Table 7. Critical safety item lot acceptance process requirements list.

ID	Class	Number	Name	Description
781647	Requirement	1	Lot Quality Validation	The critical safety item lot acceptance process shall validate the acceptability of a lot of critical safety item for fleet use
781725	Requirement	2	Engineer Lot Review	The engineer shall validate critical safety items are manufactured and tested to all USG requirements
781642	Requirement	2.1	Product Baseline Review	The engineer shall validate the product baseline meets the approved item configuration
781618	Requirement	2.2	Acceptance Test Plan Review	The engineer shall validate the acceptance test plan (ATP) meets the item lot acceptance test and data requirements
781609	Requirement	2.3	Radiographic Review	The engineer shall review the item radiographic film to confirm no defects are present according to the radiographic inspection criteria (RAC)
781742	Requirement	2.4	Lot Acceptance Test Report Review	The engineer shall review the lot acceptance test data to confirm it meets the item performance requirements
781526	Requirement	2.5	Ammunition Data Card Review	The engineer shall review the ammunition data card to confirm the lot was built to the approved configuration
781552	Requirement	2.6	Configuration Marriage Log Review	The engineer shall review the configuration marriage log to confirm traceability is maintained between an item and its sub-components
781733	Requirement	2.7	Radiographic Report	The engineer shall generate a radiographic report documenting the results of their radiographic review
781722	Requirement	3	Lot Quality Control	The USG shall provide redundancy in the approval process for all critical safety items
781748	Requirement	3.1	Technical Management Approval	The engineering manager shall provide concurrence with the acceptance of all critical safety items
781616	Requirement	3.2	Acquisition Management Approval	The acquisition manager shall provide concurrence with the acceptance of all critical safety items
781595	Requirement	3.3	Contracting Office Letter Requirement	The USG shall provide the contracting officer a letter for lot acceptance
781703	Requirement	4	Fleet Delivery Requirement	The critical safety item lot acceptance process shall meet all fleet demand schedule requirements
781506	Requirement	4.1	Product Baseline Timing	The product baseline shall be accepted prior to the assembly of the lot and submission of ammo data card, radiographic reports, marriage logs, and LAT data

ID	Class	Number	Name	Description
781706	Requirement	4.2	Acceptance Test Plan Timing	The acceptance test plan shall be accepted by the USG prior to the assembly of the lot and submission of ammo data card, radiographic reports, marriage logs, and LAT data
781614	Requirement	4.3	LAT Test Notification Timing	The vendor shall submit the acceptance test plan, product baseline, ammo data card, and radiographs prior to the submission of an LAT test notification
781724	Requirement	4.4	Lot Acceptance Schedule Requirement	The contractual acceptance of a lot of critical safety items shall be submitted within 15 days of the final technical document submittal.
781635	Requirement	5	Contractual Requirement	All participant in involved the production and acceptance of critical safety items shall follow the requirements of the contract (a standardized template for the organization)
781573	Requirement	5.1	WAWF Requirement	The vendor shall submit all technical documents to the USG via wide area workflow (WAWF)
781661	Requirement	5.2	Contractual Lot Acceptance	The contracting officer shall provide contractual acceptance of a lot of critical safety items to the manufacturer
781666	Requirement	5.3	Contractual Test Notification	The vendor shall submit a lot acceptance test (LAT) notification requesting if the USG wants to witness the LAT
781632	Requirement	5.4	Witness Disposition	The USG shall respond to the manufacturer with a witness disposition.
781533	Requirement	6	Lot Release Documentation	The lot release letter (contractual document) shall include the item lot number, the deliverable serial numbers, and document any outstanding issues with the lot that must be corrected prior to delivery to the USG.

The final activity of the problem definition stage of the process management methodology was the development of an as-is model of the process of interest. The LML modeling language was used to model the critical safety item lot acceptance process in Innoslate with action diagrams providing the primary visual model interface. The top-level action diagram from the lot acceptance process model is shown in Figure 14. Details on the LML modeling elements used for the process model are identified Table 4. The as-is model was constructed to mirror the critical safety item lot acceptance process as it is currently being executed within the DOD. The model captures the process shown in Figures 9 through 12 but depicts a single version of the process at a significantly higher resolution.

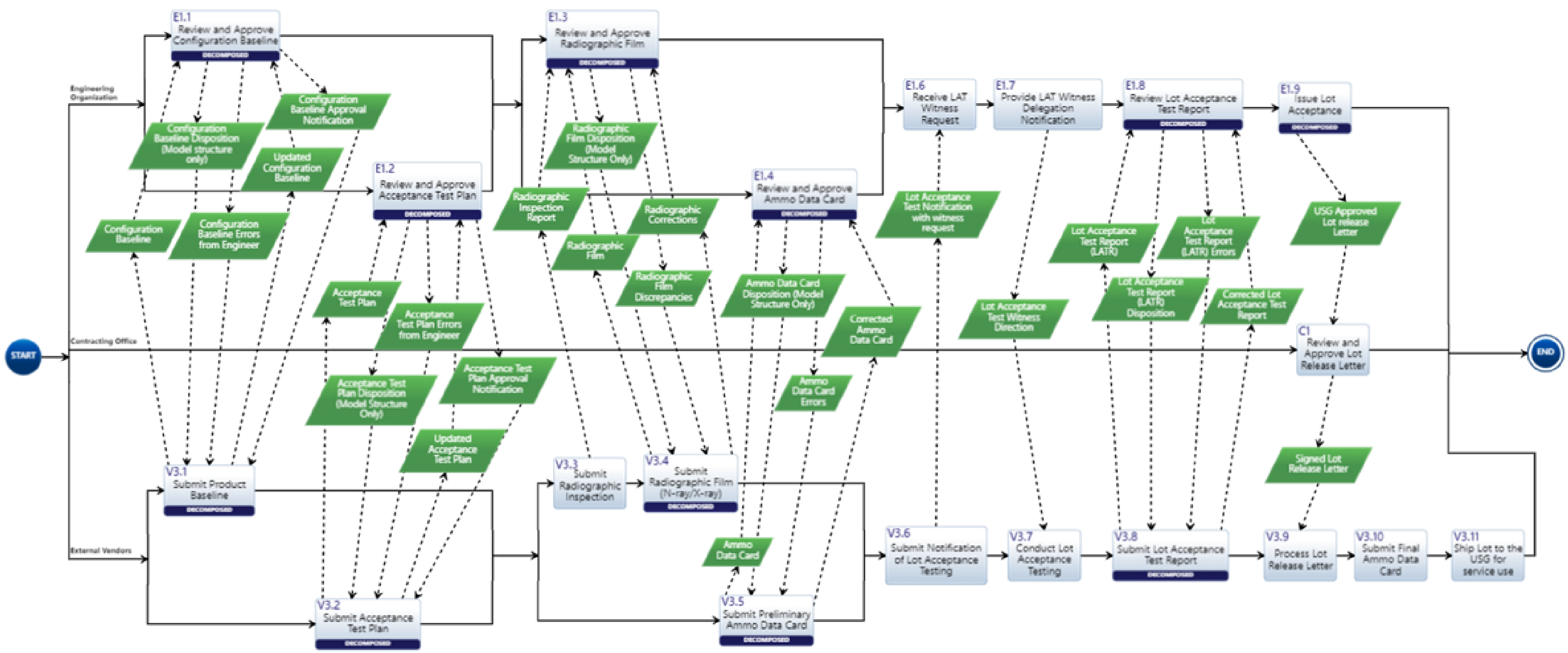

Figure 14. The top level critical safety item lot acceptance process action diagram.

The top-level action diagram shown in Figure 14 shows the three stakeholder organizations involved with the manufacturing and acceptance of critical safety items for the DOD (DOD Engineering Organization, Contracting Officer, and the Manufacturing Vendor), and the actions each organization must complete to accept a lot of critical safety items. Interactions and data items that must be transferred between the organizations are captured by the model and represented in the action diagram as inputs and outs, shown as green boxes, flowing between each organization's actions. Most of the actions within the top-level lot acceptance action diagram shown in Figure 14 represent functions consisting of several sub-actions completed by entities within each organization. Actions consisting of multiple sub-actions are modeled in further detail within the MBSE environment and are identifiable by the decomposed label shown on the bottom of an action block. An example of a decomposed action diagram is action E1.1, Review and Approve Configuration Baseline, which is shown in Figures 15. In the decomposed action diagram for action E1.1, the functions required from the entities within the engineering organization (the engineer, the acquisition manager, and the Wide Area Workflow database) to complete action E1.1 are depicted along with the required interactions and data items. Within the decomposition models inputs or output that appear to be floating with only one connection, flow to the higher-level action diagram. Two examples of inputs or outputs flowing from the higher-level lot acceptance action diagram E1.1 are the first configuration baseline input, and final output of the configuration baseline approval notification.

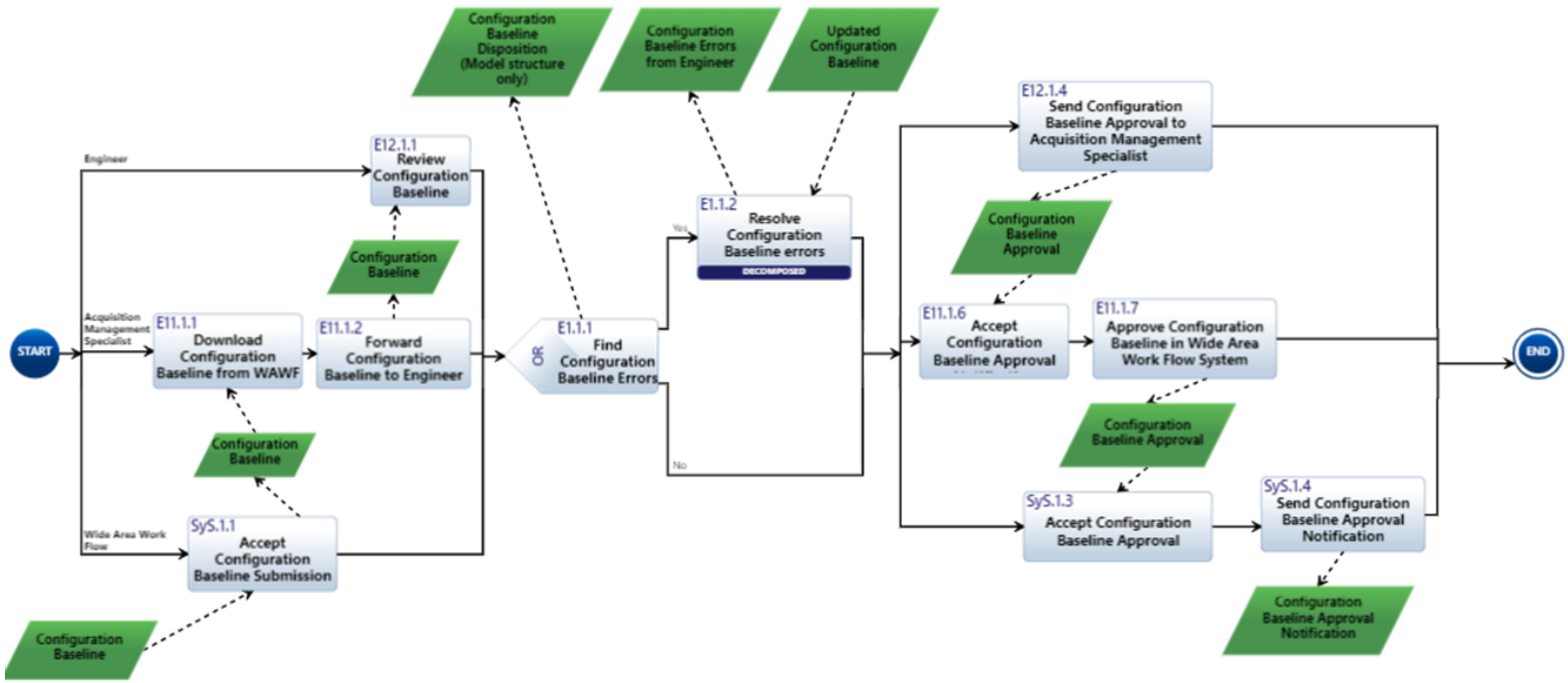

Figure 15. Decomposed action diagrams of E1.1, review and approve configuration baseline.

Due to the size of the as-is process model constructed for the critical safety item lot acceptance process, it was not feasible to depict and describe all action diagrams within the model in this section of the report. The complete as-is model for the lot acceptance process in its entirety can be found in appendix A. It is worth noting that the model is intended to be interfaced with through a modeling software like Innoslate which allows a user to navigate a model within the intended modeling environment. Reviewing the model in report format will not facilitate a reader's understanding as effectively as the model environment but will provide adequate understanding to support the case study.

Building the organization structure and process flow within the MBSE environment was only the first part of constructing the as-is model. As discussed in Chapter III, it is critical for process management effort that process performance can be simulated for the as-is model and improved iterations of the model. For the critical safety item lot acceptance process, the performance characteristic of interest was process duration as defined by the customer. Innsolate has the capability to simulate process duration along with several other performance characteristics like cost, and resource utilization, but requires input from the user to do so. The information required for simulating process duration was action durations for each individual action within the model, and the probabilities for each decision point's outcomes. Table 8 shows a sample of the duration data used for the critical safety item lot acceptance process model. The data used for the critical safety item lot acceptance process model is representative of the actual lot acceptance process and can be found in its entirety in Appendix B.

Table 8 shows the action duration data for eight of the 138 actions used to model the critical safety item lot acceptance process. As shown in the table, each actions' duration was assumed normally distributed and was assigned based on the type of action. A large portion of the current critical safety item lot acceptance process is downtime due to the workflow switching between actors. To represent the down time, a penalty was assigned to any human executed task that involved data coming from another source. The penalty assigned was 3.5 hours with a standard deviation of 1 hour. The 3.5-hour penalty was an approximation, but was loosely based on the average e-mail response time in the professional workplace during work hours (DeMers 2021) since e-mails is the primary from of data transfer and communication within most DOD organizations

Table 8. A sample of the critical safety item lot acceptance process model duration data.

Number	Name	Mean time (hours)	Standard Deviation (hours)	Transfer penalty add	Explanation	Innoslate Input
C1	Review and Approve Lot Release Letter	1	0.2	Yes	A review action: (μ=1 σ=0.2 hours) + penalty	=norm.dist(4.5, 1) hours
E1.6	Receive LAT Witness Request	1	0.1	Yes	A receipt action: (μ=.5 σ=0.1 hours) + penalty	=norm.dist(4.5, 1) hours
V3.1.1	Submit Configuration Baseline to the WAWF system	0.2	0.05	No	An upload action in a digital database	=norm.dist(0.2, 0.05) hours
V3.1.2	Accept Configuration Baseline Disposition	0.1	0.05	Yes	An email acceptance action: (μ=0.1 hours σ=0.05 hours) + penalty	=norm.dist(3.6, 1) hours
E11.1.1	Download Configuration Baseline from WAWF	0.1	0.05	Yes	A downloading action: (μ=0.1 hours σ=0.05 hours) + penalty	=norm.dist(3.6, 1) hours
E11.1.2	Forward Configuration Baseline to Engineer	0.1	0.05	No	Email forwarding action	=norm.dist(0.1, 0.05) hours
E12.1.1	Review Configuration Baseline	2	0.5	Yes	A review action (μ=2 σ=0.5 hours) + the penalty	=norm.dist(5.5, 1.1) hours
E12.1.2	Send Configuration Baseline Discrepancies to Acquisition Specialist	0.2	0.05	No	The action involves generating an email with technical details	=norm.dist(0.2, 0.05) hours

Prior to conducting simulations of the critical safety item lot acceptance process, outcome probabilities for each decision point had to be input into the model. Figure 16 below shows one example decision point, E1.2.1 Find Acceptance Test Plan Errors, and the probability entries for the two outcomes. For E1.2.1, the probability of finding an error in the acceptance test plan is 10% with a 90% probability that no error is found.

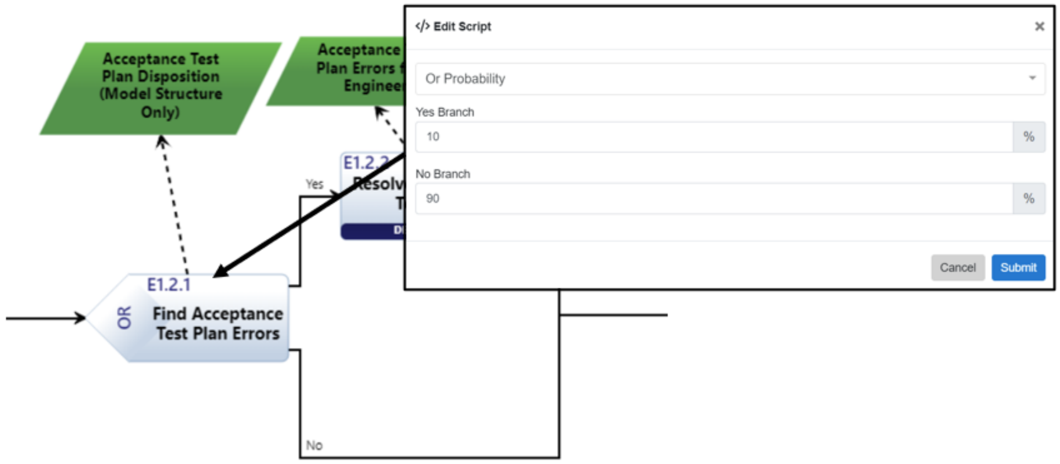

Figure 16. The probability script for decision point E1.2.1.

The probabilities selected for the critical safety item lot acceptance process are representative of the actual process.

Dependent decisions, or decision points that are based on the results of a prior decision point within the critical safety item lot acceptance process, presented another issue during modeling. Innoslate provides no structure to link a dependent decision to the outcome of a prior decision. To resolve this issue, a consumable resource was created in the model for every dependent decision and was linked to the respective parent decision. Based on the results of the parent decision, a specified quantity of the resource would be consumed. When the workflow reached the dependent decision, the outcome of the decision point would be based on the quantity of the resource remaining, and not a probability. This allowed the outcome of a dependent decision to match the outcome of a parent decision made earlier in the model. An example of this is shown in Figure 17, where decision point V3.2.3, USG Found Acceptance Test Plan Errors, is dependent on decision E1.2.1, Find Acceptance Test Plan (ATP) errors. In this case, the vendor is only going to correct errors in the ATP if errors are found by the DOD engineering organization. As shown in Figure 17, the V3.2.3 decision point checks the quantity of Resource ATP Errors, and only proceeds to the yes outcome if resource ATP errors has a quantity of zero.

Figure 17. V3.2.3 USG found acceptance test plan errors script block.

All modeling actions and resources created to support the dependent decision structure in the model were given a negligible duration (≤1 minute) since the entities do not exist in the actual process.

With the construction of the as-is critical safety item lot acceptance process model complete, simulations were run using the Monte Carlo simulation capability in Innoslate. The Monte Carlo simulation dashboard following the execution of a simulation is shown in Figure 18.

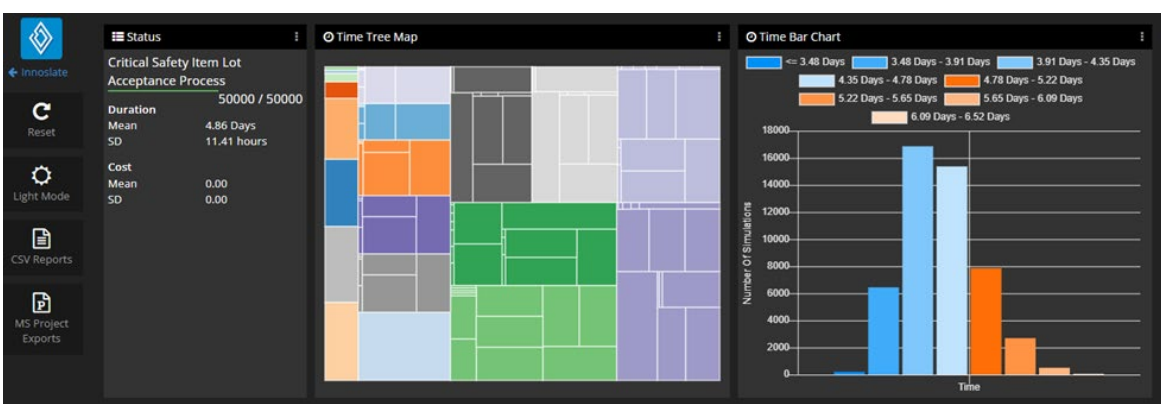

Figure 18. Innsolate Monte Carlo dashboard after simulation.

For the as-is model, a Monte Carlos simulation using 50,000 iterations predicted the critical safety item lot acceptance process would have an average duration of 116.7 hours, with a standard deviation of 11.4 hours. Figure 19 shows a graph of duration occurrence data generated from the Innsolate output.

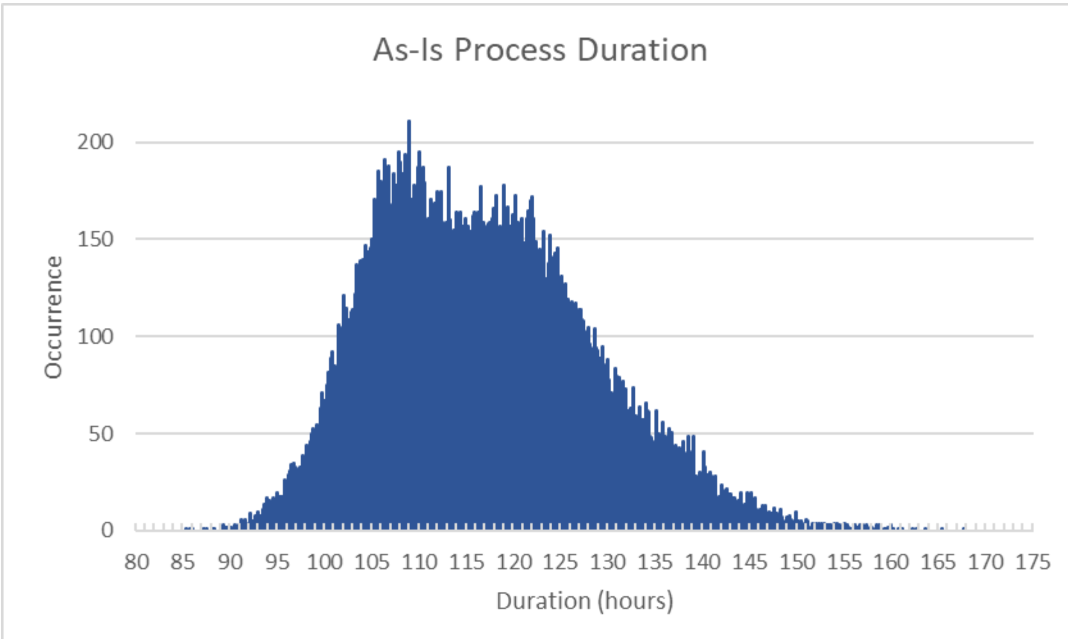

Figure 19. As-is Critical Safety Item Lot Acceptance Process duration performance.

The final activity of the "State the Problem" stage of the process management methodology was a validation of the model through collaboration with stakeholders within the engineering organization executing the process. As discussed in Chapter III, this collaboration is a key advantage offered using a collaborative process management software and helps eliminate discrepancies between a process model and an actual process. For the critical safety item lot acceptance process, both the model and the simulation data proved to accurately represent the actual process.

2. Investigate Alternatives

The second stage of the MBSE process management methodology involved identifying issues or inefficiencies within the as-is critical safety item lot acceptance process and proposing possible resolutions to each issue. According to the customer, the goal of the process management effort was a reduction in process duration by at least 20% or to an average duration of 93.36 hours or less. With this in goal in mind, the issues identified during the process management effort focused on duration.

The first analysis tool employed for the critical safety item lot acceptance process management effort was a Value-Added Analysis to determine what steps within the process add value to the customer or the organization executing the process. Using the value-added analysis process discussed in Chapter II, each action within the lot acceptance process was categorized as value-added, business value-added, or non-value added. The requirements traceability capability of an MBSE was important during this analysis since an action was only considered value-added or business value-added if it satisfied a requirement of the stakeholder. A sample of the value-added analysis performed for the critical safety item lot acceptance process is shown in Table 9 with the complete analysis shown in Appendix C.

Actions within the process were identified as value-added if they satisfied a requirement delivering value to the customer of the critical safety item lot acceptance process. An example value added action is E12.1.1, review configuration baseline. E12.1.1 was categorized as value-added because it validates the configuration of the items being manufactured is acceptable, ultimately assuring a quality product is delivered to the end user.

Actions were identified as business value-added if they satisfied a requirement that does not specifically support the customer. An example of a business value added action is E12.1.4, send configuration baseline approval. Per the contract controlling the procurement of critical safety items, the configuration baseline must be accepted. This means E12.1.4 is satisfying the requirement that the process shall meet the requirements of the contract, but the action is clerical in nature and does not provide value to the customer. As discussed above the value to the customer is the actual review of the document, action S12.1.1.

Examples of a non-value-added actions are E11.1.1 and E11.1.2, the download and forwarding of the configuration baseline. These actions were categorized as such because there is no requirement stating the acquisition specialist must download the configuration baseline from the Wide Area Workflow (WAWF) system, and the acquisition specialist performs no inspection or processing of the document prior to forwarding onto the engineer. Actions E11.1.1 and E11.1.2 are purely clerical in nature, and do not satisfy a requirement of the process.

Table 9. A sample of the value-added analysis of the critical safety item lot acceptance process.

Number	Name	Actor/Entity	Step Label (VA, BVA, or NVA, Modeling Entity)	NVA mean time per task (hours)
C1	Review and Approve Lot Release Letter	Contracting Officer	BVA	
E1.1	Review and Approve Configuration Baseline	Engineering Organization	Modeling Entity	
V3.1.1	Submit Configuration Baseline to the WAWF system	Vendor	VA	
V3.1.2	Accept Configuration Baseline Disposition	Vendor	BVA	
E11.1.1	Download Configuration Baseline from WAWF	Acquisition Specialist	NVA	3.6
E11.1.2	Forward Configuration Baseline to Engineer	Acquisition Specialist	NVA	0.1
E12.1.1	Review Configuration Baseline	Engineer	VA	
E12.1.4	Send Configuration Baseline Approval	Engineer	BVA	

The value-added analysis performed for the critical safety item lot acceptance process identified 43 actions as value added, 30 actions as business value-added, and 38 actions as non-value added. 27 actions were identified as modeling entities that do not occur in the actual process and therefore were disregarded for this analysis. In a worst-case scenario, the non-value added actions within the critical safety item lot acceptance process would total a mean duration of 82.7 hours, though incurring all non-value added actions within a single iteration of the process is highly unlikely since the occurrence of many actions is dependent on whether there are documentation errors or not.

The value-added analysis identified that one issue with the critical safety item lot acceptance process was excessive non-value-added steps which account for nearly 40% of the actions in the model (excluding modeling entities). According to Table 3 (BPM Best practices), the known solution for non-value activities within a process is the elimination of all unnecessary, or non-value-added steps from the process. Both the issue identified through the value-added analysis and the proposed solution taken from BPM best practices were logged on an issue register shown later in Table 10, and will be carried forward to the modeling stage of the process management effort.

The second analysis tool used to identify issues with the critical safety item lot acceptance process was a sensitivity analysis that examined the impact of documentation errors. While all technical documents are generated by the external vendor and therefore are not controlled by the process owner, the engineering organization, documentation errors are often blamed as a cause of significant increases in process duration. The decision was made by the process owner to determine the impact of the document issues and to demonstrate how much of the current process's duration performance was a results of documentation errors and not the process workflow. To do this, the occurrence of errors within the as-is lot acceptance process model was varied from 0% (All documentation submitted correctly the first time) to 100% (All documentation submitted incorrectly the first time) within the process model. A Monte Carlo simulation using 5,000 iterations was conducted for each document error rate. To simplify the sensitivity analysis all documents were given the same error occurrence rate per iteration of the sensitivity analysis.

The results of the sensitivity analysis, shown in Figure 20, demonstrates that documentation errors within the critical safety item lot acceptance process have the ability to increase process duration by nearly 40% if all documents are submitted with errors. Furthermore, when the average duration of the lot acceptance process with no errors, 106.1 hours, is compared to the results of the as-is model, 116.7 hours, documentation errors on average results in a duration increase of 10.6 hours, or approximately 9 percent of the total lot acceptance process. As the critical safety item lot acceptance process is improved, the 10.6 hours of duration added on average by documentation errors during a single iteration of the process could become a limiting factor for performance if controls cannot be put in place to decrease the occurrence of document errors from external stakeholders.

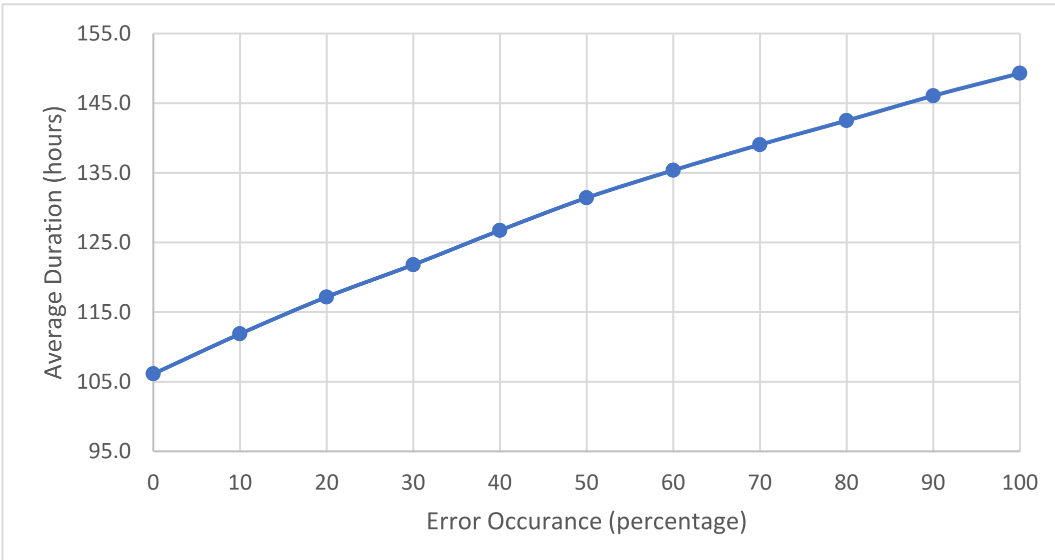

Figure 20. Lot Acceptance process duration performance graphed as a function of documents error occurrence.

The lessons learned from the field of business process management discussed in Chapter II do not provide guidance for how to improve the quality of incoming product. With that said, since quality escapes can result in significant process inefficacies, there is value in quantifying the issue and using the information generated from the model to set reasonable performance goals, and to drive process improvement efforts outside of the engineering organization's control.

The final issues identified with the critical safety item lot acceptance process were: a high number of handoffs between entities and in turn, a high number of handoff penalties within the lot acceptance process, and a high number of middle management oversite actions on the approval of the lot acceptance letter. These issues were identified by the process owner following a review of the BPM lessons and best practices found in Table 3.

According to the BPM best practices, both characteristics within the process should be minimized. See Chapter II for further discussion.

All problems identified with the critical safety item lot acceptance process during the investigate alternative stage of the thesis were logged on the issue register shown in Table 10. Unlike the example issue register discussed in the previous chapter, the issue register used for the lot acceptance process included proposed solutions to each problem that would be tested during the modeling stage of the process management effort. Priority was established for each issue based on the impact it had on total process duration. The exception to this was documentation errors since the issue cannot be resolved within the scope of this effort.

Table 10. Critical safety item lot acceptance process issue register.

Name	Issue Description	Priority	Assumptions	Impact	Proposed Solution or Improvement
Document Errors	Technical documents are submitted with errors, which result in rework and additional downtime.	4	The impact was calculated using the average durations incurred from a single document error.	Approximately 18 hours per document found with errors	Drive an external quality improvement effort
Excessive handoff Downtime	A high number of handoffs between entities results in excessive downtime	2	Email is the primary form of information transfer. Downtime was estimated using the average email response time in a workplace during work hours	An average of 3.5 hours of downtime for each handoff between entities in the process. Over 30 handoff penalties on the USG side.	Reduce the number of times the process flow changes hands, through the reorganization or elimination of steps.
Excessive Non-value adding actions	A high number of non-value added steps result in poor process duration performance	1	The quantitative impact was calculated through the summation of the average durations of all non-value added steps. There is a low chance of all non-value-added steps occurring during one iteration of the process	87.2 total hours of non-value added steps possible in the process	Eliminate as many of the non-value added steps as possible
Excessive middle manager oversite	During the lot acceptance letter approval process 3 middle manager level employees review a document	3	Each middle manager review causes a 3.5 hour handoff penalty in addition to the review and approval time	An average of 4.2 hours of duration for each middle manager review	Eliminate document reviews not explicitly required and drive decision authority down the command chain

3. Model the System

The modeling stage of the process management effort involved integrating the improvements documented in the issue register in Table 10 into the as-is critical safety item lot acceptance process model to determine if the improvements were feasible, and if so, how effective they were at improving duration performance. The improvements were integrated and tested in the process model based on the priority given to the issue in the prior step, though some improvements did address multiple process problems.

The first improvement made to the critical safety item lot acceptance process was the elimination of non-value-added actions performed by the DOD engineering organization executing the critical safety item lot acceptance process. To model this improvement in the MBSE environment, actions identified as non-value-added were deleted from the critical safety item lot acceptance process model, and the process flow was carried from the previous action. An example of the change is shown in Figure 21 where the action diagram for E1.1.2, resolve configuration baseline errors, is shown before and after the removal of all non-value-added actions.

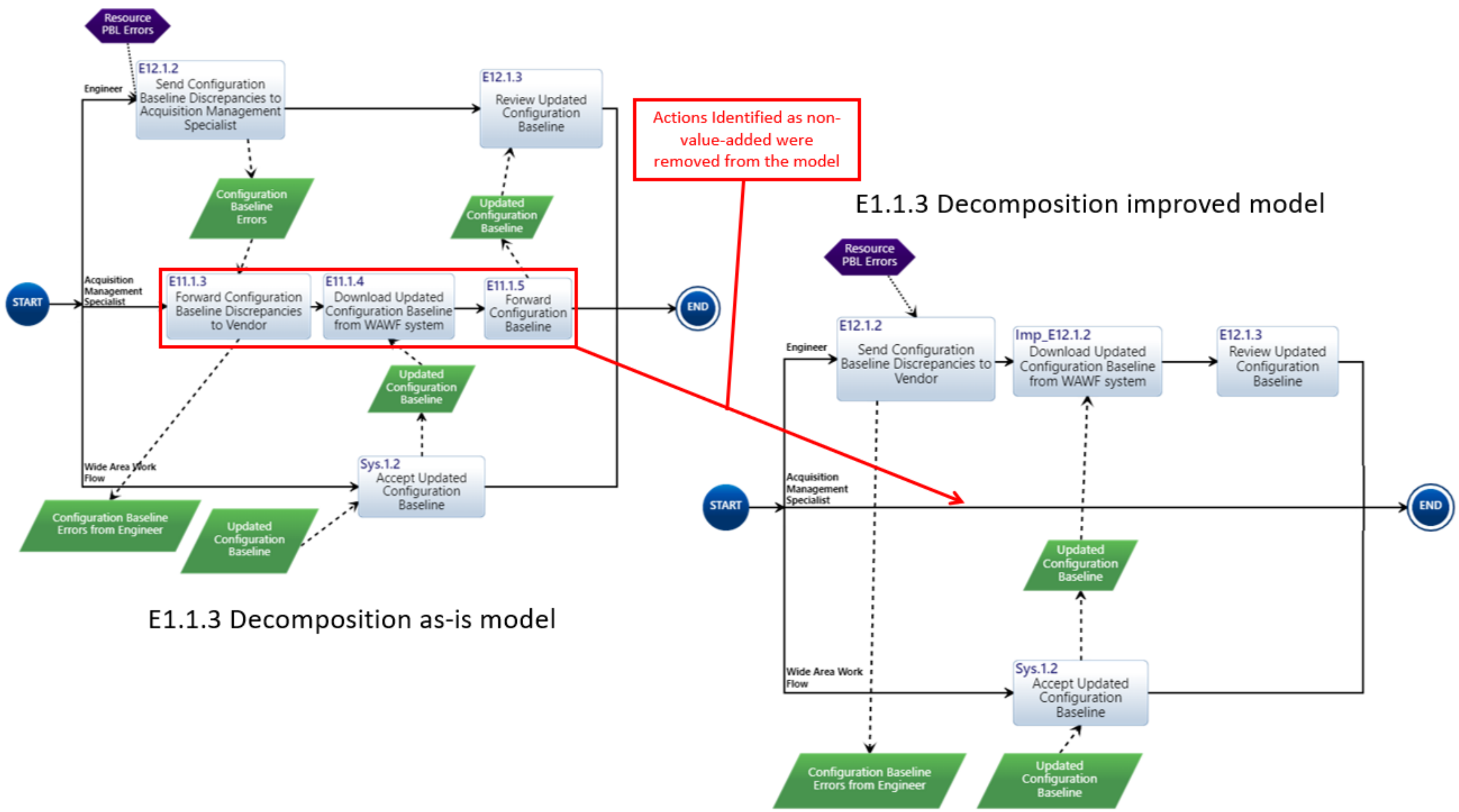

Figure 21. The action model for E1.1.2, resolve configuration baseline errors, before and after the process improvement.

Figure 21 shows how the non-value-added actions were removed from a single decomposed diagram of the critical safety item lot acceptance process and how the process flow was continued from the prior value-adding action. The same activity was performed for the entire model eliminating all non-value action except for those included in the decomposition of E1.9, Issue Lot Acceptance Letter. E1.9 was excluded from this improvement because the approval process for the lot release letter would be addressed later in the effort when the focus shifted to decision authority.

During the first revision of the process management modeling activity, 31 non-value-added tasks totaling 69.7 hours of possible process duration, were removed from the critical safety item lot acceptance process. In addition to the elimination of non-value-added steps, the improvement made during this stage decreased the total number of process handoff within the model. 18 of the non-value-added actions eliminated during this improvement incurred handoff penalties due to the process flow coming from another entity in the process. With the removal of the actions, the 18 handoff penalties were eliminated from the model.

Following the removal of non-value-added actions from the critical safety item lot acceptance process, the performance of the process was simulated using the Innsolate Monte Carlo capability. As with the original as-is process model, 50,000 iterations were used for the simulation. The first revision of the improved critical safety item lot acceptance model output a mean process duration of 99.9 hours, with a standard deviation of 8.5 hours. Figure 22 below shows the duration data from the simulation plotted as a function of duration occurrence.

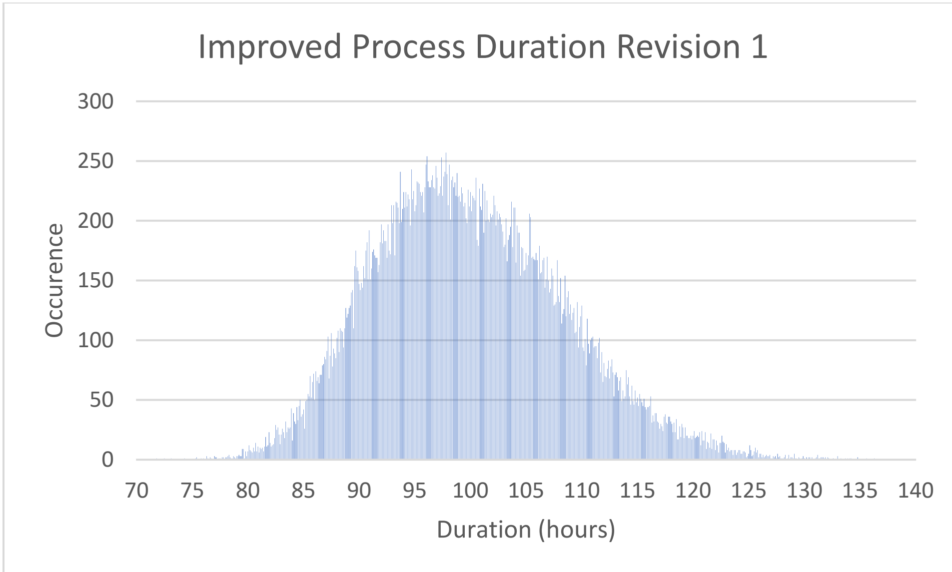

Figure 22. Revision 1 Improved Critical Safety Item Lot Acceptance Process duration performance.

As Figure 22 shows the first revision of the improved process had an average duration of 99.9 hours. This represents a 14.3% decrease in process duration from the as-is model which predicted an average process duration of 116.7 hours. While the simulation did show that the process would function with the non-value-added actions removed from the process, the goal of the process management effort of a 20% duration decrease was not met through the elimination of non-value-added actions alone. To meet the goal of a 20% decrease in duration, the improved process was carried forward to integrate additional improvements identified during the prior step.

The next issued that was addressed with the critical safety item lot acceptance process was excessive decision authority held with middle management during process E1.9, Issue lot acceptance letter. The as-is model of E1.9 is shown in Figure 23 and demonstrations that every time a lot of critical safety items is ready to be released to the DOD fleet, three middle management level employees and the engineer must review the letter to validate the content of the letter is correct. Not only were four in series reviews of the same document unnecessary as there is no requirement driving the high number of reviews, but each review carries a handoff time penalty because the process flow sequentially moves from one entity to the next.

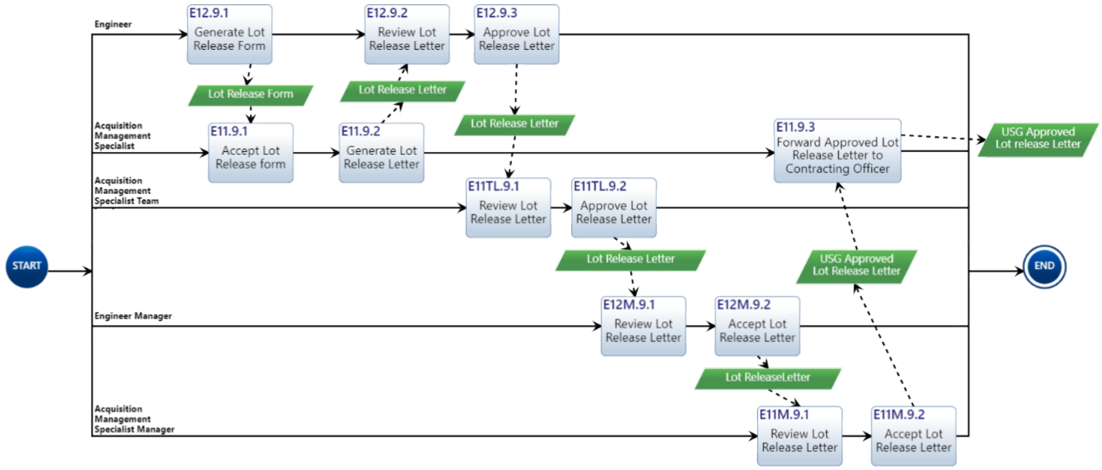

Figure 23. E1.9 issue lot acceptance letter from the as-is model.

According to Table 3, BPM best practices, the solution to excessive decision authority held with middle management is to decrease the decision authority to the working level. Unfortunately, that is not a complete solution in this case since there is a requirement for both the engineering manager, and the acquisition management specialist manager to sign off on all lot release letters. With that said, two of the four reviews, one by the engineering and one by the acquisition management specialist team lead, are not required and account for approximately 8.2 hours of duration during every occurrence of the lot acceptance process. These reviews, which were likely put in place because of one-off failures of the process to catch errors in the lot release letter, should be eliminated from the process. This follows the guidance shown in Table 3 to "Give workers most of the decision-making authority and reduce middle management" (Reijers and Mansar 2005), and to "Design business processes for typical orders and isolate exceptional orders from normal flow" (Reijers and Mansar 2005). The improved E1.9, issue lot acceptance letter, process is shown in Figure 24.

The improved E1.9 process, issue lot acceptance letter, depicted in Figure 24 completes the same function as the original as-is E1.9 process depicted Figure 23, but completes the function in a significantly shorter time through the elimination of several non-value-added reviews and handoff penalties. Even though it wasn't possible to lower all middle management decision authority to the working level, one middle management review and one peer review were eliminated. Beyond the performance impacts of this change to the process, eliminating redundant reviews will show an added level of trust to a workforce which helps empower the workforce and improves employee performance (Brower, Lester and Korsgaard 2017).

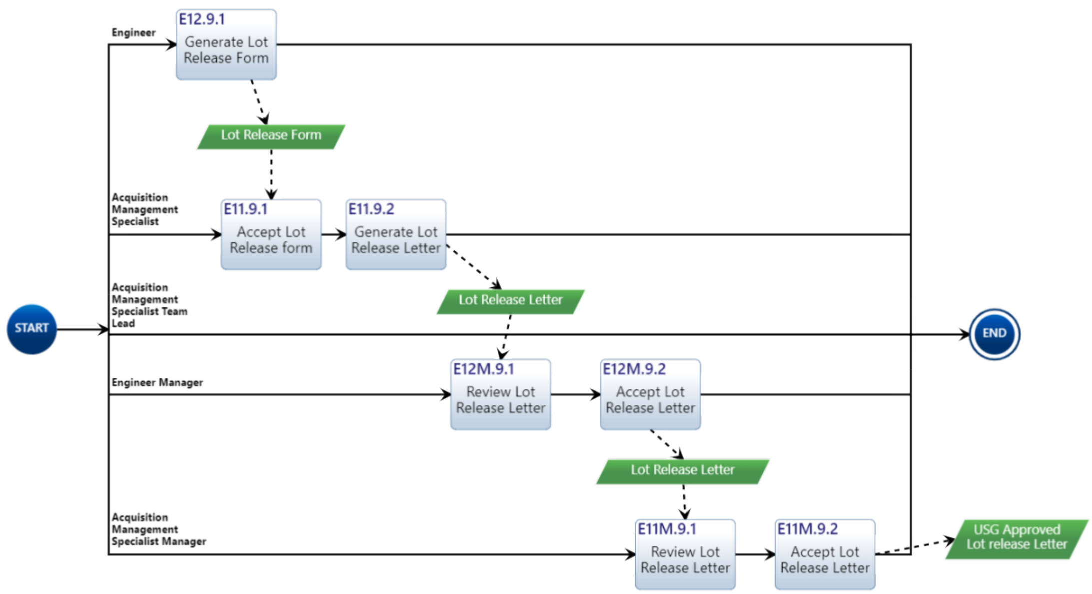

Figure 24. E1.9, issue lot acceptance letter improved revision 2.

Following the improvements made to E1.9, issue lot acceptance letter, the critical safety item lot acceptance model was simulated again using the Innoslate Monte Carlo capability with 50,000 iterations. The mean duration of the second revision improved critical safety lot acceptance process which incorporated all improvements previously discussed was 88.1 hours with a standard deviation of 8.3. This represents a 24.5% improvement in process duration and meets the performance improvement threshold set at the start of the process improvement effort. The data collected for the second revision improved process model is shown in Figure 25.

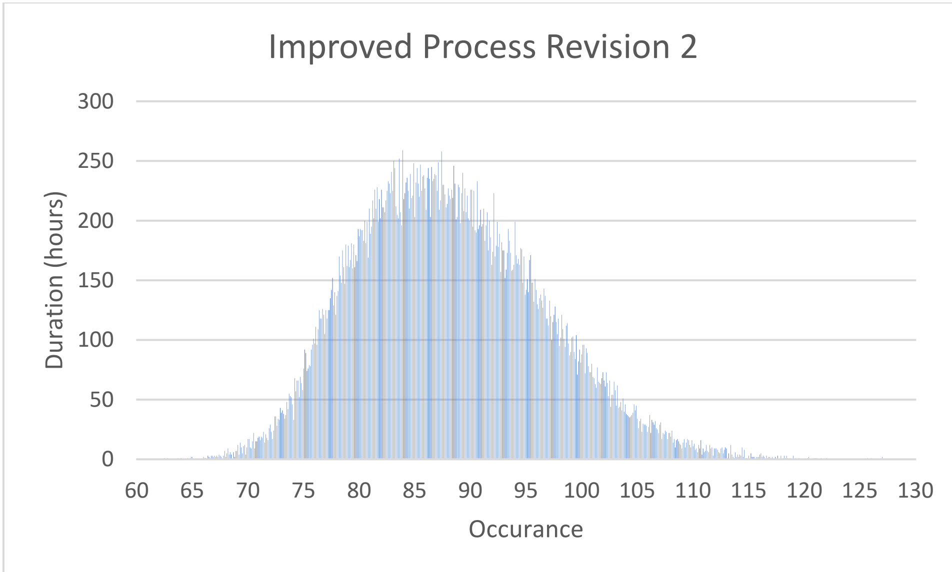

Figure 25. Revision 2 Improved Critical Safety Item Lot Acceptance Process duration performance.

The simulated process time of 88.1 hours generated by second revision of the improved critical safety lot acceptance process exceeds the 20% duration performance improvement set for the process management effort, while still meeting all requirements driving the process. Based on this performance metric the modeling stage of the process management effort was concluded. The complete improved process model generated during this stage of the effort can be found in Appendix D.

4. Case Study Conclusion

The process management effort presented in this chapter was conducted with the goal of validating that an MBSE process management methodology could be used to improve and manage an existing DOD engineering organization's process. As presented in the chapter, the goal of improving a DOD engineering process was meet with a 24.5% reduction in predicted process duration between the as-is critical safety item lot acceptance process shown in Appendix A and the improved critical safety item lot acceptance process shown in Appendix D. While this satisfies the goals set out for the case study, identifying problems within a process and designing a new improved process is only a portion of the

MBSE process management methodology, and fails to utilize all advantages offered by an MBSE approach. The remaining steps of the MBSE process management effort not covered by the case study are Integration, Launch the System, and Assess Performance. In a full application of the MBSE process management methodology these steps are necessary for the successful implementation of an improved process. During the activities associated with these steps, the collaborative capabilities of an MBSE software play a significant role as both the Integration stage and the Launch the System stage of the methodology rely heavily on involvement from stakeholders. An MBSE approach to the integration and launch stage provides an advantage over the traditional document-based approach to collaborative activities because in an MBSE approach stakeholders can actively interface with the process model in the indented modeling environment. This allows stakeholders to freely navigate the model on their own timeline and allows the examination of any model characteristic a stakeholder might be interested in in all of its detail.

V. CONCLUSION

This thesis presents a MBSE process management methodology developed to address a lack of digital process management resources available to the DOD engineering workforce. MBSE is being pushed heavily across the DOD, the research and methodology detailed in this thesis explore a novel use of MBSE that takes advantage of investments the DOD has already committed to offer a modern solution for process management. If applied to processes within the DOD's engineering workforce, the methodology presented in this thesis will give DOD engineering organizations the capability to move their process management activities to a digital modeling environment that offers modeling, analytic, and collaborative capabilities not previously available. This would allow DOD engineering organizations to modernize their process management techniques and closer align their approach with the digital process management techniques widely accepted as the standard in industry and academia.

A. RESULTS AND RECOMMENDATION

The objective of the thesis, to demonstrate how MBSE could be used to improve process management within the DOD, was achieved. Through the case study, it was demonstrated the MBSE process management methodology detailed in the thesis can be applied to a DOD engineering process to facilitate digital process improvement. Additionally, while not explicitly verified in the case study, the use of MBSE should support long term digital process management within the DOD.

The research questions identified at the start of the project were addressed by the research conducted for this thesis: the investigation of process management within academia and industry, the development of a MBSE process management methodology, and the application of the methodology to a DOD process as a case study. Each research question is shown below with a brief explanation of the findings.

1. How can the systems engineering process be applied to an engineering organization's processes to facilitate both the improvement and long-term management of the processes?

Systems engineering approaches are intended to be generic to facilitate their application to any system or problem within a system. While most people do not look at a process as a system or from a systems perspective, processes meet all requirements to be classified a system. With that in mind, a process management methodology was developed utilizing an existing systems engineering approach, and demonstrated to meet process management goals through a case study using an existing DOD process. The case study was able to demonstrate that a single iteration of the methodology could produce process performance improvements. Long-term process management capabilities were not able to be demonstrated within the scope of the thesis, and therefore were only discussed at a theoretical level.

2. How can MBSE languages be used to model a DOD organization's structure and process flow?

Chapter II specifically addresses the capability of common MBSE languages to model both an organization and an organization's processes. Prior research discussed and cited in the thesis demonstrates that the predominant process modeling language in industry, BPMN, offers very few advantages over MBSE languages. Furthermore, the case study demonstrates that a DOD engineering organization and its processes could be accurately modeled using a MBSE language.

3. What process management best practices from industry can be leveraged to improve a systems engineering approach to process management?

Numerous process management best practices were identified as part of the literature review conducted in support of the thesis. Best practices utilized as part of this research included lessons learned, such as practices or characteristics to avoid, and analysis techniques demonstrated to work for process management efforts. All best practices were integrated into the MBSE methodology to augment any lack of experience a process owner might have with managing a process. Multiple analysis techniques and lessons captured as process management best practices were demonstrated to work in unison with the MBSE process management methodology through the case study.

4. How can MBSE simulation capabilities be used to quantify process performance throughout the process life cycle?

Many MBSE software have the capability to model process performance characteristics such as process duration, process cost, and resource allocation. The importance of this capability to a process management effort is stressed throughout the thesis and was demonstrated in the case study. For the case study, process duration was the performance metric of interest and was the criteria used to measure the success of case study. During the case study, the MBSE simulation capabilities allowed the as-is process model to be validated for performance against the real process, and the performance of redesigned processes to be simulated prior to implementation. Process simulation capabilities are one of the advantages offered by MBSE and therefore are integrated throughout the process management methodology.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

The MBSE process management methodology was successfully applied to a DOD engineering process and allowed the process owner to improve process duration performance while still meeting all customer needs. While this demonstrates that MBSE can facilitate digital process management, further research is needed quantify the effectiveness of MBSE as a long-term process management solution. Recommendations for future research are:

- An assessment of MBSE's ability to facilitate long term digital process management. The case study only executed a single iteration of the MBSE methodology. Further analysis is needed on the performance and issues that arise from long term use of MBSE for process management over the life cycle of a process.

- An assessment of the effectiveness of MBSE interfaces at communicating with stakeholders not familiar with the MBSE or MBSE software.

- Further demonstration of the MBSE process management methodology on other organizations and processes.

- A more comprehensive analysis of the uses of a MBSE software's simulation capabilities for process management. The case study only simulated one process performance characteristic, duration.

APPENDIX A. AS-IS CRITICAL SAFETY ITEM LOT ACCEPTANCE MBSE MODEL

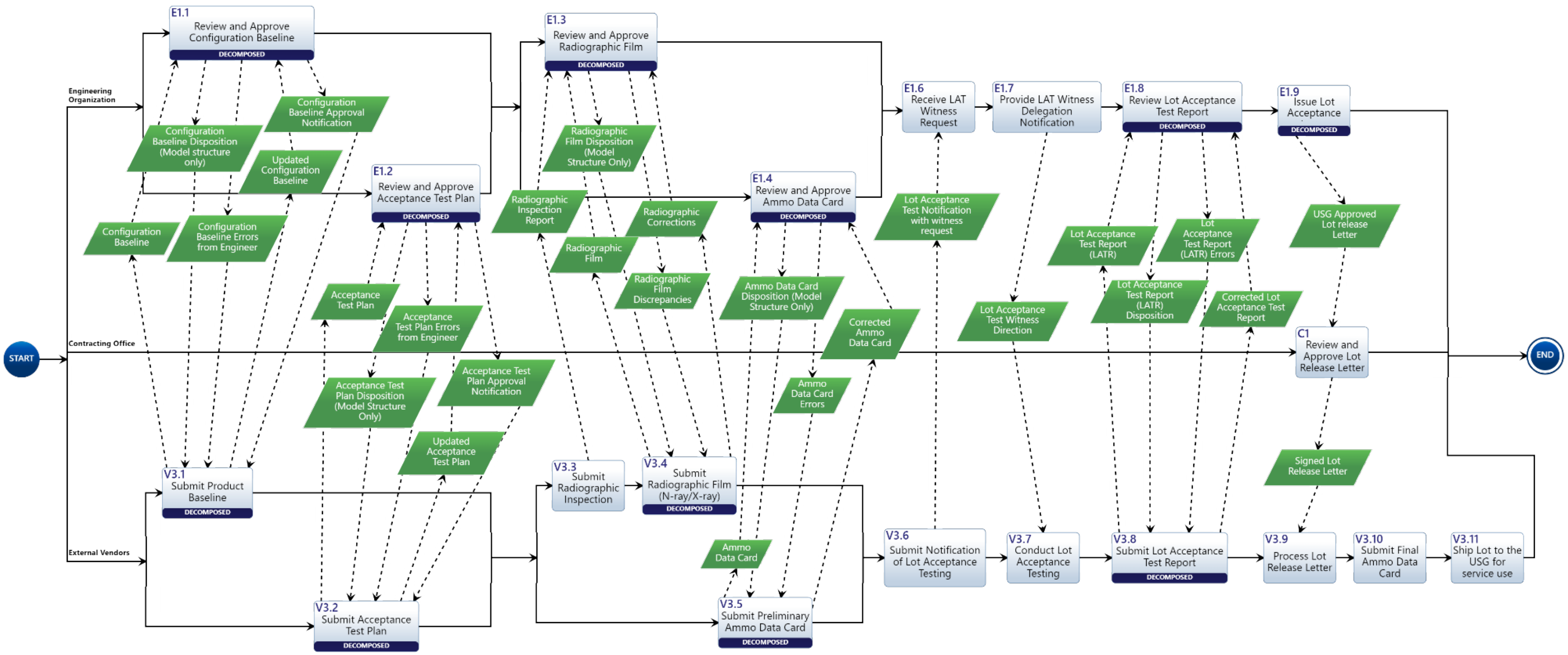

Figure 26. As-is critical safety item lot acceptance process flow diagram.

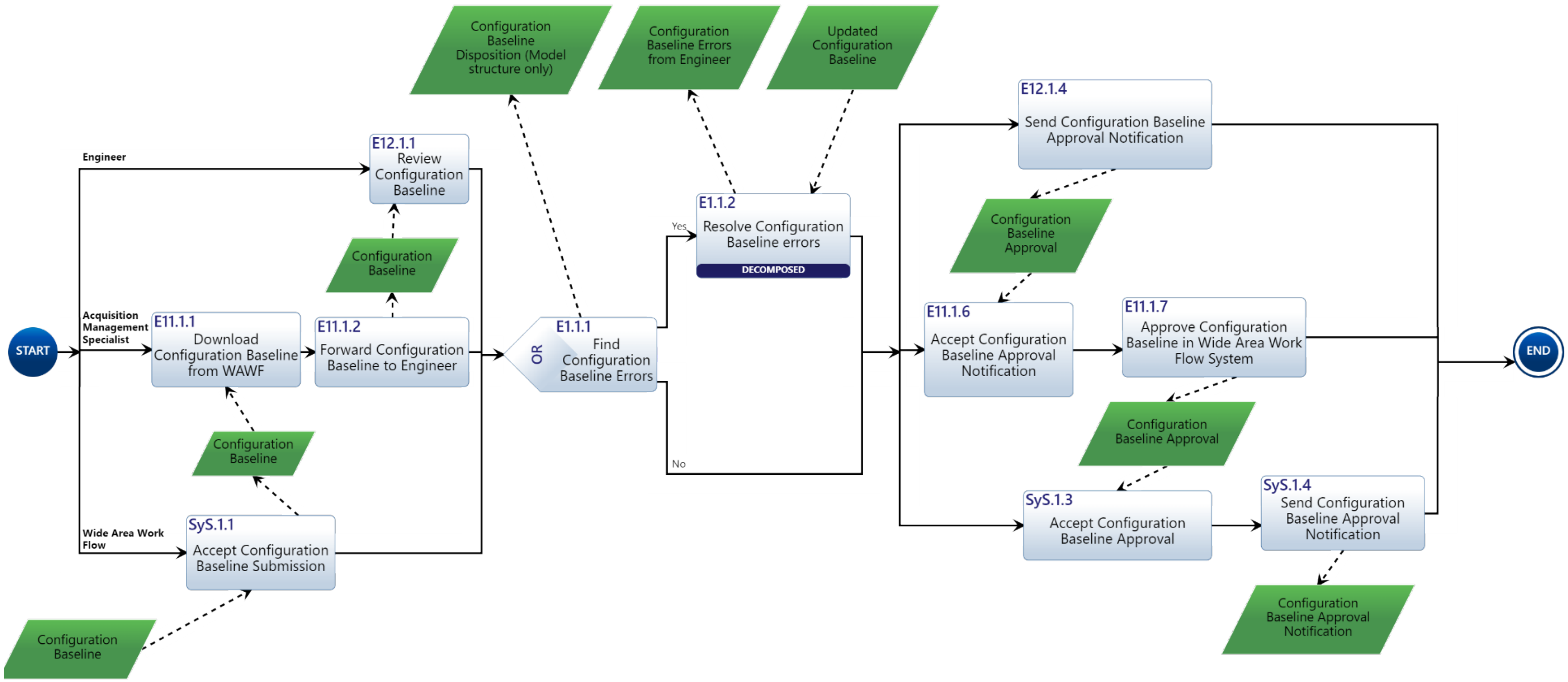

Figure 27. As-is E1.1, review and approve configuration baseline.

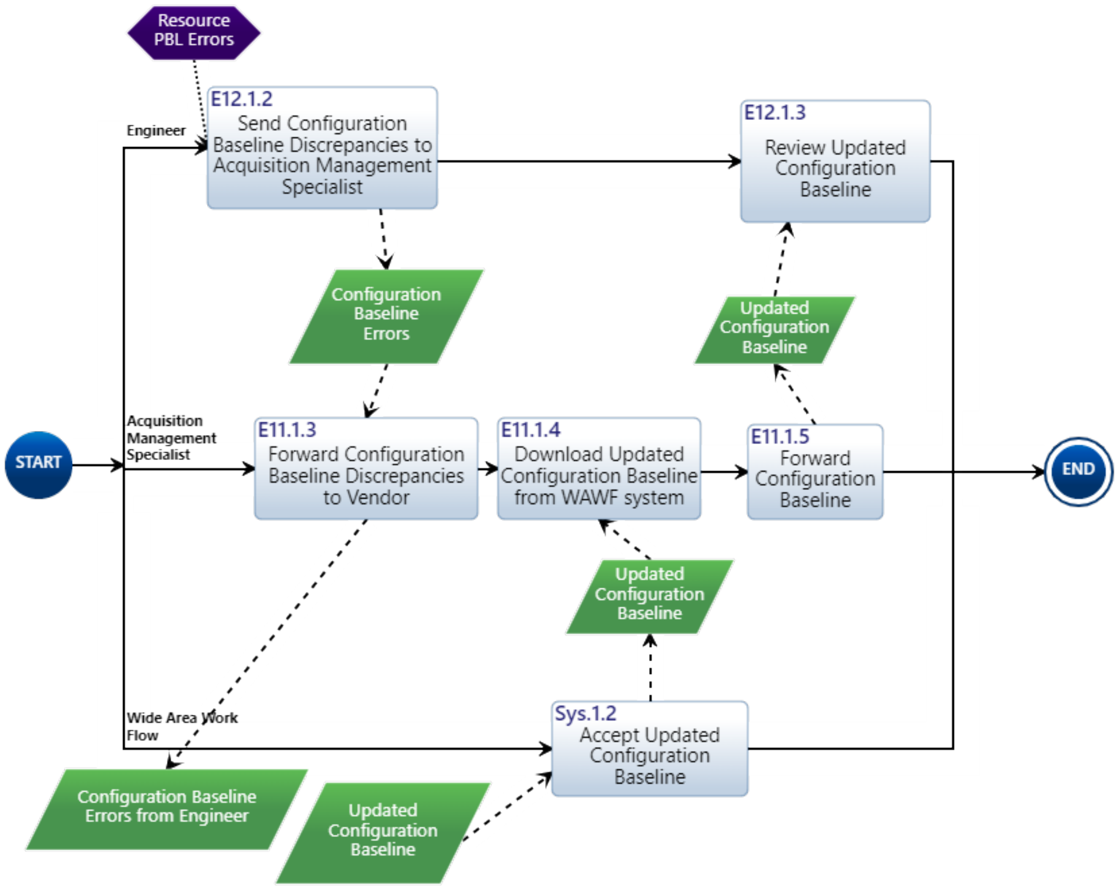

Figure 28. As-is E1.1.2, resolve configuration baseline errors.

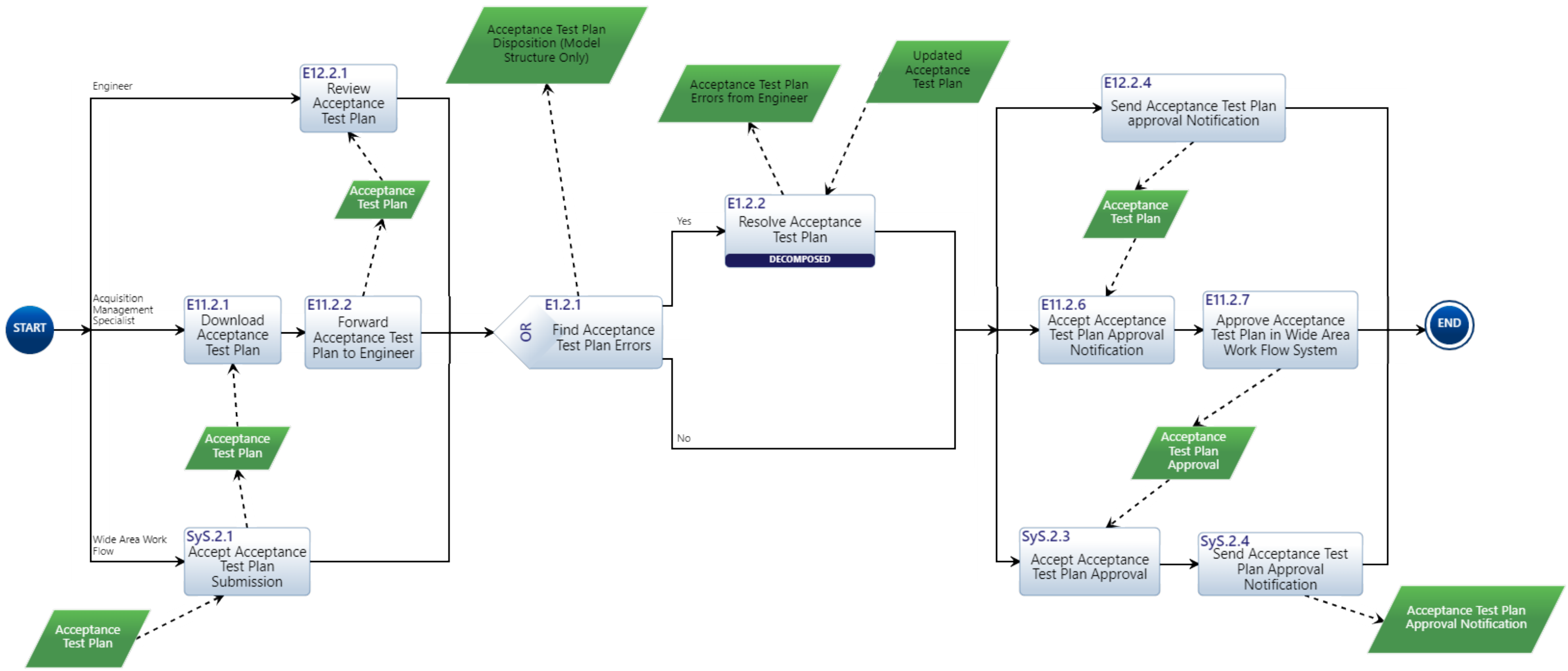

Figure 29. As-is E1.2, review and approve acceptance test plan.

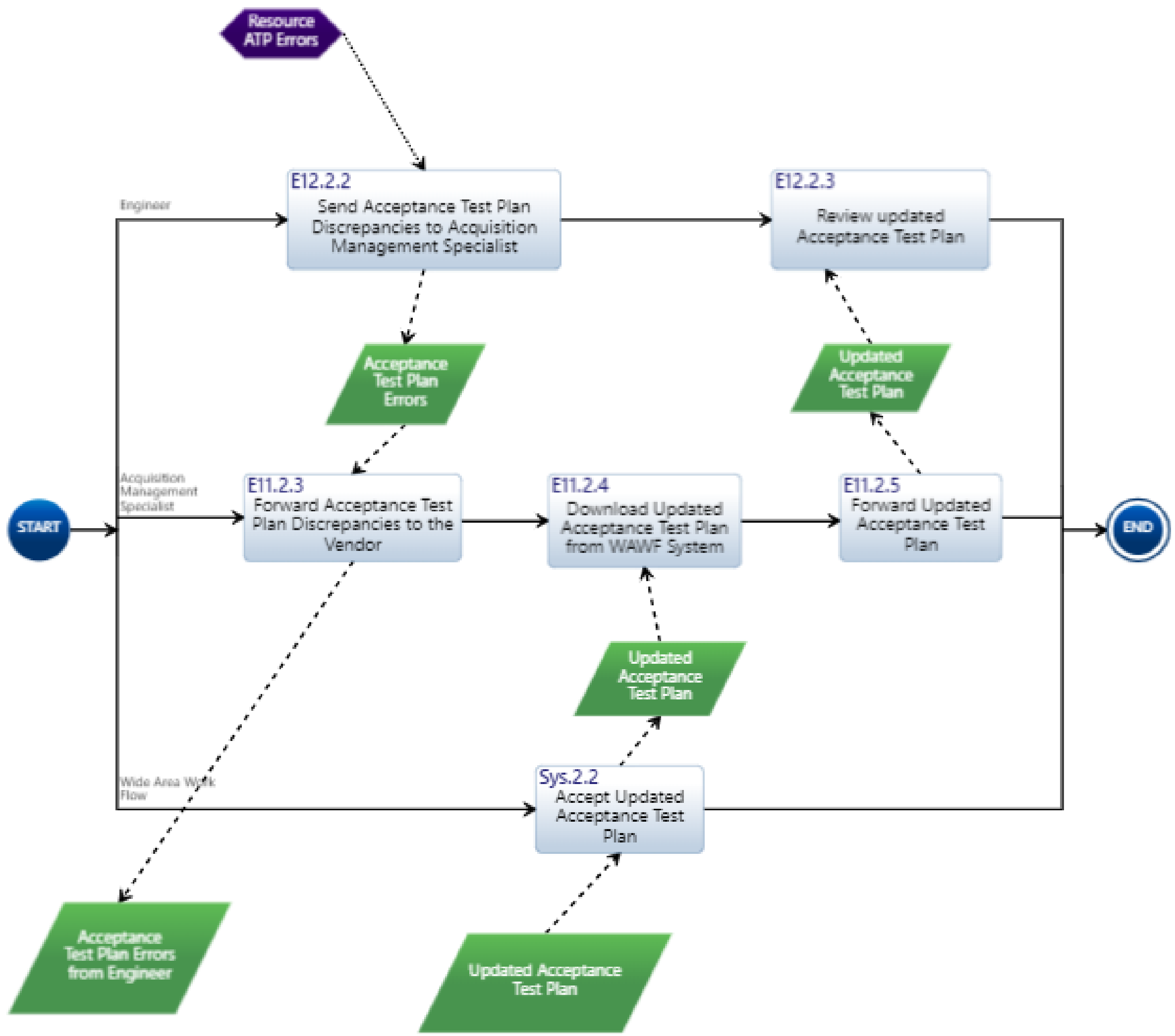

Figure 30. As-is E1.2.2, resolve acceptance test plan.

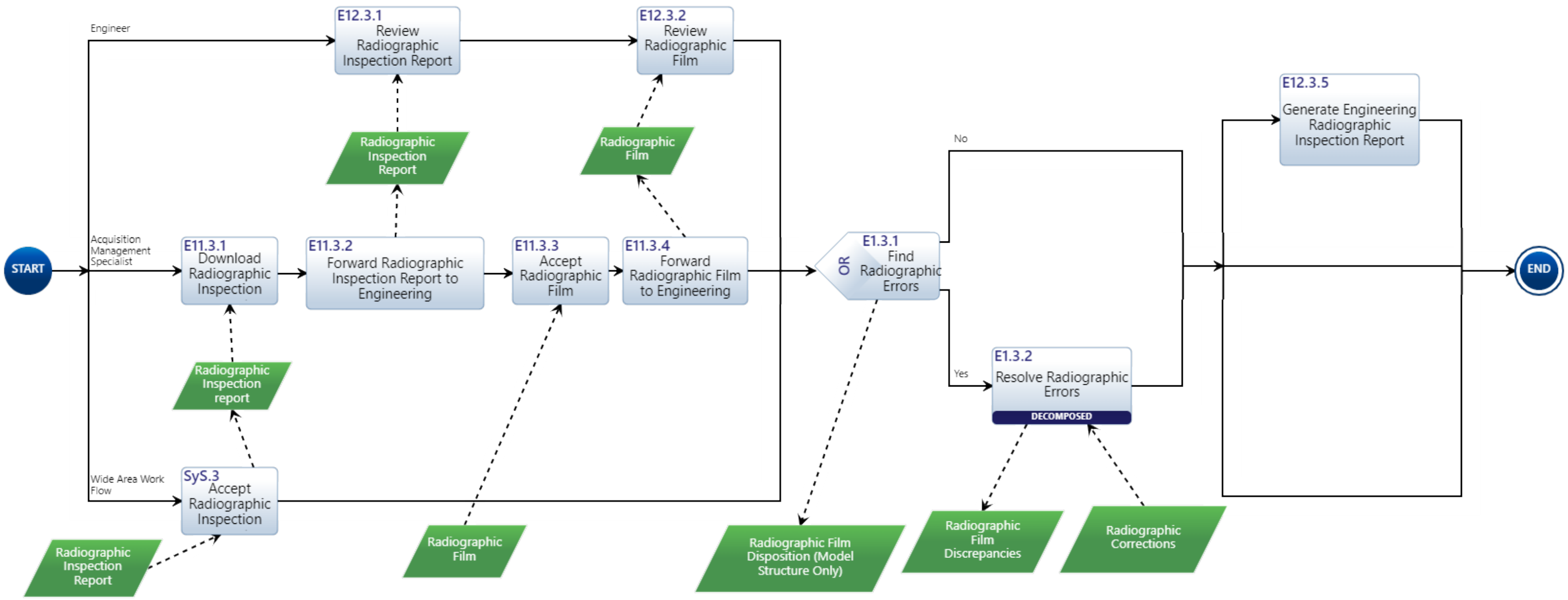

Figure 31. As-is E1.3, review and approve radiographic film.

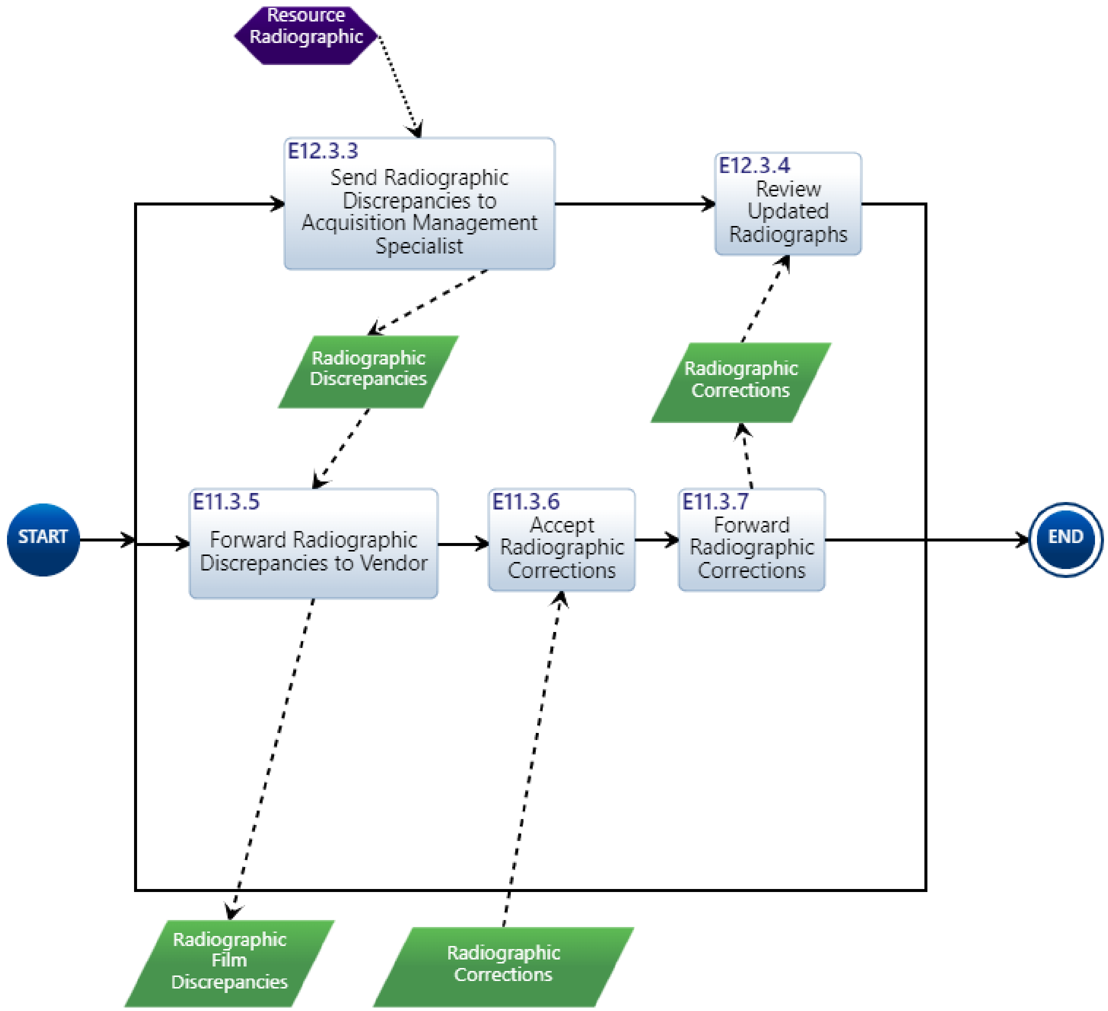

Figure 32. As-is E1.3.2, resolve radiographic errors.

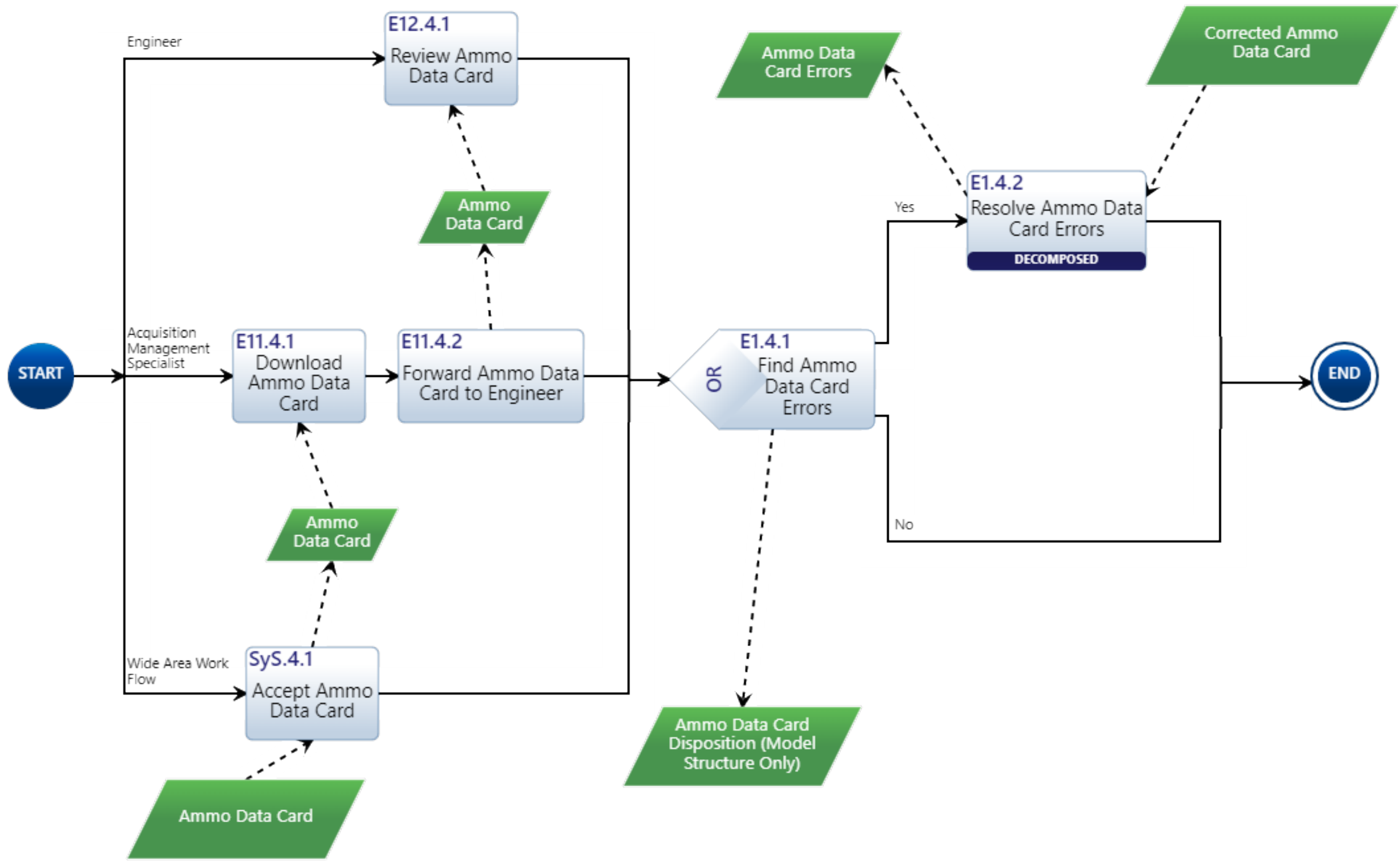

Figure 33. As-is E1.4, review and approve ammo data card.

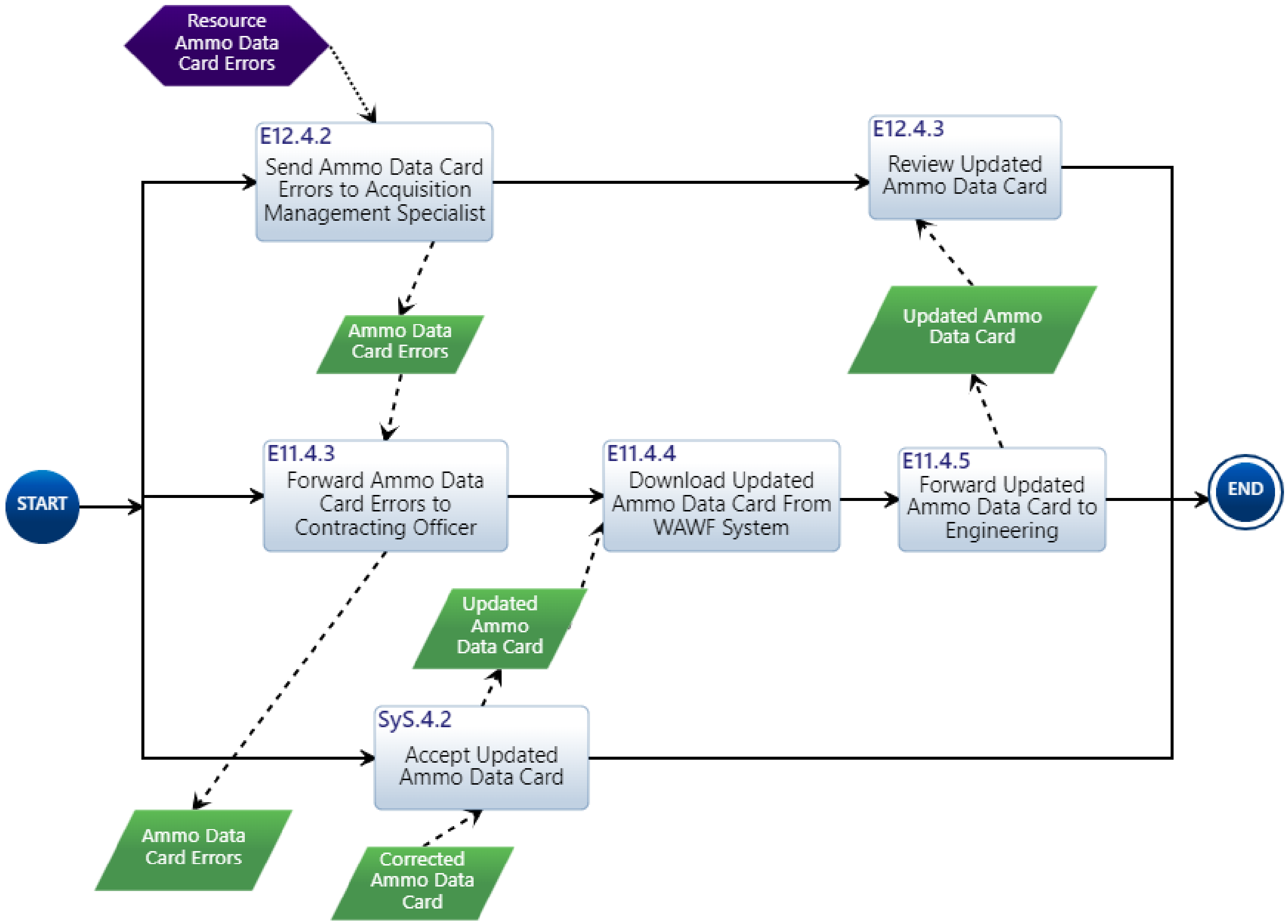

Figure 34. As-is E1.4.2, resolve ammo data card.

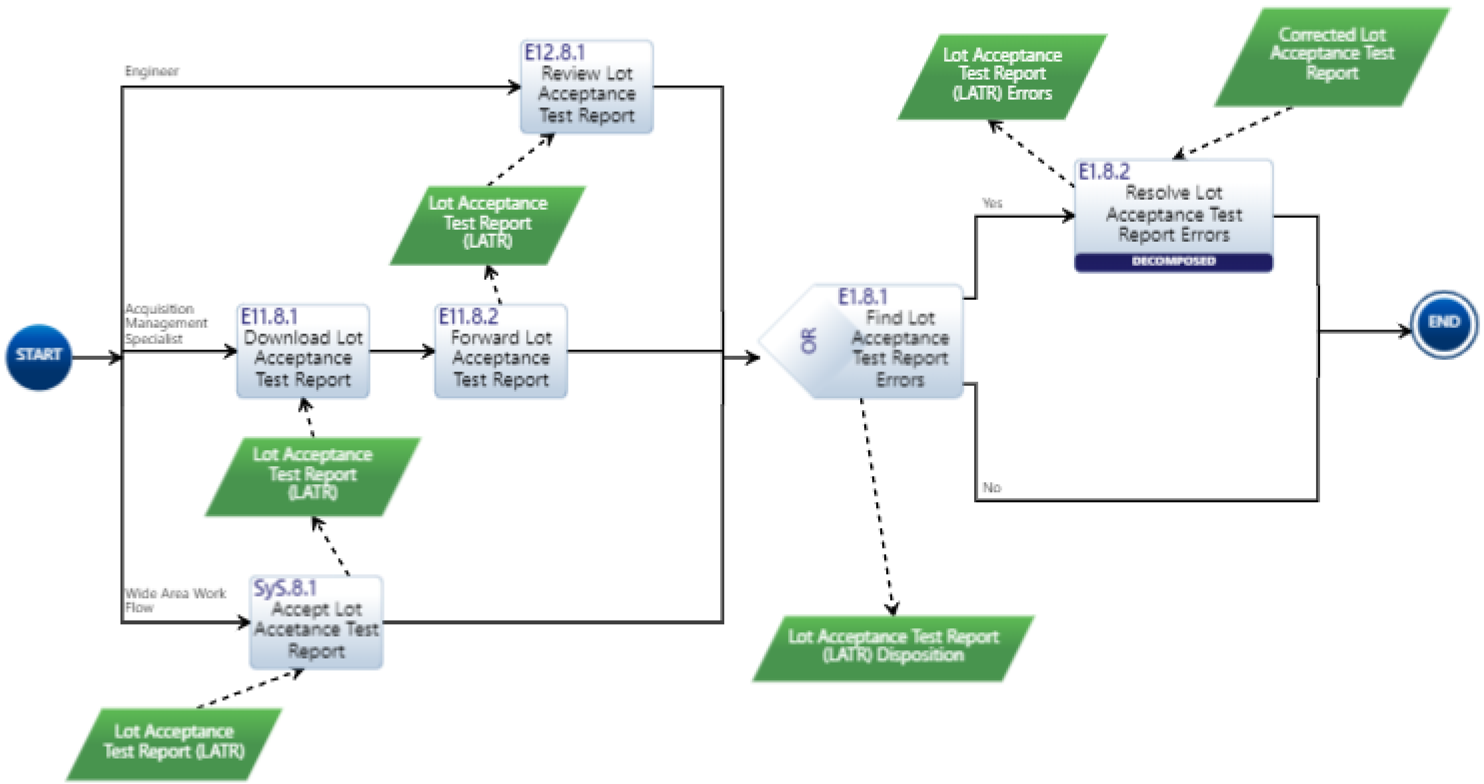

Figure 35. As-is E1.8, review lot acceptance test report.

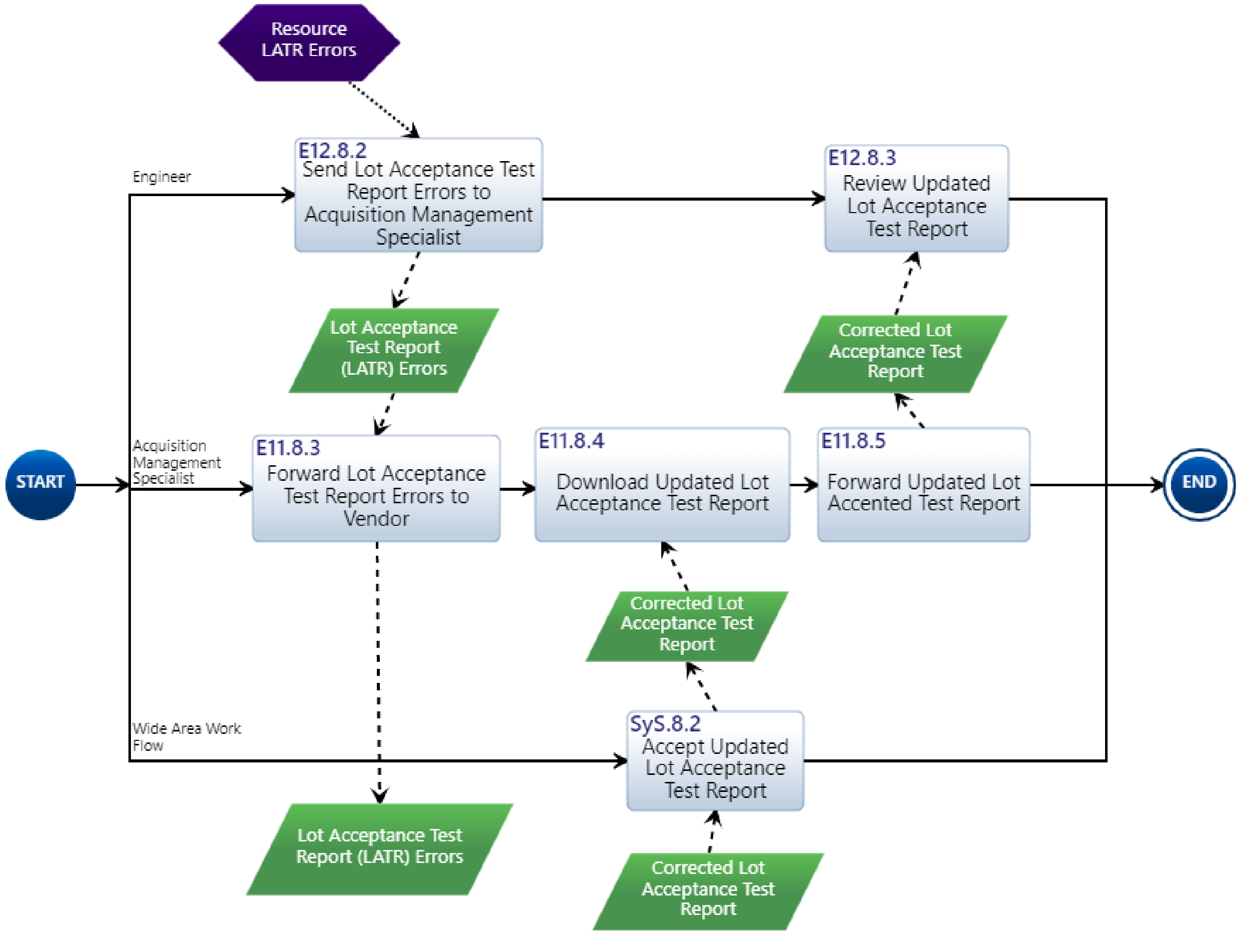

Figure 36. As-is E1.8.2, resolve lot acceptance test report errors.

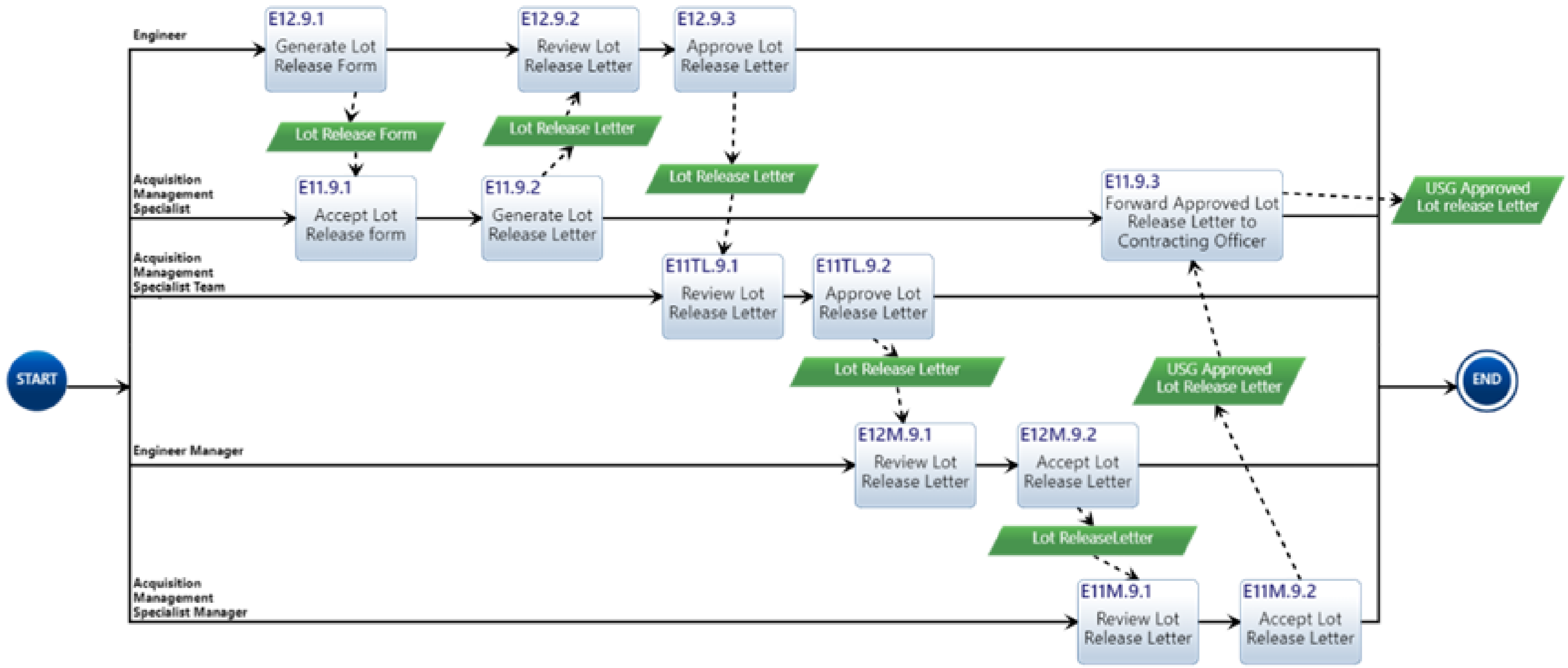

Figure 37. As-is E1.9, issue lot acceptance.

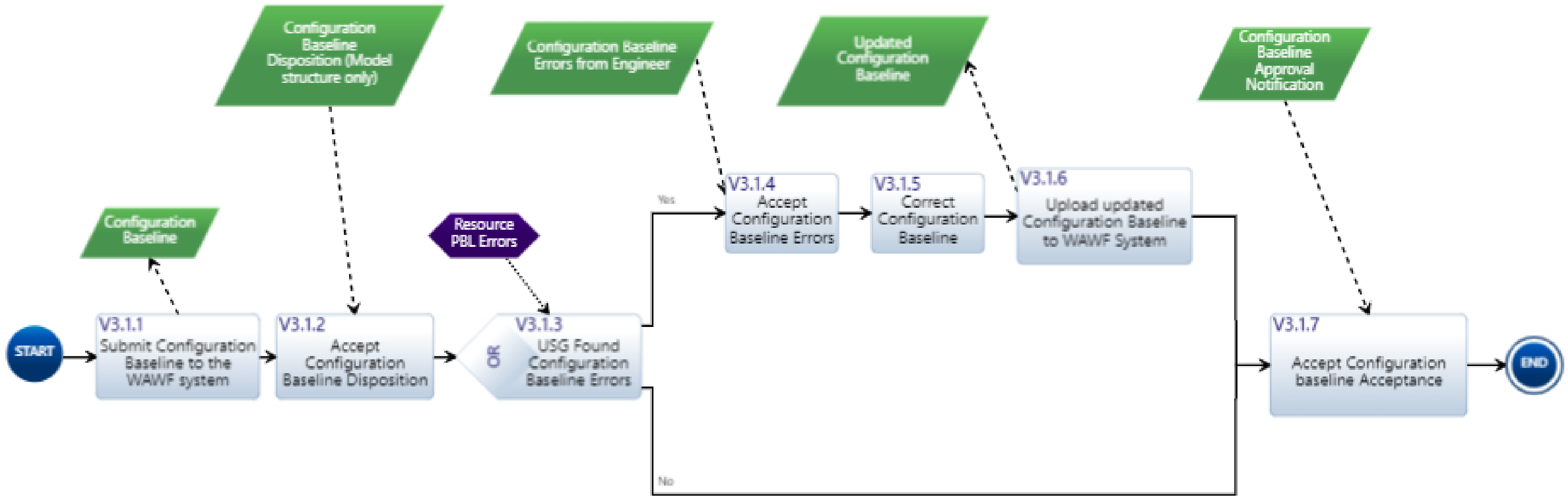

Figure 38. As-is V3.1, submit product baseline.

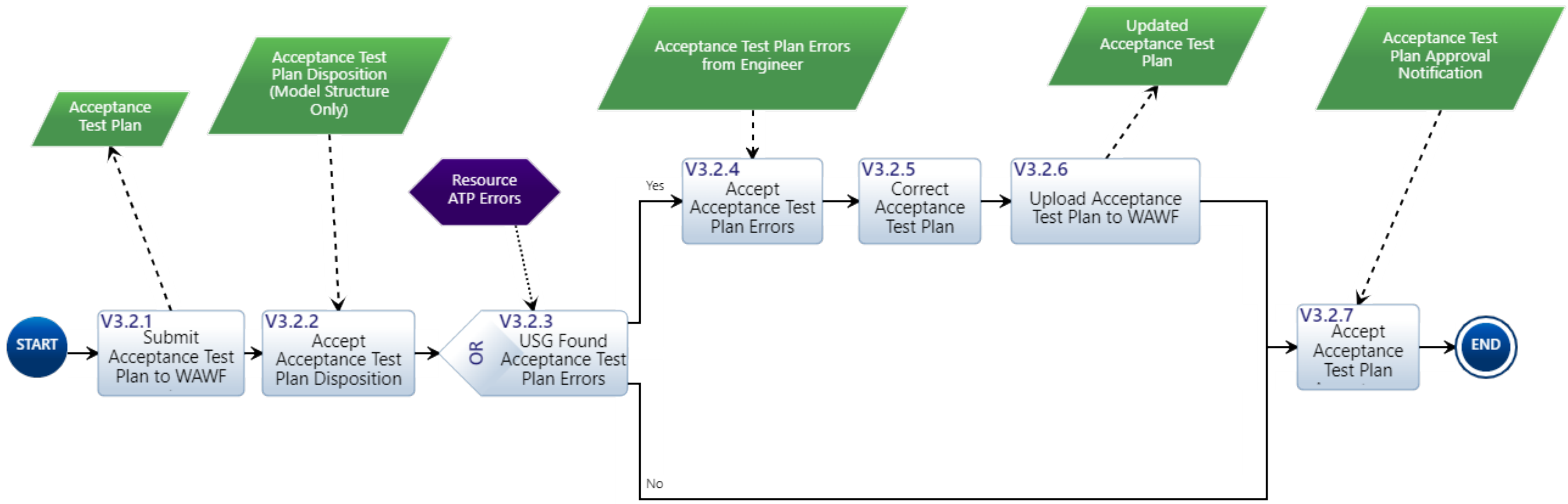

Figure 39. As-is V3.2, submit acceptance test plan.

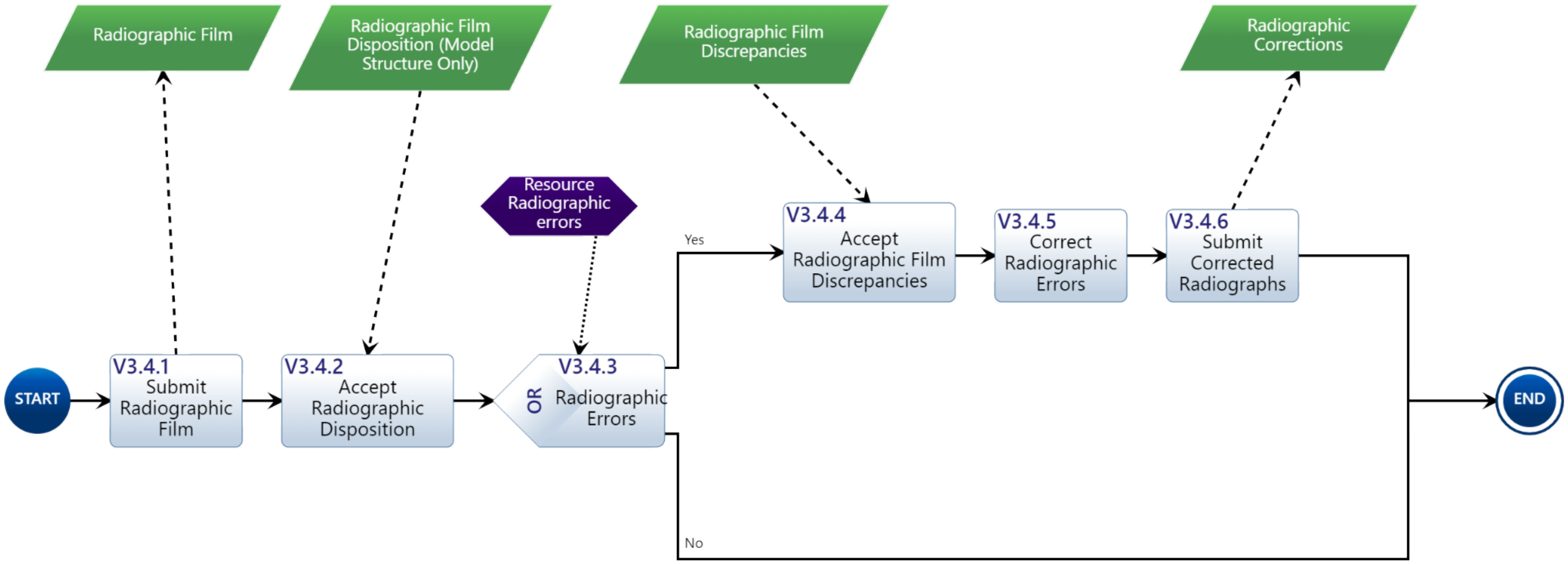

Figure 40. As-is V3.4, submit radiographic film (N-ray/X-ray).

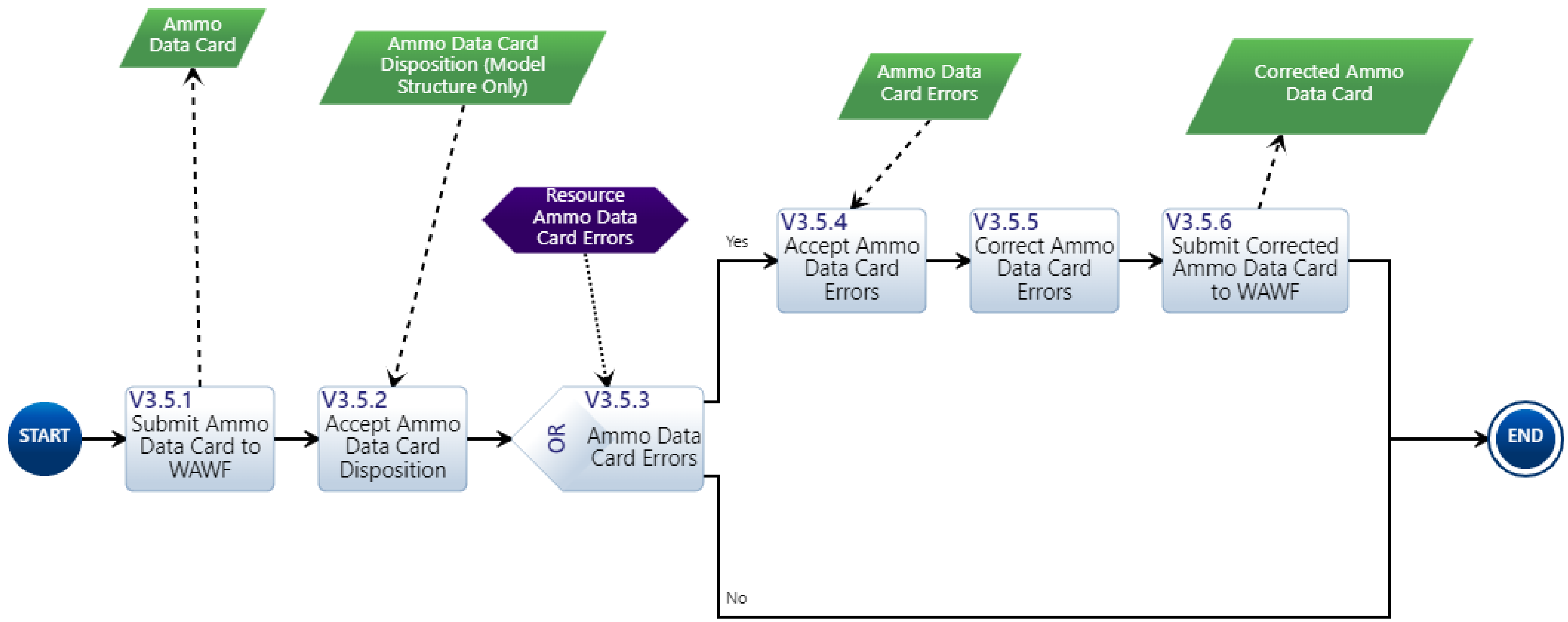

Figure 41. As-is V3.5, submit preliminary ammo data card.

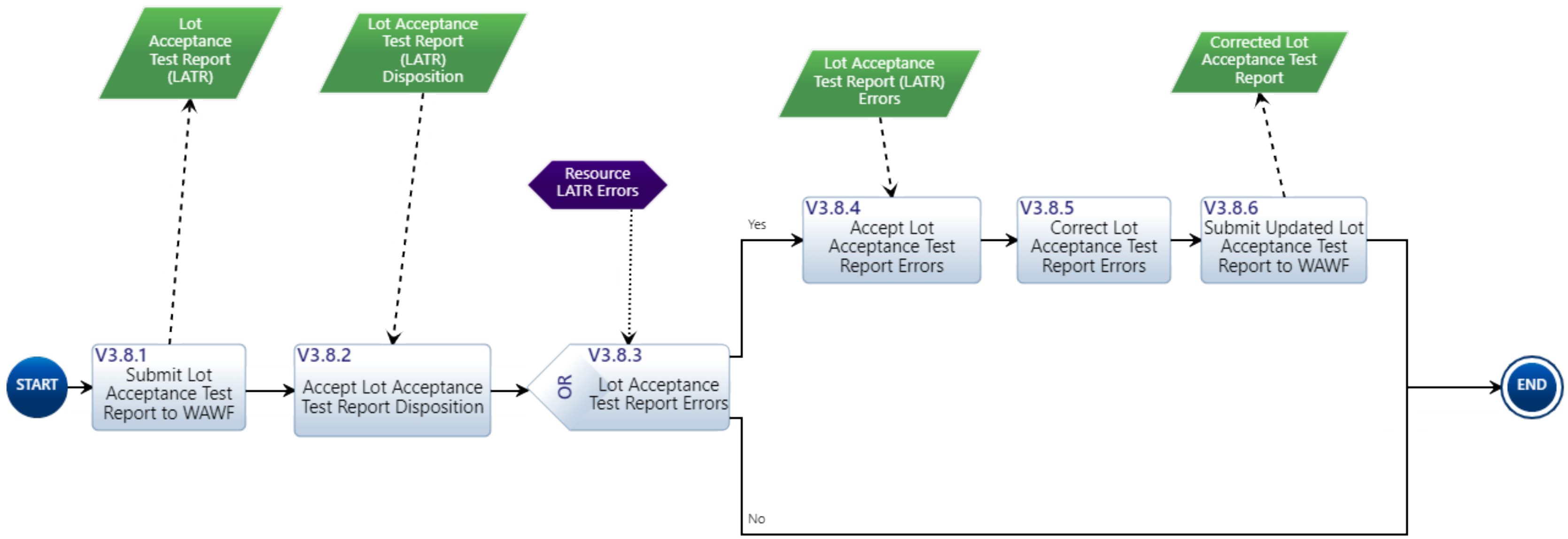

Figure 42. As-is V3.8, submit lot acceptance test report.

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APPENDIX B. AS-IS CRITICAL SAFETY ITEM LOT ACCEPTANCE PROCESS DURATION DATA

Table 11. The duration data used for the as is critical safety item lot acceptance process.

Number	Name	Mean time (hours)	Standard Deviation (hours)	Entity switch penalty μ=3.5 (hours) σ=1 (hours)	Explanation	Innoslate Input
C1	Review and Approve Lot Release Letter	1	0.2	Yes	A review action (μ=1 hours σ=0.2 hours) + the penalty	=norm.dist(4.5, 1) hours
E1.1	Review and Approve Configuration Baseline	N/A	N/A	N/A	N/A	N/A
E1.1.1	Find Configuration Baseline Errors	N/A	N/A	N/A	N/A	N/A
E1.1.2	Resolve Configuration Baseline errors	N/A	N/A	N/A	N/A	N/A
E1.2	Review and Approve Acceptance Test Plan	N/A	N/A	N/A	N/A	N/A
E1.2.1	Find Acceptance Test Plan Errors	N/A	N/A	N/A	N/A	N/A
E1.2.2	Resolve Acceptance Test Plan	N/A	N/A	N/A	N/A	N/A
E1.3	Review and Approve Radiographic Film	N/A	N/A	N/A	N/A	N/A
E1.3.1	Find Radiographic Errors	N/A	N/A	N/A	N/A	N/A
E1.3.2	Resolve Radiographic Errors	N/A	N/A	N/A	N/A	N/A

Number	Name	Mean time (hours)	Standard Deviation (hours)	Entity switch penalty μ=3.5 (hours) σ=1 (hours)	Explanation	Innoslate Input
E1.4	Review and Approve Ammo Data Card	N/A	N/A	N/A	N/A	N/A
E1.4.1	Find Ammo Data Card Errors	N/A	N/A	N/A	N/A	N/A
E1.4.2	Resolve Ammo Data Card Errors	N/A	N/A	N/A	N/A	N/A
E1.6	Receive LAT Witness Request	1	0.1	Yes	A receipt action (μ=.5 hours σ=0.1 hours) + penalty	=norm.dist(4.5, 1) hours
E1.7	Provide LAT Witness Delegation Notification	4	1.25	No	A process action	=norm.dist(4, 1.25) hours
E1.8	Review Lot Acceptance Test Report	N/A	N/A	N/A	N/A	N/A
E1.8.1	Find Lot Acceptance Test Report Errors	N/A	N/A	N/A	N/A	N/A
E1.8.2	Resolve Lot Acceptance Test Report Errors	N/A	N/A	N/A	N/A	N/A
E1.9	Issue Lot Acceptance Letter	N/A	N/A	N/A	N/A	N/A
P1	Critical Safety Item Lot Acceptance Process	N/A	N/A	N/A	N/A	N/A
V3.1	Submit Product Baseline	N/A	N/A	N/A	N/A	N/A
V3.1.1	Submit Configuration Baseline to the WAWF system	0.2	0.05	No	An upload action in a digital database	=norm.dist(0.2, 0.05) hours

Number	Name	Mean time (hours)	Standard Deviation (hours)	Entity switch penalty μ=3.5 (hours) σ=1 (hours)	Explanation	Innoslate Input
V3.1.2	Accept Configuration Baseline Disposition	0.1	0.05	Yes	An email acceptance action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
V3.1.3	USG Found Configuration Baseline Errors	N/A	N/A	N/A	N/A	N/A
V3.1.4	Accept Configuration Baseline Errors	N/A	N/A	N/A	Redundant task to complete the model	N/A
V3.1.5	Correct Configuration Baseline	2	0.5	No		=norm.dist(2, .5) hours
V3.1.6	Upload updated Configuration Baseline to WAWF System	0.2	0.05	No	An upload action in a digital database	=norm.dist(0.2, 0.05) hours
V3.1.7	Accept Configuration baseline Acceptance	0.1	0.05	Yes	A downloading action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
V3.2	Submit Acceptance Test Plan	N/A	N/A	N/A	N/A	N/A
V3.2.1	Submit Acceptance Test Plan to WAWF system	0.2	0.05	No	An upload action in a digital database	=norm.dist(0.2, 0.05) hours
V3.2.2	Accept Acceptance Test Plan Disposition	0.1	0.05	Yes	An email acceptance action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
V3.2.3	USG Found Acceptance Test Plan Errors	N/A	N/A	N/A	N/A	N/A
V3.2.4	Accept Acceptance Test Plan Errors	N/A	N/A	N/A	Redundant task to complete the model	N/A

Number	Name	Mean time (hours)	Standard Deviation (hours)	Entity switch penalty μ=3.5 (hours) σ=1 (hours)	Explanation	Innoslate Input
V3.2.5	Correct Acceptance Test Plan	2	0.5	No		=norm.dist(2, .5) hours
V3.2.6	Upload Acceptance Test Plan to WAWF	0.2	0.05	No	An upload action in a digital database	=norm.dist(0.2, 0.05) hours
V3.2.7	Accept Acceptance Test Plan Acceptance	0.1	0.05	Yes	A downloading action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
V3.3	Submit Radiographic Inspection report	0.2	0.05	No	An upload action in a digital database	=norm.dist(0.2, 0.05) hours
V3.4	Submit Radiographic Film (N-ray/X-ray)	N/A	N/A	N/A	N/A	N/A
V3.4.1	Submit Radiographic Film	0.5	0.1	No	An upload action in a digital database	=norm.dist(0.5, 0.1) hours
V3.4.2	Accept Radiographic Disposition	0.1	0.05	Yes	An email acceptance action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
V3.4.3	Radiographic Errors	N/A	N/A	N/A	N/A	N/A
V3.4.4	Accept Radiographic Film Discrepancies	N/A	N/A	N/A	Redundant task to complete the model	N/A
V3.4.5	Correct Radiographic Errors	4	1	No		=norm.dist(4,1) hours
V3.4.6	Submit Corrected Radiographs	1	0.2	No	An upload action in a digital database	=norm.dist(1, 0.2) hours

Number	Name	Mean time (hours)	Standard Deviation (hours)	Entity switch penalty μ=3.5 (hours) σ=1 (hours)	Explanation	Innoslate Input
V3.5	Submit Preliminary Ammo Data Card	N/A	N/A	N/A	N/A	N/A
V3.5.1	Submit Ammo Data Card	0.2	0.05	No	An upload action in a digital database	=norm.dist(0.2, 0.05) hours
V3.5.2	Accept Ammo Data Card Disposition	0.1	0.05	Yes	An email acceptance action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
V3.5.3	Ammo Data Card Errors	N/A	N/A	N/A	N/A	N/A
V3.5.4	Accept Ammo Data Card Errors	N/A	N/A	N/A	Redundant task to complete the model	N/A
V3.5.5	Correct Ammo Data Card Errors	2	0.5	No		=norm.dist(2, .5) hours
V3.5.6	Submit Corrected Ammo Data Card	0.2	0.05	No	An upload action in a digital database	=norm.dist(0.2, 0.05) hours
V3.6	Submit Notification of Lot Acceptance Testing	0.2	0.05	No	An email submission action	=norm.dist(0.2, 0.05) hours
V3.7	Conduct Lot Acceptance Testing	8	2	Yes	A functional test action (μ=8 hours σ=2 hours) + the penalty	=norm.dist(11.5, 3.2) hours
V3.8	Submit Lot Acceptance Test Report	N/A	N/A	N/A	N/A	N/A
V3.8.1	Submit Lot Acceptance Test Report to WAWF	0.2	0.05	No	An upload action in a digital database	=norm.dist(0.2, 0.05) hours

Number	Name	Mean time (hours)	Standard Deviation (hours)	Entity switch penalty μ=3.5 (hours) σ=1 (hours)	Explanation	Innoslate Input
V3.8.2	Accept Lot Acceptance Test Report Disposition	0.1	0.05	Yes	An email acceptance action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
V3.8.3	Lot Acceptance Test Report Errors	N/A	N/A	N/A	N/A	N/A
V3.8.4	Accept Lot Acceptance Test Report Errors	N/A	N/A	N/A	Redundant task to complete the model	N/A
V3.8.5	Correct Lot Acceptance Test Report Errors	2	0.5	No		=norm.dist(2, .5) hours
V3.8.6	Submit Updated Lot Acceptance Test Report	0.2	0.05	No	An upload action in a digital database	=norm.dist(0.2, 0.05) hours
V3.9	Process Lot Release Letter	0.1	0.05	Yes	A downloading action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
V3.10	Submit Final Ammo Data Card	0.5	0.1	No	An upload action in a digital database	=norm.dist(0.5, 0.1) hours
V3.11	Ship Lot to the USG for service use	4	1	No	The final completion activity of the process	=1 hour
E11.1.1	Download Configuration Baseline from WAWF	0.1	0.05	Yes	A downloading action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.1.2	Forward Configuration Baseline to Engineer	0.1	0.05	No	Email forwarding action	=norm.dist(0.1, 0.05) hours
E11.1.3	Forward Configuration Baseline Discrepancies to Vendor	0.1	0.05	Yes	An email forwarding action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours

Number	Name	Mean time (hours)	Standard Deviation (hours)	Entity switch penalty μ=3.5 (hours) σ=1 (hours)	Explanation	Innoslate Input
E11.1.4	Download Updated Configuration Baseline from WAWF system	0.1	0.05	Yes	An email forwarding action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.1.5	Forward Configuration Baseline	0.1	0.05	No	Email forwarding action	=norm.dist(0.1, 0.05) hours
E11.1.6	Accept Configuration Baseline Approval Notification	0.1	0.05	Yes	An email acceptance action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.1.7	Approve Configuration Baseline in Wide Area Workflow System	0.1	0.05	No	An approval action in a digital database	=norm.dist(0.1, 0.05) hours
E11.2.1	Download Acceptance Test Plan	0.1	0.05	Yes	A downloading action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.2.2	Forward Acceptance Test Plan to Engineer	0.1	0.05	No	Email forwarding action	=norm.dist(0.1, 0.05) hours
E11.2.3	Forward Acceptance Test Plan Discrepancies to the Vendor	0.1	0.05	Yes	An email forwarding action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.2.4	Download Updated Acceptance Test Plan from WAWF System	0.1	0.05	Yes	An email forwarding action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.2.5	Forward Updated Acceptance Test Plan	0.1	0.05	No	Email forwarding action	=norm.dist(0.1, 0.05) hours
E11.2.6	Accept Acceptance Test Plan Approval Notification	0.1	0.05	Yes	An email acceptance action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours

Number	Name	Mean time (hours)	Standard Deviation (hours)	Entity switch penalty μ=3.5 (hours) σ=1 (hours)	Explanation	Innoslate Input
E11.2.7	Approve Acceptance Test Plan in Wide Area Work Flow System	0.1	0.05	No	An approval action in a digital database	=norm.dist(0.1, 0.05) hours
E11.3.1	Download Radiographic Inspection report	0.1	0.05	Yes	A downloading action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.3.2	Forward Radiographic Inspection Report to Engineering	0.1	0.05	No	Email forwarding action	=norm.dist(0.1, 0.05) hours
E11.3.3	Accept Radiographic Film	0.5	0.1	Yes	A downloading action (μ=0.5 hours ?=0.1 hours) + the penalty	=norm.dist(4, 1) hours
E11.3.4	Forward Radiographic Film to Engineering	0.1	0.05	No	Forwarding action	=norm.dist(0.1, 0.05) hours
E11.3.5	Forward Radiographic Discrepancies to Vendor	0.1	0.05	Yes	An email forwarding action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.3.6	Accept Radiographic Corrections	0.1	0.05	Yes	Email Acceptance Action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.3.7	Forward Radiographic Corrections	0.1	0.05	No	Forwarding action	=norm.dist(0.1, 0.05) hours
E11.4.1	Download Ammo Data Card	0.1	0.05	Yes	A downloading action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.4.2	Forward Ammo Data Card to Engineer	0.1	0.05	No	Email forwarding action	=norm.dist(0.1, 0.05) hours

Number	Name	Mean time (hours)	Standard Deviation (hours)	Entity switch penalty μ=3.5 (hours) σ=1 (hours)	Explanation	Innoslate Input
E11.4.3	Forward Ammo Data Card Errors to Contracting Officer	0.1	0.05	Yes	An email forwarding action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.4.4	Download Updated Ammo Data Card From WAWF System	0.1	0.05	Yes	An email forwarding action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.4.5	Forward Updated Ammo Data Card to Engineering	0.1	0.05	No	Email forwarding action	=norm.dist(0.1, 0.05) hours
E11.8.1	Download Lot Acceptance Test Report	0.1	0.05	Yes	An email forwarding action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.8.2	Forward Lot Acceptance Test Report	0.1	0.05	No	Email forwarding action	=norm.dist(0.1, 0.05) hours
E11.8.3	Forward Lot Acceptance Test Report Errors to Vendor	0.1	0.05	Yes	An email forwarding action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.8.4	Download Updated Lot Acceptance Test Report	0.1	0.05	Yes	An email forwarding action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.8.5	Forward Updated Lot Accented Test Report	0.1	0.05	No	Email forwarding action	=norm.dist(0.1, 0.05) hours
E11.9.1	Accept Lot Release form	0.1	0.05	Yes	An email acceptance action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E11.9.2	Generate Lot Release Letter	2	0.75	No		=norm.dist(2, .75) hours

Number	Name	Mean time (hours)	Standard Deviation (hours)	Entity switch penalty μ=3.5 (hours) σ=1 (hours)	Explanation	Innoslate Input
E11.9.3	Forward Approved Lot Release Letter to Contracting Officer	0.1	0.05	Yes	An email forwarding action (μ=0.1 hours σ=0.05 hours) + the penalty	=norm.dist(3.6, 1) hours
E12.1.1	Review Configuration Baseline	2	0.5	Yes	A review action (μ=2 hours σ=0.5 hours) + the penalty	=norm.dist(5.5, 1.1) hours
E12.1.2	Send Configuration Baseline Discrepancies to Acquisition Management Specialist	0.2	0.05	No	The actions involves generating an email with technical details	=norm.dist(0.2, 0.05) hours
E12.1.3	Review Updated Configuration Baseline	0.5	0.1	Yes	A review action (μ=.5 hours σ=0.1 hours) + penalty	=norm.dist(4, 1) hours
E12.1.4	Send Configuration Baseline Approval to Acquisition Management Specialist	0.1	0.05	No	An email action sending a notification	=norm.dist(0.1, 0.05) hours
E12.2.1	Review Acceptance Test Plan	2	0.5	Yes	A review action (μ=2 hours σ=0.5 hours) + the penalty	=norm.dist(5.5, 1.1) hours
E12.2.2	Send Acceptance Test Plan Discrepancies to Acquisition Management Specialist	0.2	0.05	No	The actions involves generating an email with technical details	=norm.dist(0.2, 0.05) hours
E12.2.3	Review updated Acceptance Test Plan	0.5	0.1	Yes	A review action (μ=.5 hours σ=0.1 hours) + penalty	=norm.dist(4, 1) hours
E12.2.4	Send Acceptance Test Plan Approval to Acquisition Management Specialist	0.1	0.05	No	An email action sending a notification	=norm.dist(0.1, 0.05) hours
E12.3.1	Review Radiographic Inspection Report	0.5	0.1	Yes	A review action (μ=.5 hours σ=0.1 hours) + the penalty	=norm.dist(4, 1) hours

Number	Name	Mean time (hours)	Standard Deviation (hours)	Entity switch penalty μ=3.5 (hours) σ=1 (hours)	Explanation	Innoslate Input
E12.3.2	Review Radiographic Film	4.5	1	yes	A review action (μ=5 hours σ=1 hours) + the penalty	=norm.dist(8, 1.4) hours
E12.3.3	Send Radiographic Discrepancies to Acquisition Management Specialist	0.2	0.05	No	The actions involves generating an email with technical details	=norm.dist(0.2, 0.05) hours
E12.3.4	Review Updated Radiographs	1	0.1	Yes	A review action (μ=.5 hours σ=0.1 hours) + penalty	=norm.dist(4.5, 1) hours
E12.3.5	Generate Engineering Radiographic Acceptance Report	1	0.2	No	A document generation action (μ=0.5 hours σ=0.1 hours)	=norm.dist(.1, 0.2) hours
E12.4.1	Review Ammo Data Card	1	0.2	Yes	A review action (μ=1 hours σ=0.2 hours) + the penalty	=norm.dist(4.5, 1) hours
E12.4.2	Send Ammo Data Card Errors to Acquisition Management Specialist	0.2	0.05	No	The actions involves generating an email with technical details	=norm.dist(0.2, 0.05) hours
E12.4.3	Review Updated Ammo Data Card	0.5	0.1	Yes	A review action (μ=.5 hours σ=0.1 hours) + penalty	=norm.dist(4, 1) hours
E12.8.1	Review Lot Acceptance Test Report	2	0.5	Yes	A review action (μ=2 hours σ=0.5 hours) + the penalty	=norm.dist(5.5, 1.1) hours
E12.8.2	Send Lot Acceptance Test Report Errors to Acquisition Management Specialist	0.2	0.05	No	The actions involves generating an email with technical details	=norm.dist(0.2, 0.05) hours
E12.8.3	Review Updated Lot Acceptance Test Report	0.5	0.1	Yes	A review action (μ=.5 hours σ=0.1 hours) + penalty	=norm.dist(4, 1) hours
E12.9.1	Generate Lot Release Form	2	0.75	no		=norm.dist(2, .75) hours

Number	Name	Mean time (hours)	Standard Deviation (hours)	Entity switch penalty μ=3.5 (hours) σ=1 (hours)	Explanation	Innoslate Input
E12.9.2	Review Lot Release Letter	0.5	0.1	Yes	A review action (μ=.5 hours σ=0.1 hours) + penalty	=norm.dist(4, 1) hours
E12.9.3	Approve Lot Release Letter	0.1	0.05	No	An email action	=norm.dist(0.1, 0.05) hours
SyS.1.1	Accept Configuration Baseline Submission	0.05	0.01		Action completed by a digital database	=norm.dist(0.05, 0.01) hours
SyS.1.2	Accept Updated Configuration Baseline	0.05	0.01		Action completed by a digital database	=norm.dist(0.05, 0.01) hours
SyS.1.3	Accept Configuration Baseline Approval	0.05	0.01		Action completed by a digital database	=norm.dist(0.05, 0.01) hours
SyS.1.4	Send Configuration Baseline Approval Notification	0.05	0.01		Action completed by a digital database	=norm.dist(0.05, 0.01) hours
SyS.2.1	Accept Acceptance Test Plan Submission	0.05	0.01		Action completed by a digital database	=norm.dist(0.05, 0.01) hours
Sys.2.2	Accept Updated Acceptance Test Plan	0.05	0.01		Action completed by a digital database	=norm.dist(0.05, 0.01) hours
SyS.2.3	Accept Acceptance Test Plan Approval	0.05	0.01		Action completed by a digital database	=norm.dist(0.05, 0.01) hours
SyS.2.4	Send Acceptance Test Plan Approval Notification	0.05	0.01		Action completed by a digital database	=norm.dist(0.05, 0.01) hours
SyS.3	Accept Radiographic Inspection report	0.05	0.01		Action completed by a digital database	=norm.dist(0.05, 0.01) hours
SyS.4.1	Accept Ammo Data Card	0.05	0.01		Action completed by a digital database	=norm.dist(0.05, 0.01) hours

Number	Name	Mean time (hours)	Standard Deviation (hours)	Entity switch penalty μ=3.5 (hours) σ=1 (hours)	Explanation	Innoslate Input
SyS.4.2	Accept Updated Ammo Data Card	0.05	0.01		Action completed by a digital database	=norm.dist(0.05, 0.01) hours
SyS.8.1	Accept Lot Acceptance Test Report	0.05	0.01		Action completed by a digital database	=norm.dist(0.05, 0.01) hours
SyS.8.2	Accept Updated Lot Acceptance Test Report	0.05	0.01		Action completed by a digital database	=norm.dist(0.05, 0.01) hours
E11M.9.1	Review Lot Release Letter	0.5	0.1	Yes	A review action (μ=.5 hours σ=0.1 hours) + penalty	=norm.dist(4, 1) hours
E11M.9.2	Accept Lot Release Letter	0.1	0.05	No	An email action	=norm.dist(0.1, 0.05) hours
E12M.9.1	Review Lot Release Letter	1	0.25	Yes	A review action (μ=.5 hours σ=0.1 hours) + penalty	=norm.dist(4.5, 1) hours
E12M.9.2	Accept Lot Release Letter	0.1	0.05	No	An email action	=norm.dist(0.1, 0.05) hours
E11TL.9.1	Review Lot Release Letter	0.5	0.1	Yes	A review action (μ=.5 hours σ=0.1 hours) + penalty	=norm.dist(4, 1) hours
E11TL.9.2	Approve Lot Release Letter	0.1	0.05	No	An email action	=norm.dist(0.1, 0.05) hours

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APPENDIX C. CRITICAL SAFETY ITEM LOT ACCEPTANCE PROCESS VALUE ADDED ANALYSIS

Table 12. The critical safety item lot acceptance process value added analysis results.

Number	Name	Actor/Entity	Step Label (VA, BVA, or NVA, Modeling Entity)	NVA time Mean
C1	Review and Approve Lot Release Letter	Contracting Officer	BVA	
E1.1	Review and Approve Configuration Baseline	Engineering Organization	Modeling Entity	
E1.1.1	Find Configuration Baseline Errors	Engineering Organization	Modeling Entity	
E1.1.2	Resolve Configuration Baseline errors	Engineering Organization	Modeling Entity	
E1.2	Review and Approve Acceptance Test Plan	Engineering Organization	Modeling Entity	
E1.2.1	Find Acceptance Test Plan Errors	Engineering Organization	Modeling Entity	
E1.2.2	Resolve Acceptance Test Plan	Engineering Organization	Modeling Entity	
E1.3	Review and Approve Radiographic Film	Engineering Organization	Modeling Entity	
E1.3.1	Find Radiographic Errors	Engineering Organization	Modeling Entity	
E1.3.2	Resolve Radiographic Errors	Engineering Organization	Modeling Entity	
E1.4	Review and Approve Ammo Data Card	Engineering Organization	Modeling Entity	
E1.4.1	Find Ammo Data Card Errors	Engineering Organization	Modeling Entity	
E1.4.2	Resolve Ammo Data Card Errors	Engineering Organization	Modeling Entity	
E1.6	Receive LAT Witness Request	Engineering Organization	BVA	
E1.7	Provide LAT Witness Delegation Notification	Engineering Organization	BVA	
E1.8	Review Lot Acceptance Test Report	Engineering Organization	Modeling Entity	
E1.8.1	Find Lot Acceptance Test Report Errors	Engineering Organization	Modeling Entity	
E1.8.2	Resolve Lot Acceptance Test Report Errors	Engineering Organization	Modeling Entity	
E1.9	Issue Lot Acceptance Letter	Engineering Organization	Modeling Entity	
P1	Critical Safety Item Lot Acceptance Process	Universe	Modeling Entity	
V3.1	Submit Product Baseline	Vendor	Modeling Entity	
V3.1.1	Submit Configuration Baseline to the WAWF system	Vendor	VA	

Number	Name	Actor/Entity	Step Label (VA, BVA, or NVA, Modeling Entity)	NVA time Mean
V3.1.2	Accept Configuration Baseline Disposition	Vendor	BVA	
V3.1.3	USG Found Configuration Baseline Errors	Vendor	Modeling Entity	
V3.1.4	Accept Configuration Baseline Errors	Vendor	BVA	
V3.1.5	Correct Configuration Baseline	Vendor	VA	
V3.1.6	Upload updated Configuration Baseline to WAWF System	Vendor	VA	
V3.1.7	Accept Configuration baseline Acceptance	Vendor	BVA	
V3.2	Submit Acceptance Test Plan	Vendor	Modeling Entity	
V3.2.1	Submit Acceptance Test Plan to WAWF system	Vendor	VA	
V3.2.2	Accept Acceptance Test Plan Disposition	Vendor	BVA	
V3.2.3	USG Found Acceptance Test Plan Errors	Vendor	Modeling Entity	
V3.2.4	Accept Acceptance Test Plan Errors	Vendor	VA	
V3.2.5	Correct Acceptance Test Plan	Vendor	VA	
V3.2.6	Upload Acceptance Test Plan to WAWF	Vendor	VA	
V3.2.7	Accept Acceptance Test Plan Acceptance	Vendor	BVA	
V3.3	Submit Radiographic Inspection report	Vendor	VA	
V3.4	Submit Radiographic Film (N-ray/X-ray)	Vendor	Modeling Entity	
V3.4.1	Submit Radiographic Film	Vendor	VA	
V3.4.2	Accept Radiographic Disposition	Vendor	VA	
V3.4.3	Radiographic Errors	Vendor	Modeling Entity	
V3.4.4	Accept Radiographic Film Discrepancies	Vendor	VA	
V3.4.5	Correct Radiographic Errors	Vendor	VA	
V3.4.6	Submit Corrected Radiographs	Vendor	VA	
V3.5	Submit Preliminary Ammo Data Card	Vendor	Modeling Entity	
V3.5.1	Submit Ammo Data Card	Vendor	VA	
V3.5.2	Accept Ammo Data Card Disposition	Vendor	VA	
V3.5.3	Ammo Data Card Errors	Vendor	Modeling Entity	
V3.5.4	Accept Ammo Data Card Errors	Vendor	VA	

Number	Name	Actor/Entity	Step Label (VA, BVA, or NVA, Modeling Entity)	NVA time Mean
V3.5.5	Correct Ammo Data Card Errors	Vendor	VA	
V3.5.6	Submit Corrected Ammo Data Card	Vendor	VA	
V3.6	Submit Notification of Lot Acceptance Testing	Vendor	VA	
V3.7	Conduct Lot Acceptance Testing	Vendor	VA	
V3.8	Submit Lot Acceptance Test Report	Vendor	Modeling Entity	
V3.8.1	Submit Lot Acceptance Test Report to WAWF	Vendor	VA	
V3.8.2	Accept Lot Acceptance Test Report Disposition	Vendor	VA	
V3.8.3	Lot Acceptance Test Report Errors	Vendor	Modeling Entity	
V3.8.4	Accept Lot Acceptance Test Report Errors	Vendor	VA	
V3.8.5	Correct Lot Acceptance Test Report Errors	Vendor	VA	
V3.8.6	Submit Updated Lot Acceptance Test Report	Vendor	VA	
V3.9	Process Lot Release Letter	Vendor	BVA	
V3.10	Submit Final Ammo Data Card	Vendor	VA	
V3.11	Ship Lot to the USG for service use	Vendor	VA	
E11.1.1	Download Configuration Baseline from WAWF	Acquisition Specialist	NVA	3.6
E11.1.2	Forward Configuration Baseline to Engineer	Acquisition Specialist	NVA	0.1
E11.1.3	Forward Configuration Baseline Discrepancies to Vendor	Acquisition Specialist	NVA	3.6
E11.1.4	Download Updated Configuration Baseline from WAWF system	Acquisition Specialist	NVA	3.6
E11.1.5	Forward Configuration Baseline	Acquisition Specialist	NVA	0.1
E11.1.6	Accept Configuration Baseline Approval Notification	Acquisition Specialist	NVA	3.6
E11.1.7	Approve Configuration Baseline in Wide Area Work Flow System	Acquisition Specialist	NVA	0.1
E11.2.1	Download Acceptance Test Plan	Acquisition Specialist	NVA	3.6
E11.2.2	Forward Acceptance Test Plan to Engineer	Acquisition Specialist	NVA	0.1
E11.2.3	Forward Acceptance Test Plan Discrepancies to the Vendor	Acquisition Specialist	NVA	3.6

Number	Name	Actor/Entity	Step Label (VA, BVA, or NVA, Modeling Entity)	NVA time Mean
E11.2.4	Download Updated Acceptance Test Plan from WAWF System	Acquisition Specialist	NVA	3.6
E11.2.5	Forward Updated Acceptance Test Plan	Acquisition Specialist	NVA	0.1
E11.2.6	Accept Acceptance Test Plan Approval Notification	Acquisition Specialist	NVA	3.6
E11.2.7	Approve Acceptance Test Plan in Wide Area Workflow System	Acquisition Specialist	NVA	0.1
E11.3.1	Download Radiographic Inspection report	Acquisition Specialist	NVA	3.6
E11.3.2	Forward Radiographic Inspection Report to Engineering	Acquisition Specialist	NVA	0.1
E11.3.3	Accept Radiographic Film	Acquisition Specialist	NVA	3.6
E11.3.4	Forward Radiographic Film to Engineering	Acquisition Specialist	NVA	0.1
E11.3.5	Forward Radiographic Discrepancies to Vendor	Acquisition Specialist	NVA	3.6
E11.3.6	Accept Radiographic Corrections	Acquisition Specialist	NVA	3.6
E11.3.7	Forward Radiographic Corrections	Acquisition Specialist	NVA	0.1
E11.4.1	Download Ammo Data Card	Acquisition Specialist	NVA	3.6
E11.4.2	Forward Ammo Data Card to Engineer	Acquisition Specialist	NVA	0.1
E11.4.3	Forward Ammo Data Card Errors to Contracting Officer	Acquisition Specialist	NVA	3.6
E11.4.4	Download Updated Ammo Data Card from WAWF System	Acquisition Specialist	NVA	3.6
E11.4.5	Forward Updated Ammo Data Card to Engineering	Acquisition Specialist	NVA	0.1
E11.8.1	Download Lot Acceptance Test Report	Acquisition Specialist	NVA	3.6
E11.8.2	Forward Lot Acceptance Test Report	Acquisition Specialist	NVA	0.1
E11.8.3	Forward Lot Acceptance Test Report Errors to Vendor	Acquisition Specialist	NVA	3.6
E11.8.4	Download Updated Lot Acceptance Test Report	Acquisition Specialist	NVA	3.6
E11.8.5	Forward Updated Lot Accented Test Report	Acquisition Specialist	NVA	0.1
E11.9.1	Accept Lot Release form	Acquisition Specialist	NVA	3.6
E11.9.2	Generate Lot Release Letter	Acquisition Specialist	NVA	2
E11.9.3	Forward Approved Lot Release Letter to Contracting Officer	Acquisition Specialist	NVA	3.6

Number	Name	Actor/Entity	Step Label (VA, BVA, or NVA, Modeling Entity)	NVA time Mean
E12.1.1	Review Configuration Baseline	Engineer	VA	
E12.1.2	Send Configuration Baseline Discrepancies to Acquisition Management Specialist	Engineer	VA	
E12.1.3	Review Updated Configuration Baseline	Engineer	VA	
E12.1.4	Send Configuration Baseline Approval to Acquisition Management Specialist	Engineer	BVA	
E12.2.1	Review Acceptance Test Plan	Engineer	VA	
E12.2.2	Send Acceptance Test Plan Discrepancies to Acquisition Management Specialist	Engineer	VA	
E12.2.3	Review updated Acceptance Test Plan	Engineer	VA	
E12.2.4	Send Acceptance Test Plan Approval to Acquisition Management Specialist	Engineer	BVA	
E12.3.1	Review Radiographic Inspection Report	Engineer	VA	
E12.3.2	Review Radiographic Film	Engineer	VA	
E12.3.3	Send Radiographic Discrepancies to Acquisition Management Specialist	Engineer	VA	
E12.3.4	Review Updated Radiographs	Engineer	VA	
E12.3.5	Generate Engineering Radiographic Acceptance Report	Engineer	BVA	
E12.4.1	Review Ammo Data Card	Engineer	VA	
E12.4.2	Send Ammo Data Card Errors to Acquisition Management Specialist	Engineer	VA	
E12.4.3	Review Updated Ammo Data Card	Engineer	VA	
E12.8.1	Review Lot Acceptance Test Report	Engineer	VA	
E12.8.2	Send Lot Acceptance Test Report Errors to Acquisition Management Specialist	Engineer	VA	
E12.8.3	Review Updated Lot Acceptance Test Report	Engineer	VA	
E12.9.1	Generate Lot Release Form	Engineer	BVA	
E12.9.2	Review Lot Release Letter	Engineer	NVA	3.6

Number	Name	Actor/Entity	Step Label (VA, BVA, or NVA, Modeling Entity)	NVA time Mean
E12.9.3	Approve Lot Release Letter	Engineer	NVA	0.1
SyS.1.1	Accept Configuration Baseline Submission	WAWF System	BVA	
SyS.1.2	Accept Updated Configuration Baseline	WAWF System	BVA	
SyS.1.3	Accept Configuration Baseline Approval	WAWF System	BVA	
SyS.1.4	Send Configuration Baseline Approval Notification	WAWF System	BVA	
SyS.2.1	Accept Acceptance Test Plan Submission	WAWF System	BVA	
Sys.2.2	Accept Updated Acceptance Test Plan	WAWF System	BVA	
SyS.2.3	Accept Acceptance Test Plan Approval	WAWF System	BVA	
SyS.2.4	Send Acceptance Test Plan Approval Notification	WAWF System	BVA	
SyS.3	Accept Radiographic Inspection report	WAWF System	BVA	
SyS.4.1	Accept Ammo Data Card	WAWF System	BVA	
SyS.4.2	Accept Updated Ammo Data Card	WAWF System	BVA	
SyS.8.1	Accept Lot Acceptance Test Report	WAWF System	BVA	
SyS.8.2	Accept Updated Lot Acceptance Test Report	WAWF System	BVA	
E11M.9.1	Review Lot Release Letter	Acquisition Specialist Manager	BVA	
E11M.9.2	Accept Lot Release Letter	Acquisition Specialist Manager	BVA	
E12M.9.1	Review Lot Release Letter	Engineering Manager	BVA	
E12M.9.2	Accept Lot Release Letter	Engineering Manager	BVA	
E11TL.9.1	Review Lot Release Letter	Acquisition Specialist Team Lead	NVA	3.6
E11TL.9.2	Approve Lot Release Letter	Acquisition Specialist Team Lead	NVA	0.1

APPENDIX D. REVISION 2 IMPROVED CRITICAL SAFETY ITEM LOT ACCEPTANCE MBSE MODEL

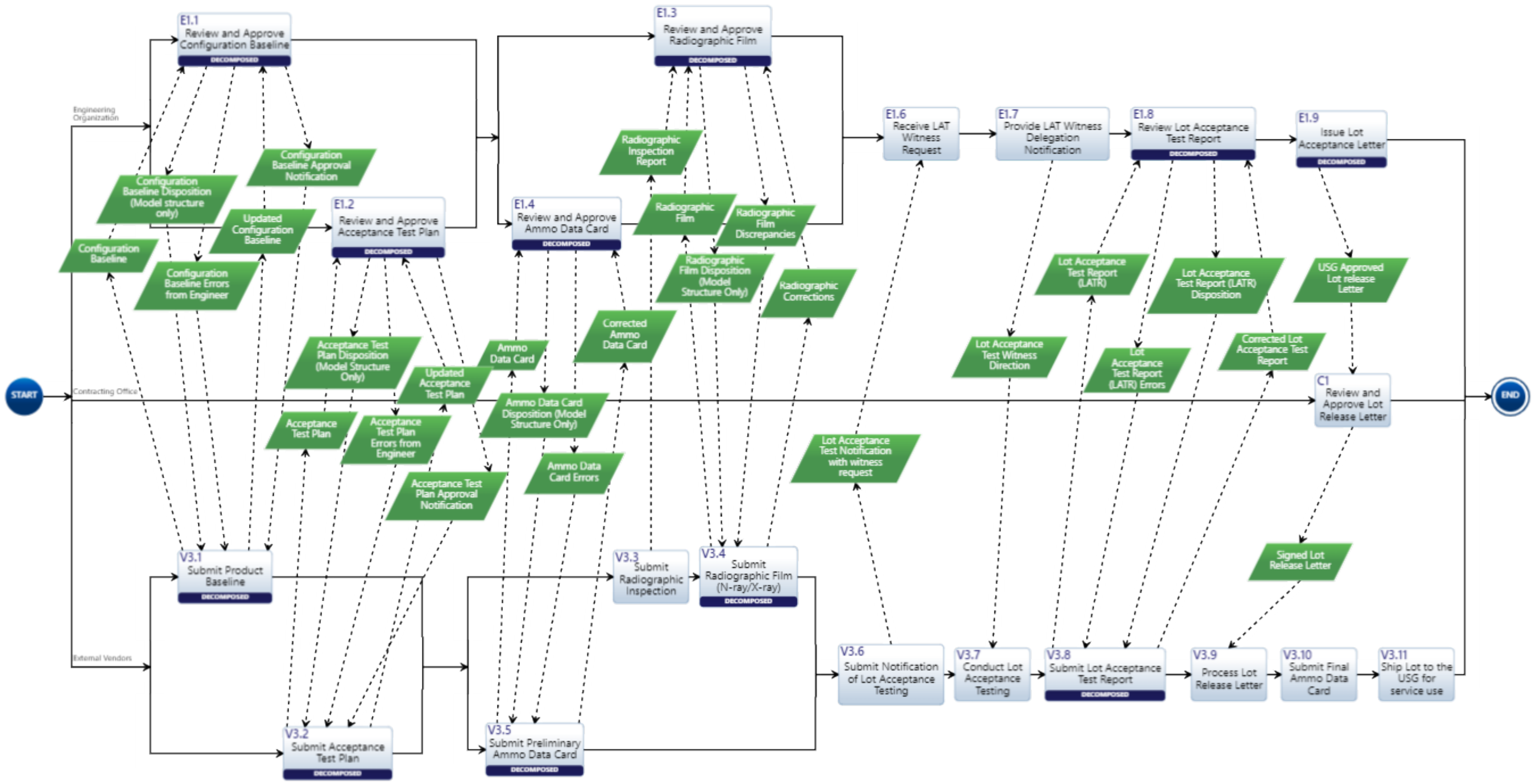

Figure 43. Revision 2 improved critical safety item lot acceptance process flow diagram.

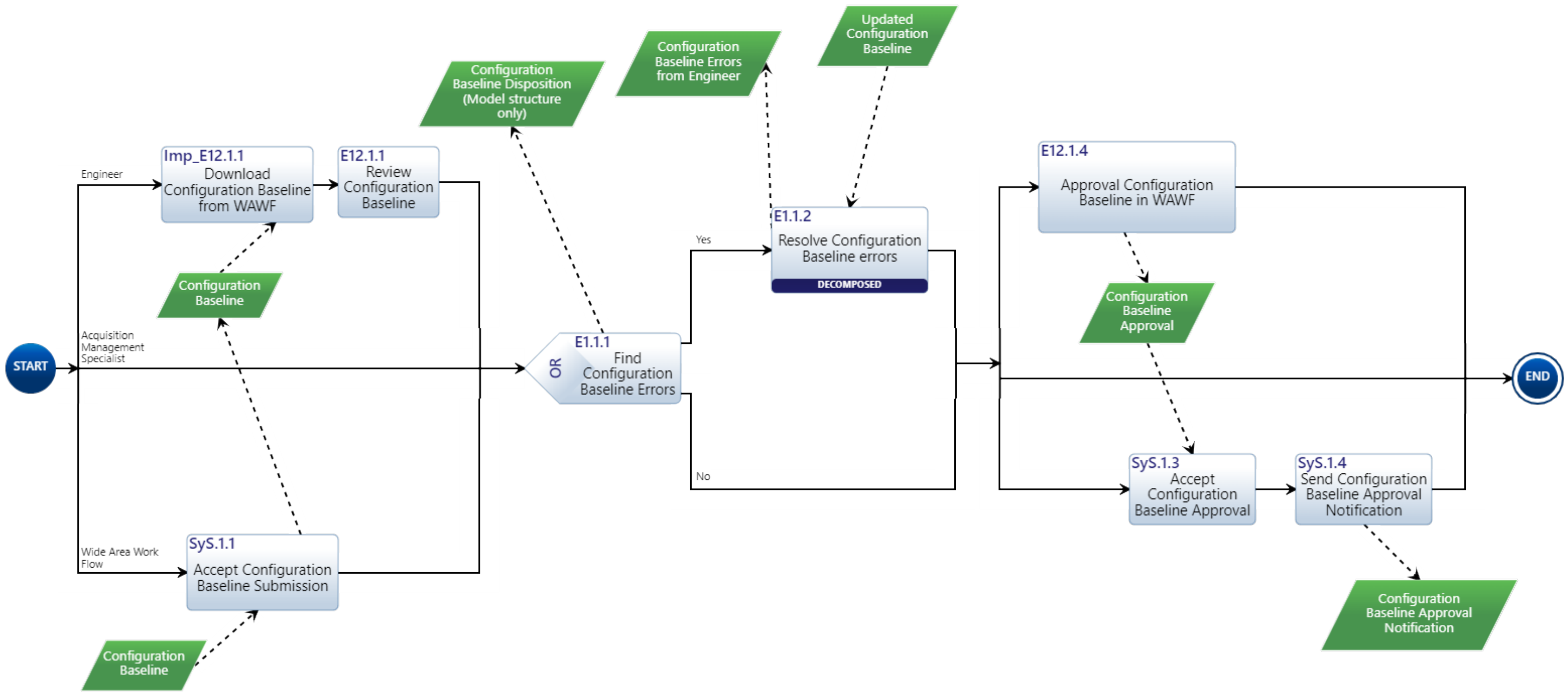

Figure 44. Revision 2 improved E1.1, review and approve configuration baseline.

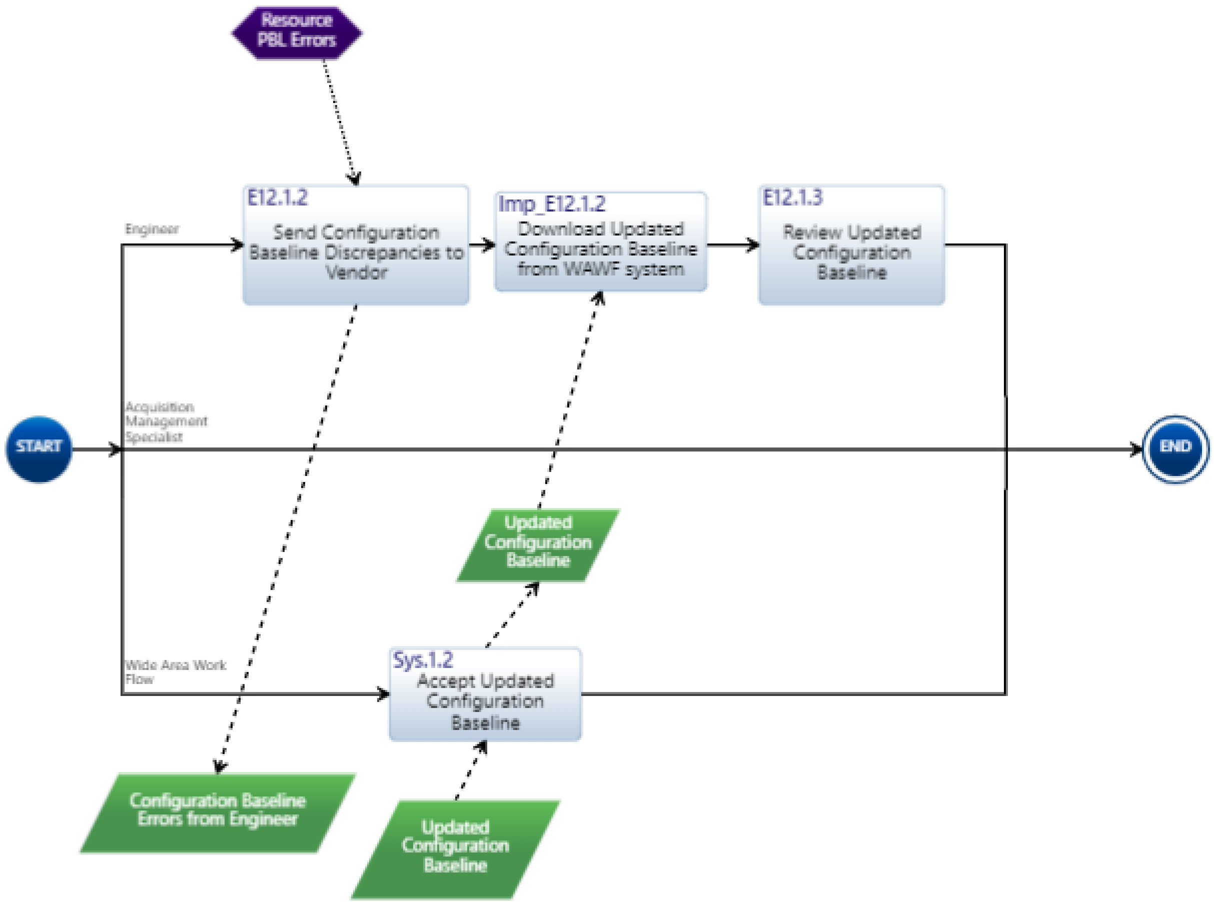

Figure 45. Revision 2 improved E1.1.2, resolve configuration baseline errors.

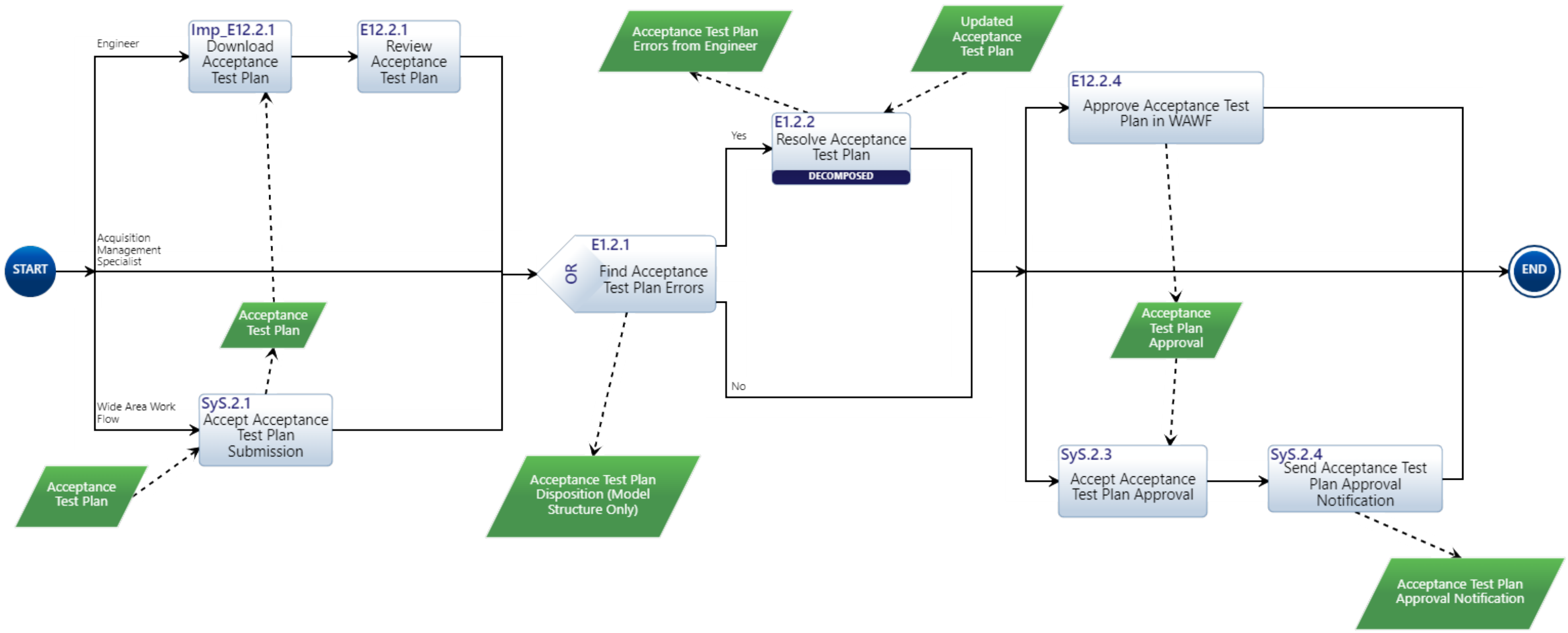

Figure 46. Revision 2 improved E1.2 review and approve acceptance test plan.

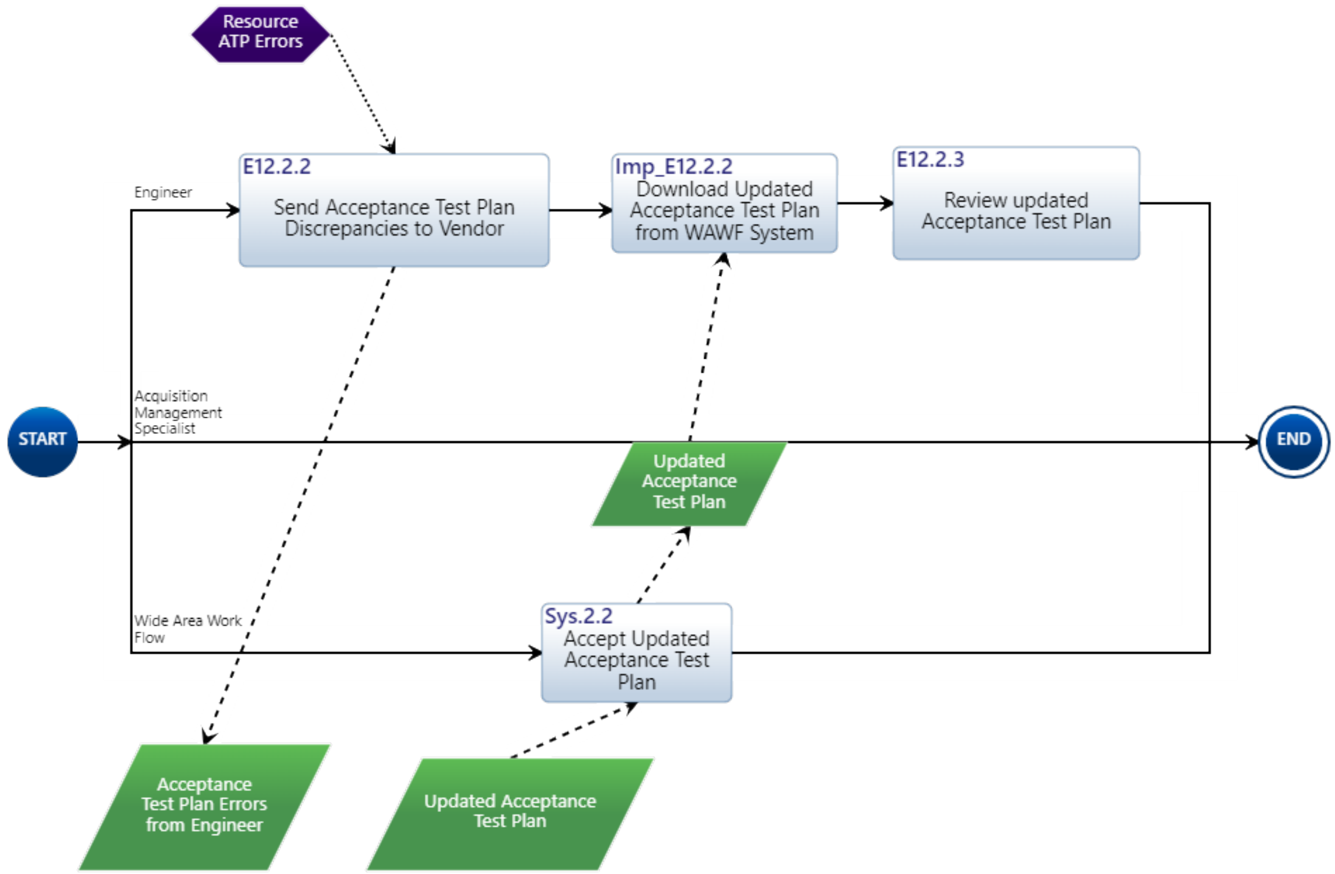

Figure 47. Revision 2 improved E1.2.2, resolve acceptance test plan.

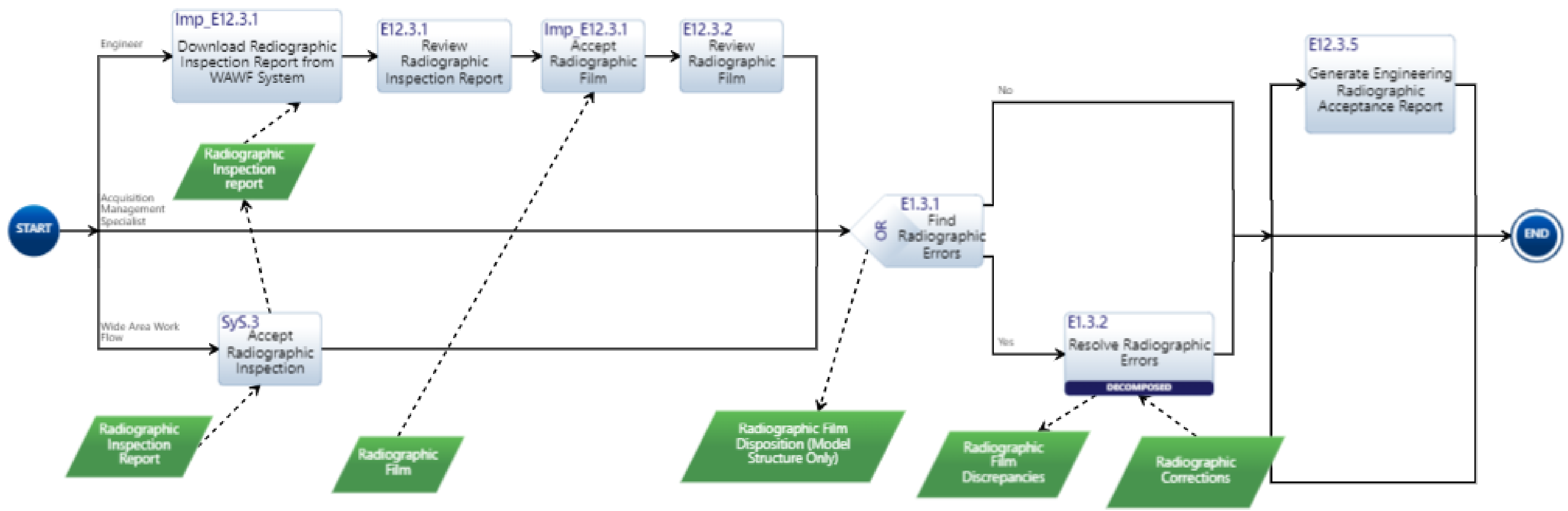

Figure 48. Revision 2 improved E1.3 review and approve radiographic film.

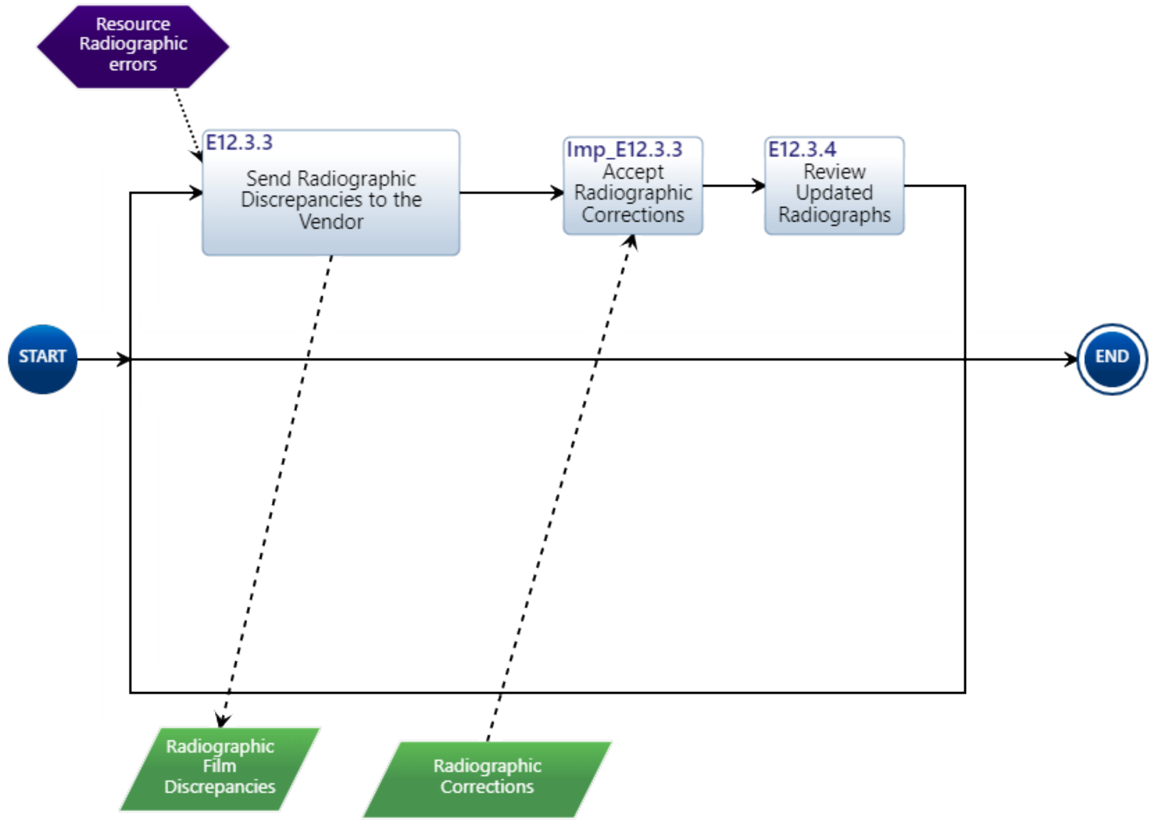

Figure 49. Revision 2 improved E1.3.2, resolve radiographic errors.

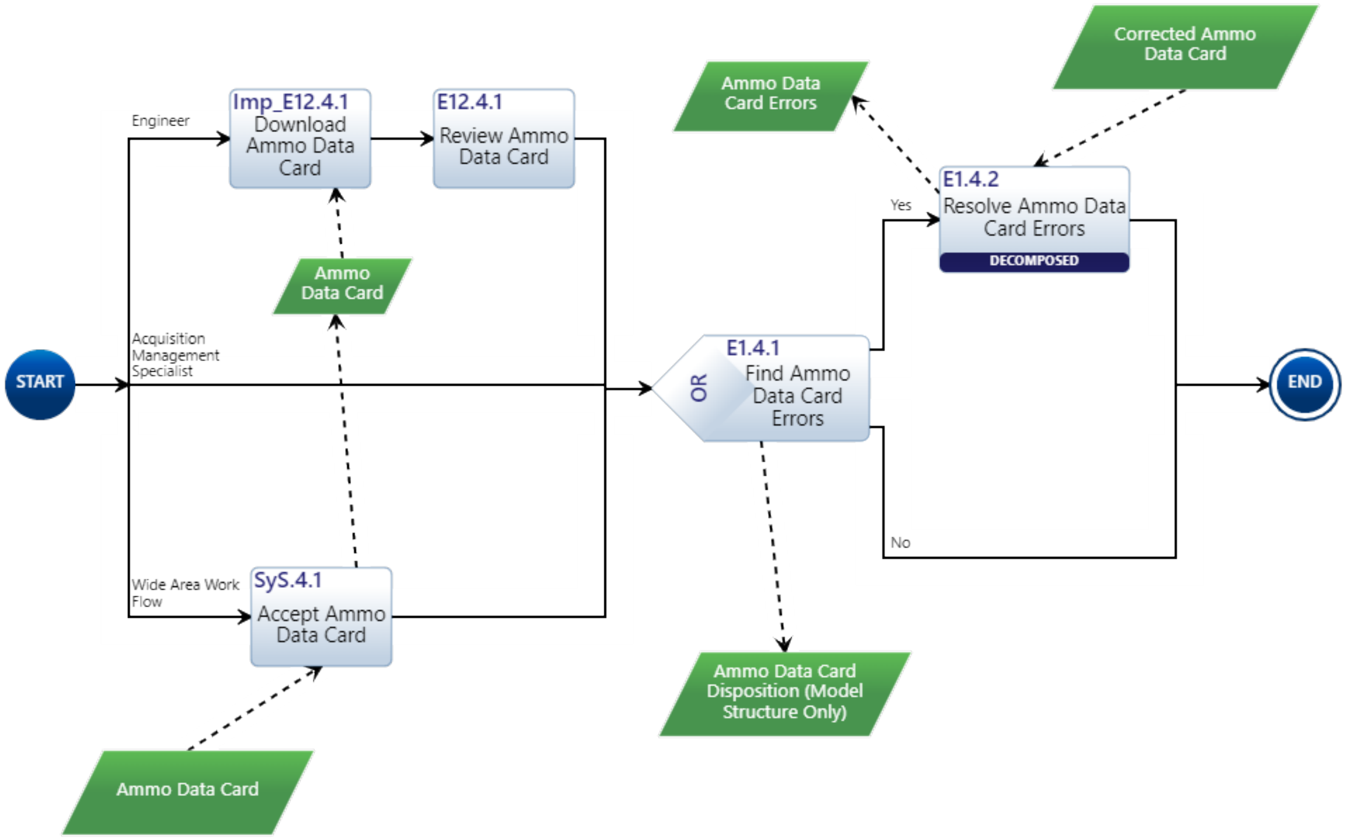

Figure 50. Revision 2 improved E1.4, review and approve ammo data card.

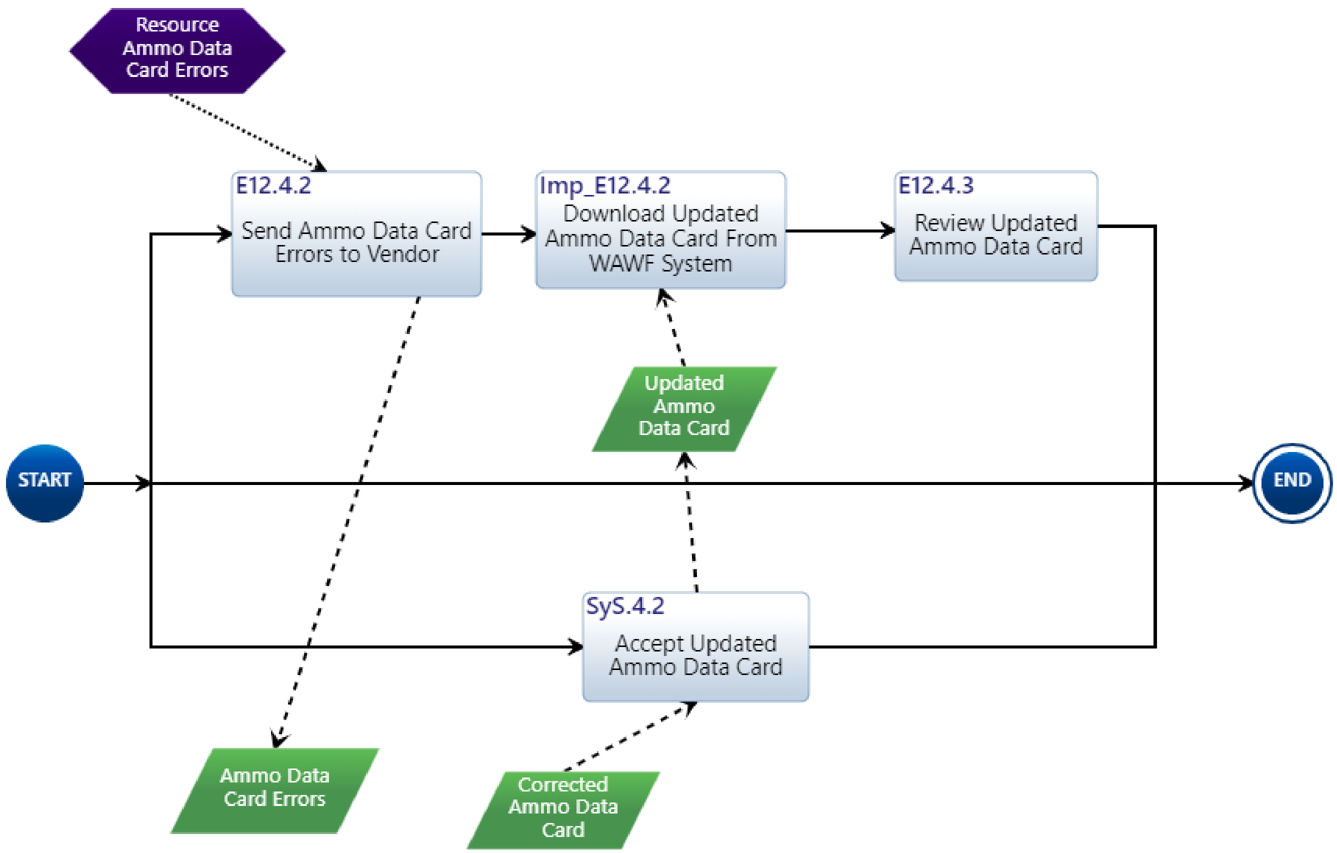

Figure 51. Revision 2 improved E1.4.2, resolve ammo data card errors.

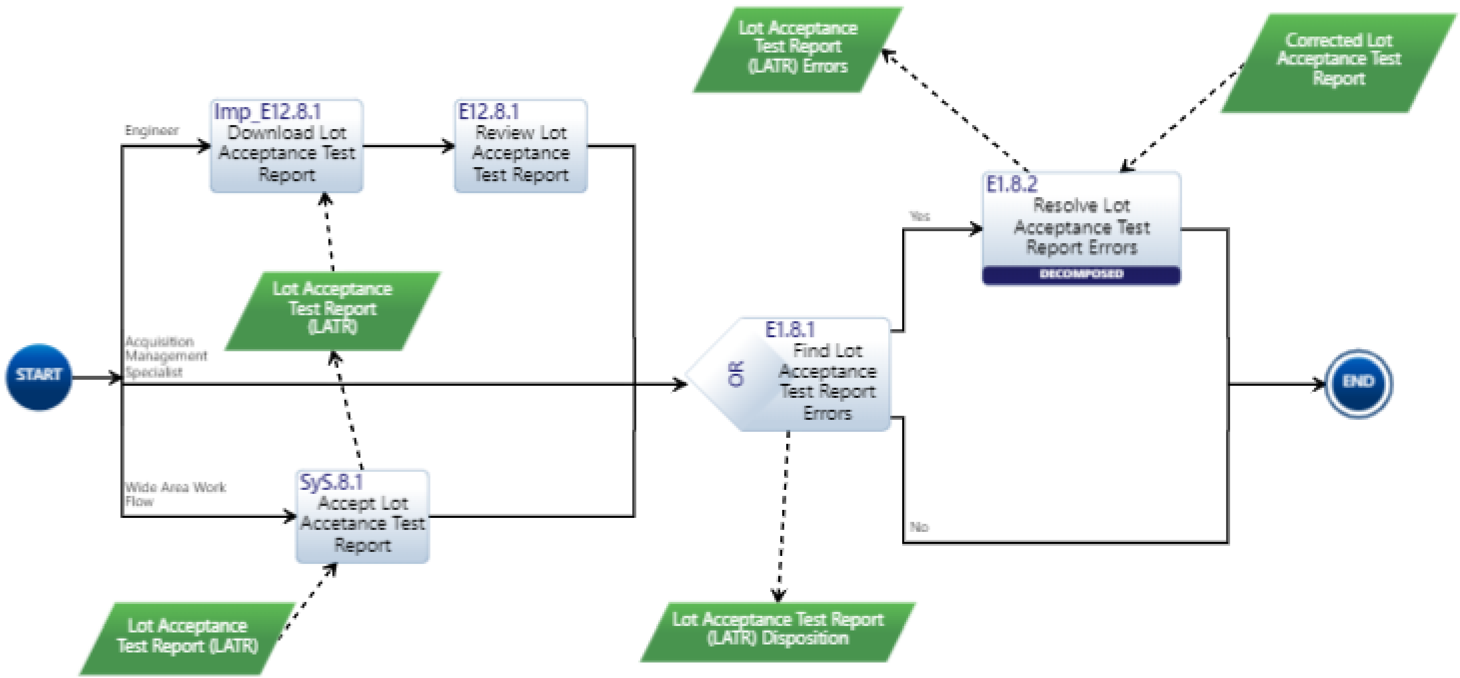

Figure 52. Revision 2 improved E1.8, review lot acceptance test report.

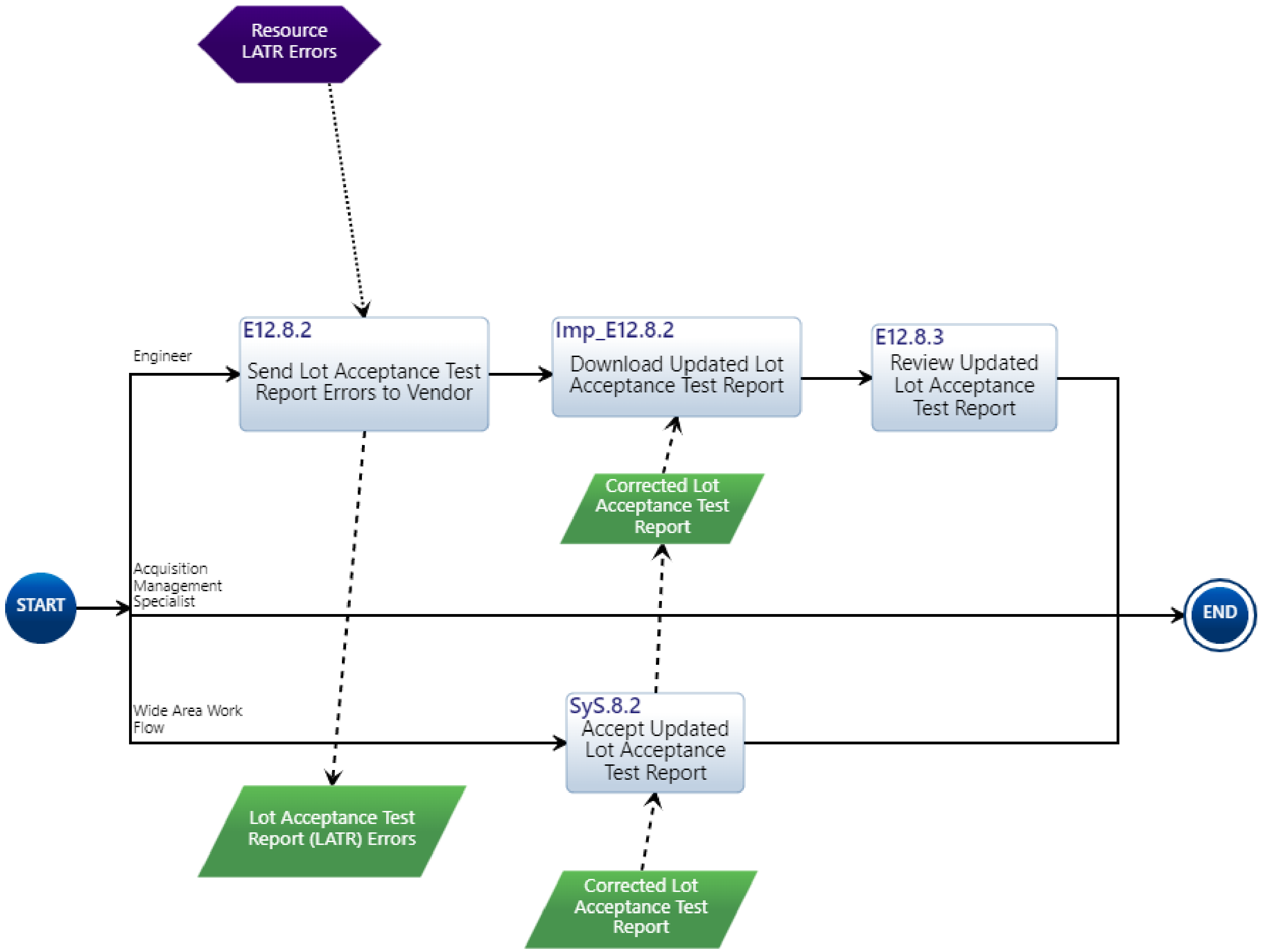

Figure 53. Revision 2 improved E1.8.2, resolve lot acceptance test report errors.

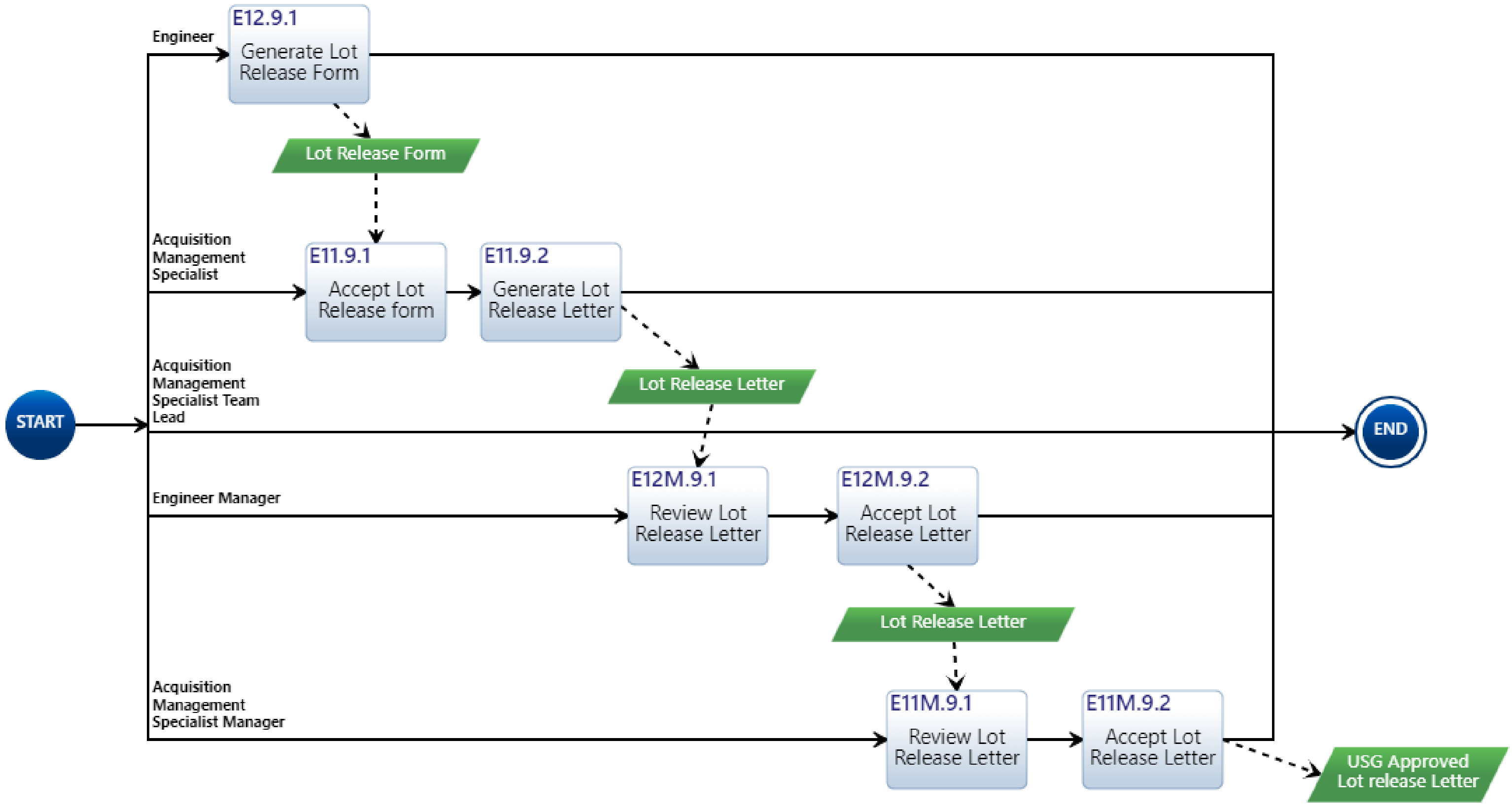

Figure 54. Revision 2 improved E1.9, issue lot acceptance letter.

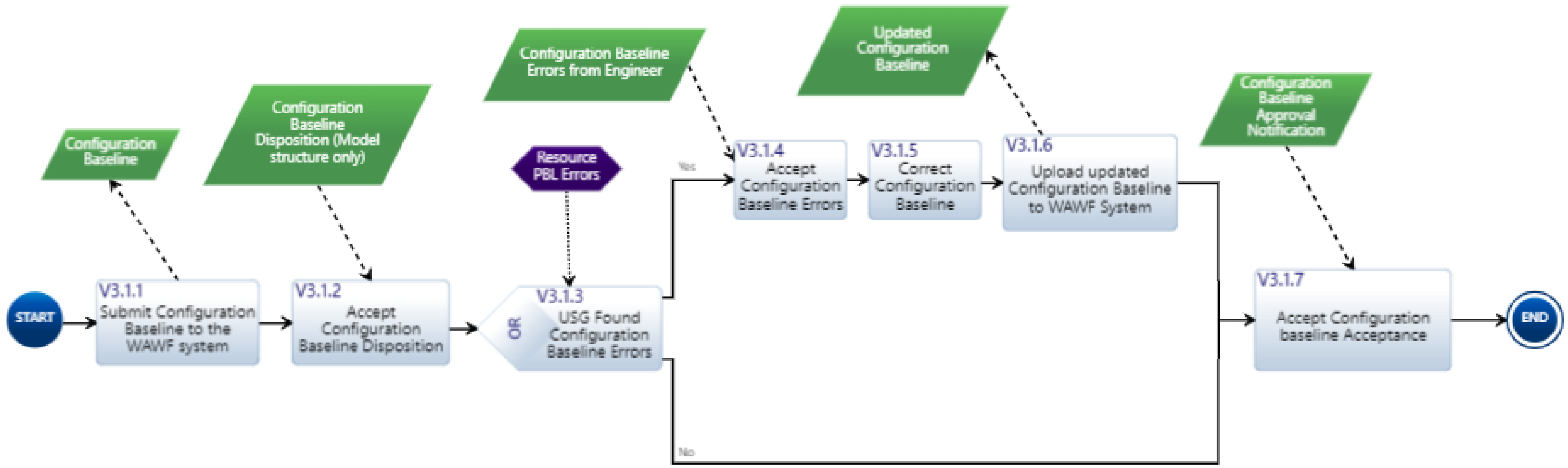

Figure 55. Revision 2 improved V3.1, submit product baseline.

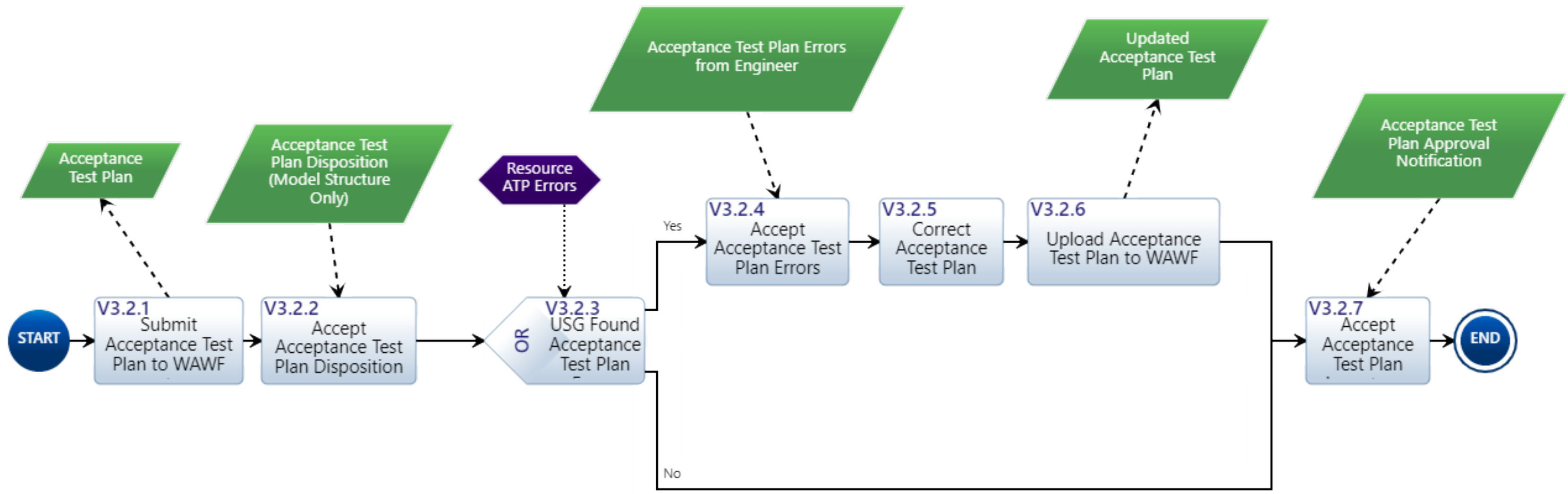

Figure 56. Revision 2 improved V3.2, submit acceptance test plan.

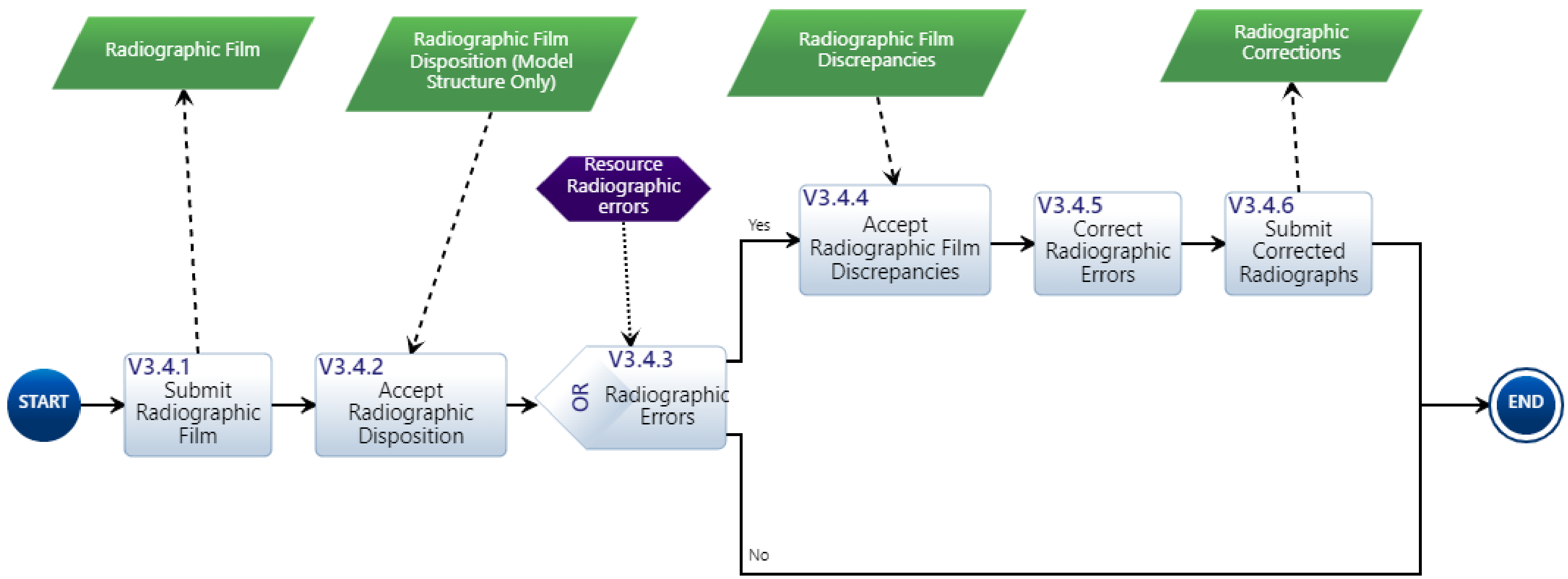

Figure 57. Revision 2 improved V3.4 submit radiographic film (N-ray/X-ray).

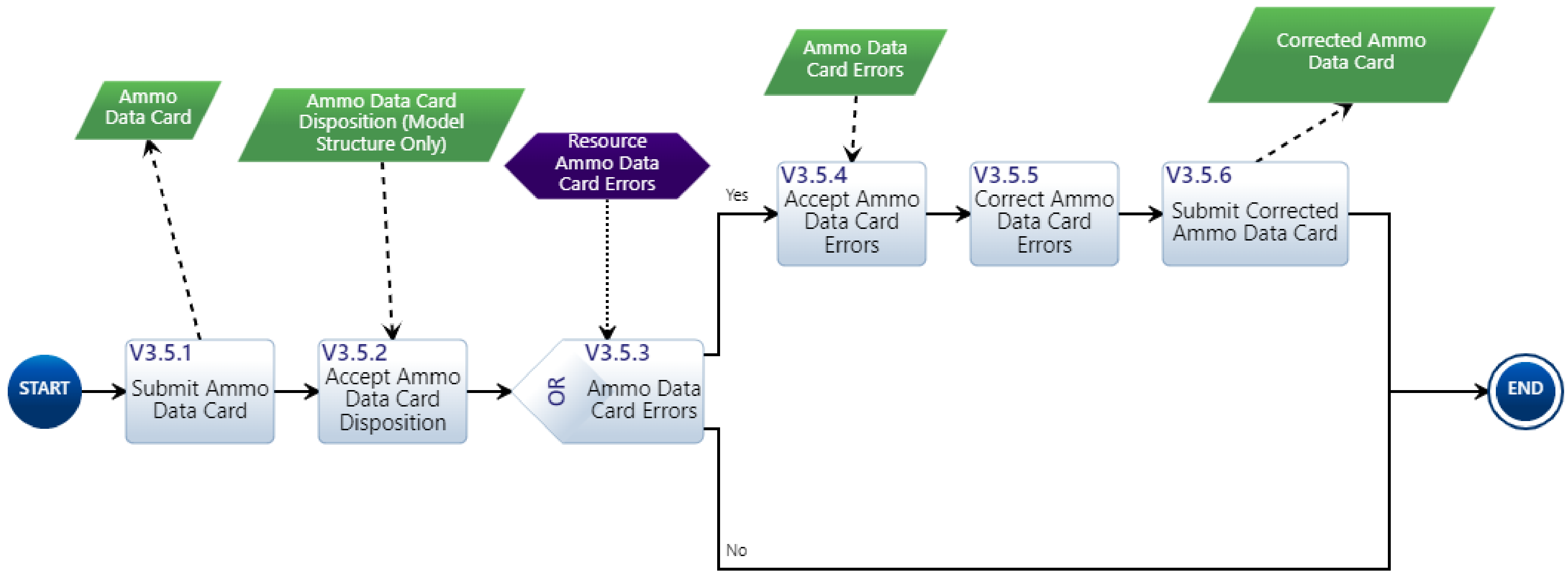

Figure 58. Revision 2 improved V3.5, submit preliminary ammo data card.

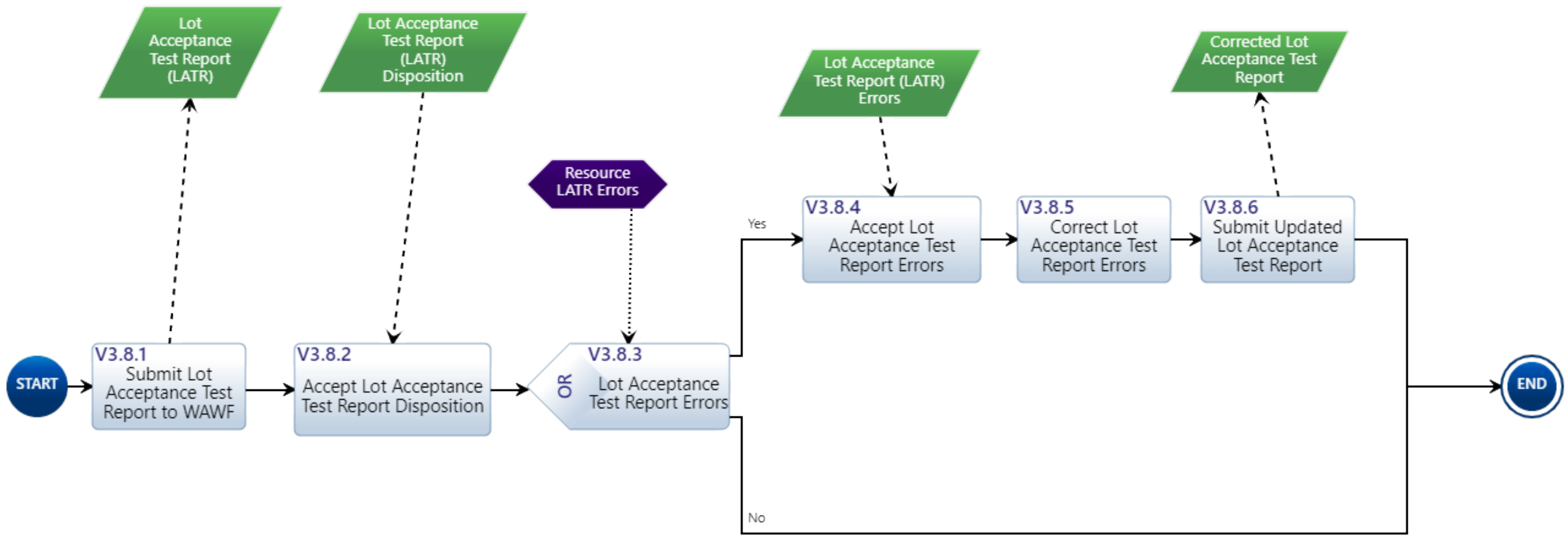

Figure 59. Revision 2 improved V3.8, submit lot acceptance test report.

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