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THESIS

COMPARISON OF REQUIREMENTS UNDERSTANDING IN MODEL-BASED SYSTEMS ENGINEERING VERSUS TRADITIONAL METHODS

by

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13. ABSTRACT (maximum 200 words)

Today, Model-Based Systems Engineering (MBSE) is used to meet the fast completion of complex projects and products. Yet, little research has been performed on the cognitive process involved in utilizing models to represent specifications. This thesis studies how well systems engineers can understand requirements in an MBSE environment. Systems engineers using models were tested to determine whether they understand a system in the same way or differently from systems engineers using text-based requirements for the same system. Subjects' comprehension on model-based versus text-based tactical sling specifications was measured based on the accuracy of the answers provided by the subjects in an online survey. The subjects' responses were used to evaluate experiment hypotheses and determine the effectiveness, efficiency, usefulness, and usability of modeling languages. Due to the low number of participants, the study could not definitively show whether the systems engineers using models understand system requirements in the same way or differently from systems engineers using text-based versions of the requirements. The study, however, did substantiate that models were more effective for eliciting correct responses to multiple-answer questions, suggesting that systems engineers and stakeholders can comprehend complex system requirements better in an MBSE environment.

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COMPARISON OF REQUIREMENTS UNDERSTANDING IN MODEL-BASED SYSTEMS ENGINEERING VERSUS TRADITIONAL METHODS

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ABSTRACT

Today, Model-Based Systems Engineering (MBSE) is used to meet the fast completion of complex projects and products. Yet, little research has been performed on the cognitive process involved in utilizing models to represent specifications. This thesis studies how well systems engineers can understand requirements in an MBSE environment. Systems engineers using models were tested to determine whether they understand a system in the same way or differently from systems engineers using text-based requirements for the same system. Subjects' comprehension on model-based versus text-based tactical sling specifications was measured based on the accuracy of the answers provided by the subjects in an online survey. The subjects' responses were used to evaluate experiment hypotheses and determine the effectiveness, efficiency, usefulness, and usability of modeling languages. Due to the low number of participants, the study could not definitively show whether the systems engineers using models understand system requirements in the same way or differently from systems engineers using text-based versions of the requirements. The study, however, did substantiate that models were more effective for eliciting correct responses to multiple-answer questions, suggesting that systems engineers and stakeholders can comprehend complex system requirements better in an MBSE environment.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	analysis of variance
BPMN	Business Process Modeling Notation
CITI	Collaborative Institutional Training Initiative
CSCW	Computer Supported Cooperative Work
CSRML	Collaborative Systems Requirements Modeling Language
DES	Digital Engineering Strategy
DoD	Department of Defense
DoDAF	DoD Architecture Framework
EFFBD	Enhanced Functional Flow Block Diagram
GQM	Goal Question Metric
IRB	Institutional Review Board
MA	multiple answers
MBSE	Model-Based Systems Engineering
MOPP	Mission Oriented Protective Posture
NPS	Naval Postgraduate School
ODASD(SE)	Office of the Deputy Assistant Secretary of Defense for Systems Engineering
PEOU	perceived ease of use
PU	perceived usefulness
SA	single answer
SE	systems engineering
SOI	system of interest
SysML	Systems Modeling Language
TTDSE	traditional top-down system engineering
UML	Unified Modeling Language

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EXECUTIVE SUMMARY

Expectation of fast completion of complex projects and products, especially in the defense acquisition sector, is steering the systems engineering (SE) community to favor Model-Based Systems Engineering (MBSE) over the traditional document-based systems engineering approach (Friedenthal, Moore, and Steiner 2012). This expectation is aligned with the Department of Defense's (DoD) Digital Engineering Strategy (DES) 2018, according to which "the Department is transforming its engineering practices to digital engineering, incorporating technology innovations into an integrated, digital, model-based approach" (Office of the Deputy Assistant Secretary of Defense for Systems Engineering [ODASD(SE)] 2018).

Although MBSE is one of the tools to support this strategy, it has not been informed by a robust body of research on the cognitive processes involved in utilizing models to represent system requirement specifications. Program success often depends on how well the different engineers and stakeholders can understand the models. Therefore, it is of cardinal importance to examine how an individual perceives the usefulness and usability of MBSE in the absence of text documents.

This thesis studied how well systems engineers can understand requirements in an MBSE environment. Specifically, the thesis (1) utilized the Systems Modeling Language (SysML) block definition, requirements, and use-case diagrams to represent the performance specification for a tactical sling, and (2) evaluated how different systems engineers comprehend the system requirements by comparing the model-based and the text-based specifications. This thesis tested whether systems engineers using models understand the system requirements the same as or differently from systems engineers using text-based requirements for the same system.

To address the research objectives just described, a research model linking the audience, modeling language, and system engineering process was adapted from a 2017 research proposal by Ronald Giachetti, Karen Holness, and Mollie McGuire. This thesis

is related to that research proposal because models were used to represent the system requirements, to test the understanding of the systems engineers.

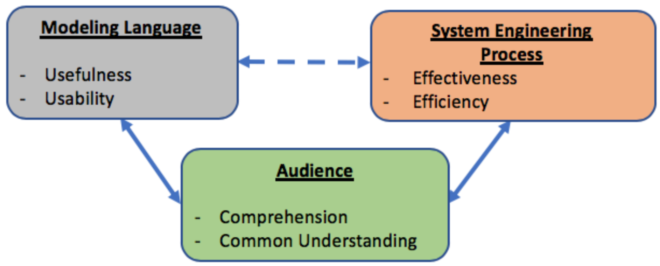

Figure 1. Research Model. Adapted from Giachetti, Holness, and McGuire (2017).

The experimental goal was to measure the subjects' comprehension of model-based versus text-based tactical sling specifications based on the accuracy of the answers provided by subjects in an online survey. The thesis conducted the experiment as follows: (1) subjects were randomly assigned to either a model-based or text-based requirements specification group, and had to complete an online questionnaire of open-ended, numeric, and "yes" or "no" questions about the requirements provided; (2) subjects in both groups were assigned with same set of questions; and (3) subjects' responses were used to evaluate the experiment hypotheses (see Table 1) and determine the effectiveness, efficiency, usefulness, and usability of the modeling languages.

Table 1. Experiment Hypotheses

H1: The average accuracy of answers for the Section 1 questions is the same for the model-based and text-based groups.
H2: The average time taken to provide "correct" answers for Section 1 questions is the same for the model-based and text-based groups.
H3: The usefulness of the performance specifications is the same for model-based and text-based groups.
H4: The usability of the performance specifications is the same for model-based and text-based groups.

To achieve qualitative data analysis, descriptive tests were conducted to identify different key metrics (i.e., mean, standard deviation, frequency count, and percentage of different category) for the questionnaire. The purpose was to provide an overview of the responses that were sorted into the model-based and text-based groupings. Using this sorted data, we evaluated the experiment hypotheses and identified several correlations between the subjects' demographics and the results.

The experiment concluded with a total of 40 responses, summarized in Table 2. There were 11 subjects who completed the questionnaire and 29 subjects' responses were excluded due to incomplete data characteristics being portrayed.

Table 2. Summary of Questionnaire Responses

Total Responses	Completed	Incomplete Responses		
		Exited at Introduction Page	Exited at Consent Form	Exited Half Way
40	11	10	9	10

Due to the low number of participants, the study did not significantly show whether the systems engineers using models understand the system requirements in the same way or differently from the systems engineers using text-based requirements. Nonetheless, it did substantiate that models were more effective for multiple-answer questions that corresponded to more complex requirements. The study suggests that systems engineers and stakeholders can comprehend complex system requirements better under an MBSE setting.

Our work clearly has some limitations: (1) insufficient data points to conduct inferential statistics to draw inferences about the population; and (2) inability to verify whether the time taken to answer the questionnaire for H2 could be attributed to the question itself or to some type of distraction. Nevertheless, we believe our work could be a springboard to: (1) engage the SE community with these findings; (2) educate them with the relevant knowledge to overcome possible pitfalls; and (3) enhance their experiences during the transition to MBSE across the relevant areas.

Several challenges arose to present future work opportunities. First, one could conduct a factor analysis to identify questions that are relevant to measure comprehension by analyzing their similarities and grouping them together. Next, a researcher could conduct a more deliberate effort to recruit at least 100 participants, to achieve the statistical power per GPower 3.0. Lastly, follow-on research could construct a controlled environment for the experiment to attain a more accurate assessment of the time taken to complete the questionnaire.

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I. INTRODUCTION

A. BACKGROUND

Expectation of fast completion of complex projects and products, especially in the defense acquisition sector, is steering the systems engineering (SE) community to favor the Model-Based System Engineering (MBSE) approach over the traditional document-based systems engineering one (Friedenthal, Moore, and Steiner 2012). Typically, to model a complex system, multiple interrelated models are utilized to represent different views of the system (e.g., workflows and reporting relationships). These models are expected to (1) enhance the quality of the design and specification; (2) facilitate better communication among the development team members; and (3) ensure better requirement traceability.

Although organizations are now using multiple, interrelated models, there has been a lack of research on the cognitive processes involved in utilizing these models. For instance, Jill H. Larkin and Herbert A. Simon (1987) conducted research on a single type of diagram to: (1) investigate how the diagram affects humans' ability to search, recognize, and infer, and (2) identify the cognitive processes involved in reasoning. Nevertheless, "Issues concerning the coordination of multiple diagrams of different types, the integration of information dispersed across multiple diagrams representing different system perspectives, and the problem of extracting information from multiple diagrams of different types remain largely unstudied" (Woods 1995).

The lack of research addressing the approach used to derive the specifications is particularly concerning in terms of the successful completion of complex projects and products. The key contributing factor to that success lies in the ability of the stakeholders to comprehend the different system perspectives and make informed decisions based on the given type of reference materials (i.e., text form or models).

B. THESIS PURPOSE

This thesis aims to study how well systems engineers can understand requirements in a MBSE environment. Specifically, the thesis (1) utilizes the Systems

Modeling Language (SysML) models of structure, requirements, and behavior diagrams to represent the performance specification for a tactical sling, and (2) evaluates how different systems engineers interpret the system requirements by comparing the model-based and the text-based specifications. With that, this thesis explores the impact of MBSE on the traditional SE process.

C. RESEARCH QUESTION

This thesis research tests whether systems engineers using models understand the system requirements the same as or differently from systems engineers using text-based requirements for the same system. To answer this research question, a research model linking the audience, modeling language, and systems engineering process was adapted from a 2017 research proposal by Ronald Giachetti, Karen Holness, and Mollie McGuire. The research proposal was to investigate how models affect, if at all, stakeholders' understanding, reasoning, and decision making about the acquisition of complex weapons systems. This thesis is related to that research proposal because models are used to represent the system requirements, which are then used to test the understanding of the system engineers. In this respect, the usefulness and usability of the modeling language, coupled with the effectiveness and efficiency of the SE process, is also evaluated. See Figure 1.

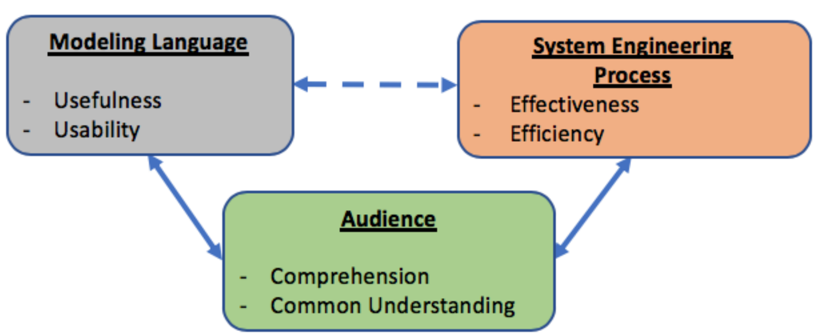

Figure 1. Research Model. Adapted from Giachetti, Holness, and McGuire (2017).

The modeling language is described by two factors. We define usefulness as the quality of representing and communicating the tactical sling specifications, and usability as the ease of using the modeling language.

The audience represents the systems engineers who interact with the model during the SE process. We are interested in their capabilities to comprehend and achieve a common understanding of the tactical sling specifications.

The last group depicts the efficiency and effectiveness of the SE process. Noting the purpose of the modeling language is to support system acquisition, it is critical to understand the characteristics (i.e., usefulness and usability) of the language and its effects on human cognition, as well as how that affects the efficiency and effectiveness of the acquisition process. We define efficiency based on the time spent to generate an output and effectiveness as the accuracy of the engineering activity.

As a whole, the operational effectiveness is measured by how well the systems engineers can answer questions contained in the developed survey about the tactical sling specifications.

D. ORGANIZATION OF STUDY

Chapter I introduces the research topic comparing the ability of systems engineers to understand system requirements when employing an MBSE approach versus traditional text-based methods. It provides an overview of the purpose of the research, the research question, and organization of the study.

Chapter II provides an overview of the SE process. It begins with the introduction to how both the traditional SE and the MBSE methods are applied to (1) derive the system specifications, and (2) help stakeholders to understand the requirements. Next, it provides the impetus for exploring the usefulness and usability of MBSE to represent the system (i.e., system requirements) digitally. Then, it investigates different methodologies adopted by previous studies to analyze the usefulness and usability of system models.

Chapter III introduces the selected SysML structure, requirements, and behavior models used to model the modified tactical sling specifications. The goal is to allow readers to comprehend the capabilities of these models and to facilitate their understanding of the system requirements.

Chapter IV illustrates the methodology used in this thesis to compare how well the requirements are understood between the MBSE approach and the traditional method. It establishes the design of a two-condition experiment for two different test groups: (a) the model-based group; and (b) the text-based group. This includes the process of: (1) obtaining the Institutional Review Board's (IRB) approval; (2) creating the reference materials, (3) designing the questionnaire for the two test groups; and (4) formulating the data analysis methodology to analyze the responses collected from the subjects. In particular, the questionnaire aims to study the participants' levels of comprehension and the accuracy of the specifications based on the type of reference materials presented.

Finally, after the research question has been answered through results analysis, Chapter V presents the conclusions of this study. Furthermore, it describes how this study leads to opportunities for further research.

II. LITERATURE REVIEW

A. TRADITIONAL SYSTEMS ENGINEERING

The primary focus of a systems engineering project is to create a system using a structured yet flexible process to convert requirements into functional and physical architectures, using specifications and scenario baselines. The conduct of this process provides control and traceability for the development of solutions to meet customer needs. With that, it is imperative that requirements are conveyed as intended to the key stakeholders for effective decision making.

Traditionally, engineers generate requirements from three different perspectives (a) the operational view; (b) the functional view; and (c) the physical view with the involvement of the key stakeholders to provide a holistic approach in meeting the customer's needs (Defense Acquisition University Press 2001). First, the operational view addresses how the system will serve its users. Thereafter, the functional view focuses on what the system needs to perform to achieve the desired operational behavior. Finally, the physical view centers on how the system achieves the functional and other requirements. These three architectures are then documented into the decision database, in hardcopy or electronic forms, which are then exchanged among the stakeholders.

In the traditional systems engineering process, requirement traceability is maintained in a text-based form, tracing requirements to specifications (highlighted in red boxes) at different levels (see Figure 2). "The traceability between requirements and design is maintained by identifying the part of the system or subsystem that satisfies the requirements and/or the verification procedures used to verify the requirements" (Friedenthal, Moore, and Steiner 2012, 16).

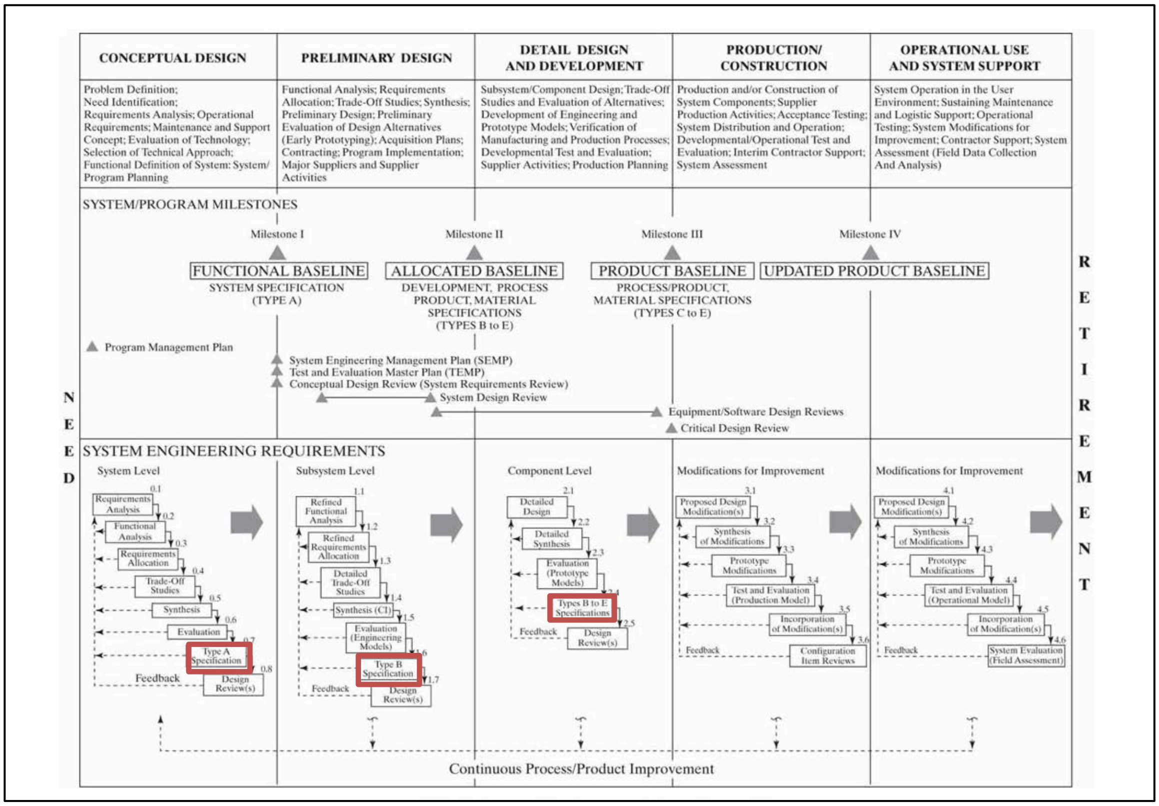

Figure 2. System Performance Specifications. Adapted from Blanchard and Fabrycky (2011).

While the traditional document-based approach can be stringent, it presents fundamental challenges. Information is recorded across numerous documents, making it challenging for information exchange among the different phases of systems engineering analysis (i.e., engineering, design, and requirements) to achieve consistency and completeness. Without this traceability, it is difficult to assess the impact of changes to any aspect of the system, which can lead to poor synchronization between design and requirements. It is also difficult to "recycle" these documents for improved versions of past systems (Friedenthal, Moore, and Steiner 2012). With that, potential quality issues are expected to surface during the integration and testing phase onwards. Gartner Group (2011) reported that one of the contributing factors to delivered defects (i.e., defects delivered to the user) was due to requirements defects.

Therefore, a visual modeling language for conducting system engineering was introduced. The double-headed arrows in Figure 3 represent the key terms and basic process of the traditional, top-down system engineering (TTDSE) addressed by the diagram types of SysML (Buede 2009). The utilization of models as part of the systems engineering process is called Model-Based System Engineering. An overview of MBSE and how it helps users to understand the system better is illustrated in the next section.

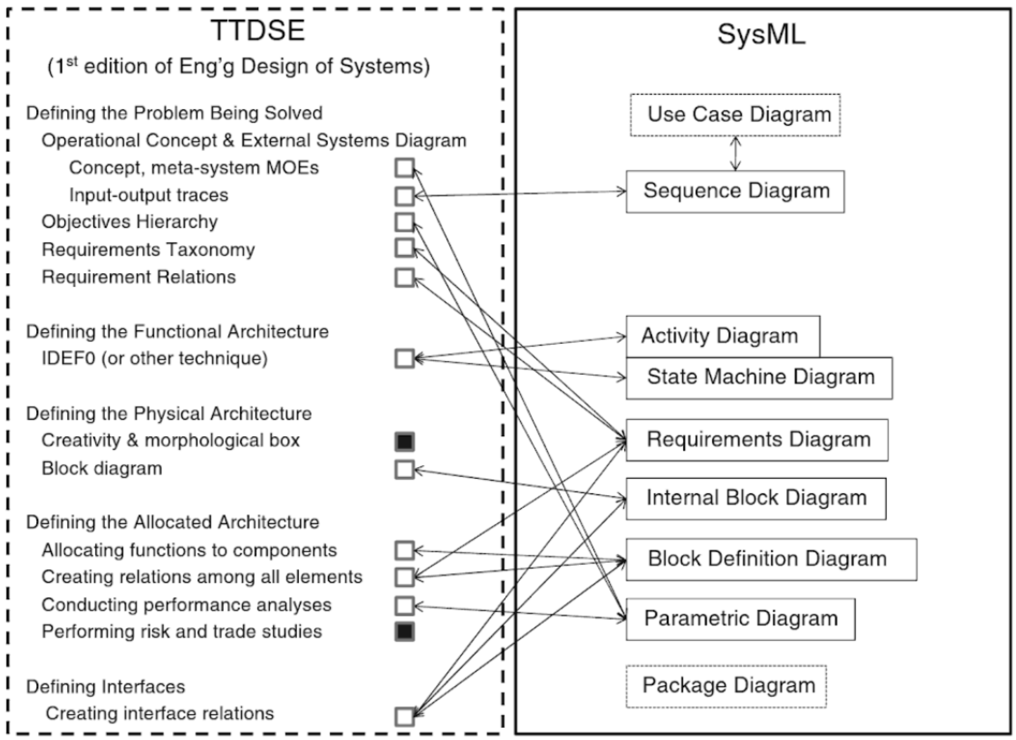

Figure 3. Comparison of TTDSE and SysML. Source: Buede (2009, Fig. 2.8).

B. MODEL-BASED SYSTEMS ENGINEERING

Model-Based Systems Engineering has been defined as

> the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and throughout development and later life cycle phases. In particular, MBSE is expected to replace the traditional document centric approach and influence future practice of systems

engineering by being fully integrated into the definition of the systems engineering processes. (International Council on Systems Engineering 2007, 4)

In terms of system development, MBSE provides a framework to guide the systems engineering team to be consistent and effective (Long and Scott 2011, 65). The system models use a consistent language to illustrate the interconnectivity between the model elements that represent the key aspects (i.e., structure, behavior, requirements and parametric) of the system (see Figure 4).

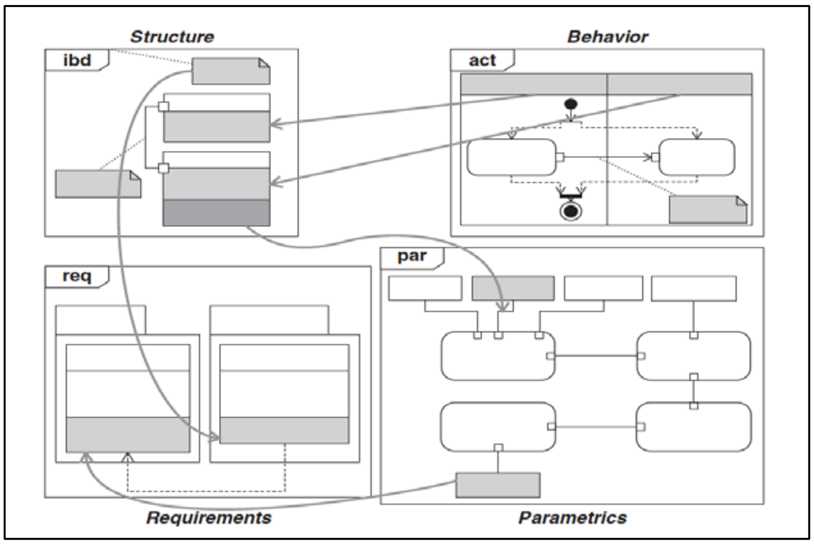

Figure 4. Interconnectivity between the Key Aspects. Source: Friedenthal, Moore, and Steiner (2012, Fig. 2.1).

This crisscross interconnectivity allows a targeted approach to view the system model through the desired operational, functional, and physical perspectives (see Figure 5). For instance, the software developer will be able to see whether the design of the software model fulfills the requirements and supports the allocation to the components of the system. With that, it maintains the requirement traceability to the system components.

MBSE designs the system in layers and completes the systems engineering activities at one layer before decomposing or elaborating the next layer. In layer one, work focuses on the requirements domain while layer two emphasizes the functional or behavior domain. Upon completion of each layer's activities, meaningful draft specifications are produced for the systems engineering team. This enables the development team to produce a coherently designed solution that answers the system requirements posed by the problem, a significant benefit over the conventional approaches.

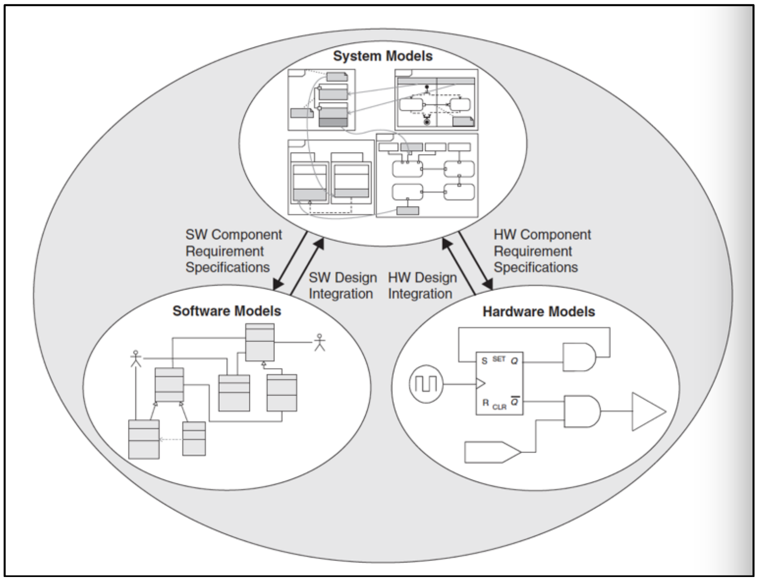

Figure 5. Different Perspectives of the System Model. Source: Friedenthal, Moore, and Steiner (2012, Fig 2.2).

For U.S. DoD defense applications, the specifications are defined in accordance to the DoD Architecture Framework (DoDAF). "DoDAF 2.0 serves as the overarching, comprehensive framework and conceptual model enabling the development of architectures to facilitate the DoD managers at all levels to make informed decisions through organized information sharing across department, joint capability areas, mission, component and program boundaries" (U.S. Department of Defense, 2009). Through DoDAF 2.0, user defined views (e.g., data views, operational views, and system/services view) are created for specific purposes to allow easy comprehension of the architectural data. Edwin Shuman (2010) maps the different DoDAF views to four key architecture modeling languages. Each of these languages is briefly described in Figure 6.

Viewpoint	Fishwick Category	DODAF Model Number	Model Type	Structured Modeling Language	UML	SysML	BPMN
Data Viewpoint	Conceptual	DIV-2 (OV-7)	Logical Data Model	IDEF 1X, ERD	Class Diagram	Block Diagram	
Operational Viewpoint	Conceptual	OV-1	Concept Diagram		Use Case	Use Case	
	Functional	OV-2	Operational Node Connectivity Diagram		Communication Diagram	Block Diagram	BPMN
	Functional	OV-3	Information Exchange Matrix			Allocation Tables	
	Conceptual	OV-4	Operational Relationships Diagram		Class Diagram	Block Diagram; Package Diagram	
	Functional	OV-5a	Hierarchical Activity Diagram			Block Diagram; Package Diagram	
	Functional	OV-5b	Activity Diagram	IDEF 0	Actvity Diagram	Activity Diagram	BPMN
	Functional	OV-6c	Operational Event Trace Diagram		Sequence Diagram	Sequence Diagram	BPMN
	Declarative	OV-6b	Operational State Transition Description		State Diagram	State Diagram	
	Functional	OV-6a	Operational Rules Diagram	IDEF 3		Activity Diagram	BPMN
Systems / Services Viewpoints	Functional	SV-1	System to System Node Connectivity Diagram		Communication Diagram	Block Diagram	
	Functional	SV-4	Data Flow Diagram	Data Flow Digaram	Communication Diagram	Activity Diagram	BPMN
	Functional	SV-6	System Data Exchange Matrix			Allocation Tables	
	Functional	SV-7	Systems Measures Matrix	IDEF3		Parametric Diagram	BPMN
	Functional	SV-10c	Systems and Services Event-Trace Description		Sequence Diagram	Sequence Diagram	BPMN
	Declarative	SV-10b	Systems and Services State Transition Description		State Diagram	State Diagram	
	Functional	SV-10a	System Rules Model	IDEF 3		Activity Diagram	BPMN

Figure 6. Modeling Languages–DoDAF Alignment.
Source: Shuman (2011).

1. Structured Modeling

Structured analysis uses "a collection of modeling and analysis techniques to provide a formal mathematical framework and computer based environment for conceiving, representing, and manipulating a wide variety of models" (Geoffrion 1987). These models are IDEF0, data flow diagrams, and the entity-relationship diagrams for data modeling (U.S. Department of Defense 2009).

2. Unified Modeling Language

The Unified Modeling Language (UML) aims to analyze, describe, and document the aspects of a software system. Primarily, it uses object-oriented principles to model behavior and structure diagrams. While the behavior diagrams represent the "dynamic behavior of the objects in a system, the static structure of a system" is represented by the structure diagrams (Shuman 2011).

3. Systems Modeling Language

SysML adopts the UML profile, and is a domain-specific systems engineering modeling language "used for specifying, analyzing, designing, and verifying complex systems" (Shuman 2011). Activity diagrams, internal block diagrams, parametric diagrams, and requirement diagrams are models used to represent hardware, software, information, people, processes, and facilities (Objects Management Group 2009).

4. Business Process Modeling Notation

Business Process Modeling Notation (BPMN) is based on flow charting and is similar to UML activity diagrams (Shuman 2011). It is comprised of four basic categories of elements: flow objects, connecting objects, swimlanes, and artifacts (Object Management Group 2006).

The mapping of DoDAF views to the various architecture modeling languages builds a common understanding among the key stakeholders. Additionally, this develops a comprehensive architecture that is in accordance with the defined requirements. To achieve this, the selected modeling language needs to be capable of representing the required DoDAF views. Based on Figure 6, SysML is capable of mapping a majority of the DoDAF viewpoints.

While the selection of a modeling language to represent the requirements is critical, the success of the project often depends on how well the different engineers and stakeholders can understand the models. This is because different individuals can generate a different interpretation of the same requirement statement. Shail K. Dinkar (2014) has observed that errors of visualization arise when the models that represent the problem-spaced domain are not adequately mapped onto the solution-space domain. He has also stated that error of conception occurs when the development team poorly understands the objectives of the solution. In a broader perspective, a majority of the misunderstanding of requirements can be attributed to poor visualization of the interaction between the end-user and the system.

Furthermore, Dean Leffingwell (1997) found that 40 percent of total project cost is associated with rework due to low-quality requirements. Therefore, knowing how different individuals perceive the requirements is of paramount importance and may reduce project costs. With that, the next section examines how an individual perceives (i.e., visualizes and conceptualizes) the usefulness and usability of MBSE in the absence of text documents.

C. THE IMPETUS OF EXPLORING USEFULNESS AND USABILITY IN MBSE

According to the U.S. *DoD Digital Engineering Strategy (DES) 2018*, the DoD is "transforming its engineering practices to digital engineering, incorporating technology innovations into an integrated, digital, model-based approach" (Office of the Deputy Assistant Secretary of Defense for Systems Engineering (ODASD[SE]) 2018). The five goals of the DES are to:

- formalize development, integration, and use of models to inform enterprise and program decision making
- provide an enduring, authoritative source of truth
- incorporate technological innovation to improve engineering practice

- establish infrastructure and environment to perform activities, collaborate, and communicate across stakeholders
- transform the culture and workforce to adopt and support digital engineering across the life-cycle. (ODASD[SE]), 2018, 4)

One of the tools to achieve these goals is through MBSE. In the move to MBSE, simple static text-form documents that just provided contents for the engineers and stakeholders to read have evolved into complex dynamic models that can be generated and modified by different stakeholders in a collaborative manner. This will enable the DoD to develop a living document that aligns implementation efforts across the department to provide critical capability to the warfighter as quickly as possible (ODASD[SE] 2018). Therefore, it is imperative to explore the usefulness and usability of MBSE as part of the SE process. A key part of being useful is to comprehend the characteristics of the system of interest (SOI).

Fred D. Davis has proposed two main individual beliefs necessary for users to use a technology: (a) perceived usefulness (PU), and (b) perceived ease of use (PEOU) (Davis 1989). He defined the (1) "perceived usefulness as the prospective user's subjective probability that using a specific application system will increase his or her job performance within an organizational context. Perceived ease of use refers to the degree to which the prospective user expects the target system to be free of effort" (Davis 1989, 840) Having a useful and usable approach to represent the system requirements is the key to achieving the best quality in the developed system as part of the SE process.

D. PREVIOUS STUDIES IN MODEL USEFULNESS AND USABILITY

Different approaches have been used to investigate the usefulness and usability of system models. This section describes the methods used by previous studies.

1. Structure Equation Modeling Analysis

Fida Chandio et al. (2014) investigated the "importance of perceived usefulness, perceived ease of use and intention to use online information resources for Evidence-based Medicine (EBM)" in two steps. The first step examined the reliability and validity using a measurement model that encompasses the aforementioned three factors, using confirmatory factor analysis. This indicated how well the model fitted the data. The second step was to evaluate the influence of individual factors on each other as represented by the H1, H2, and H3 hypotheses in the structure model (see Figure 7). All the relations were significant on the basis of two tailed tests. Conclusively, Chandio et al. found “perceived usefulness as a strong predictor in acceptance and behavioral intention research as compared to the perceived ease of use.”

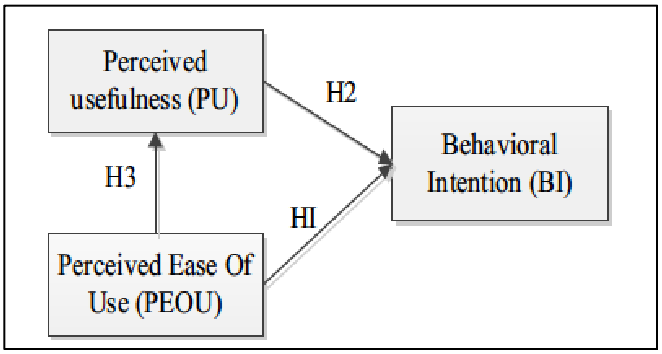

Figure 7. Research Model. Source: Chandio et al. (2014).

2. Protocol Analysis

Jinwoo Kim, Jungpil Hahn, and Hyoungmee Hahn (2000) proposed a diagramming reasoning framework that studied the cognitive processes of perceptual and conceptual integration used by an individual to understand business processes. Multiple diagrams (i.e., class diagrams, state transition diagrams, event trace diagrams, input-output diagrams, data flow diagrams, use-case diagrams, and context diagrams) were presented by Kim et al. Using this framework, they identified fundamental problem sources as an integral part of a system development methodology.

Verbal and action protocols, coupled with the time of occurrence were collected. Perceptual data were collected based on the individual subject’s action during problem solving by either “paying attention to a certain diagram if the title of the diagram was identified or if a certain visual item in the diagram was located by pointing towards it or explicitly mentioning its name” (Kim et al. 2000). Then, Kim et al. (2000) summarized these data into a diagram transition graph that depicted the subjects’ transitions among the multiple diagrams during the experiment. On the other hand, conceptual data were collected based on the verbal protocols of the subjects when presented with the given business process. These data were then summarized into a hypothesis behavior graph by Kim et al. (2000). Based on the number of correct problems identified by the subjects, the overall performance was determined.

3. Goal Question Metric

Basili, Victor.R., Gianluigi Caldiera, and H Dieter Rombach (1994) introduced the Goal Question Metric (GQM) model. The hierarchical structure begins with a goal (e.g., purpose of measurement), which is then refined into questions. Thereafter, quantifiable metrics to answer these questions are identified to achieve the goal.

Using the GQM approach, Miguel Teruel et al. (2012) compared and evaluated two different requirements specification language (i.e., i* and Collaborative Systems Requirements Modeling Language (CSRML)) to determine which language can specify requirements of collaborative systems better. Each conducted experiment encompassed an introductory session using either i* or CSRML for two different Computer Supported Cooperative Work (CSCW) systems (i.e., Jigsaw or Conference). Then, subjects (students) were divided into two different groups, with the assigned type of modeling language for each collaborative system. See Figure 8.

		Domain	
		Jigsaw	***Conference***
Language	***i****	Group 1	Group 2
	CSRML	Group 2	Group 1

Figure 8. Experiments Design. Source: Teruel et al. (2012).

To test the subjects' comprehension on the requirements specifications of two different CSCW systems, the students had to complete a questionnaire consisting of true or false answers. The same set of questions was presented for each system, irrespective to the specification language used. For statistical purposes, the time taken to complete the questionnaire was also gathered. Additionally, analysis of variance (ANOVA) tests were conducted on the mean values to examine the defined null hypotheses. See Figure 9.

Null-Hypothesis	H_{0A}: CSRML has the same average score for understandability as *i** when modeling CSCW systems requirements. H_{1A}: $\neg H_{0A}$ H_{0B}: The average score for understandability is the same regardless the domain used in the experiment. H_{1B}: $\neg H_{0B}$ H_{0AB}: CSRML has the same average score for understandability as *i** when modeling CSCW systems requirements, regardless the domain used in the experiment and viceversa. H_{1AB}: $\neg H_{0AB}$

Figure 9. Null Hypotheses of Experiments. Source: Teruel et al. (2012).

The different studies demonstrated how model-based efforts could be applied to create a holistic view and support the stakeholders' level of comprehension on different systems for informed decision making. Additionally, the different analytic approaches used to evaluate these studies helped in the characterization of the MBSE approach adopted herein, and in shaping the evaluation criteria and forming the basis for this thesis.

In Chapter III, an overview of the different model types that were derived from the tactical sling text-based specifications is provided. With that, the information integrity between the model-based and text-based specifications is maintained. Furthermore, valuable insights on what the models represent and how the models were created is also elaborated. The specific research methodology used for this thesis is presented in Chapter IV.

III. SYSTEM MODELING OF A TACTICAL SLING BELT

For this thesis, we selected the Vitech CORE systems engineering software to model the tactical sling specifications. The model includes three types of SysML diagrams: (1) Block Definition Diagram, (2) Requirement Diagram, and (3) Use Case Diagram. Based on the identified use-cases, the enhanced functional flow block diagrams (EFFBD) are also created to illustrate the flow of functions performed by the specific actors or components to complete the seven key operations. See Appendix A for the tactical sling model-based performance specifications.

A. BLOCK DEFINITION DIAGRAM

The block definition diagram represented the structural elements of the system, their composition, and classification. In this case, it decomposed the field attire into three key elements: (1) Warfighter, (2) Weapon, and (3) Tactical Sling. This was followed by a further breakdown of the SOI—the Tactical Sling—into a (1) Tactical Sling Belt, (2) Tactical Sling Belt Buckle, and (3) Tactical Sling Quick-Release Fastener. This provided an overview of the components involved to achieve the system requirements (see Figure 10).

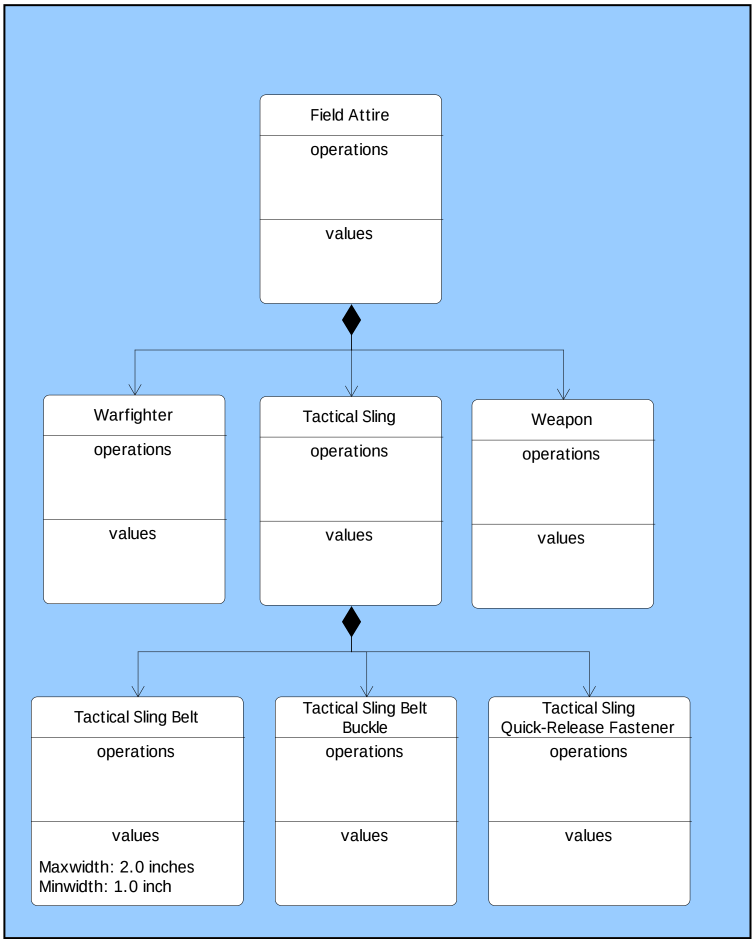

Figure 10. Block Definition Diagram for Tactical Sling

B. REQUIREMENTS DIAGRAM

Next, the requirements diagram represented the requirements, their relationship with the derived requirements based on the context, design elements, and use-cases to promote requirement traceability. In general, the tactical sling encompassed three different types of requirements: (1) Operating Requirements, (2) Interface and Interoperability Requirements, and (3) Support and Ownership Requirements. With that, the requirements diagram provided an overview of the system performance requirements to be achieved (see Figure 11).

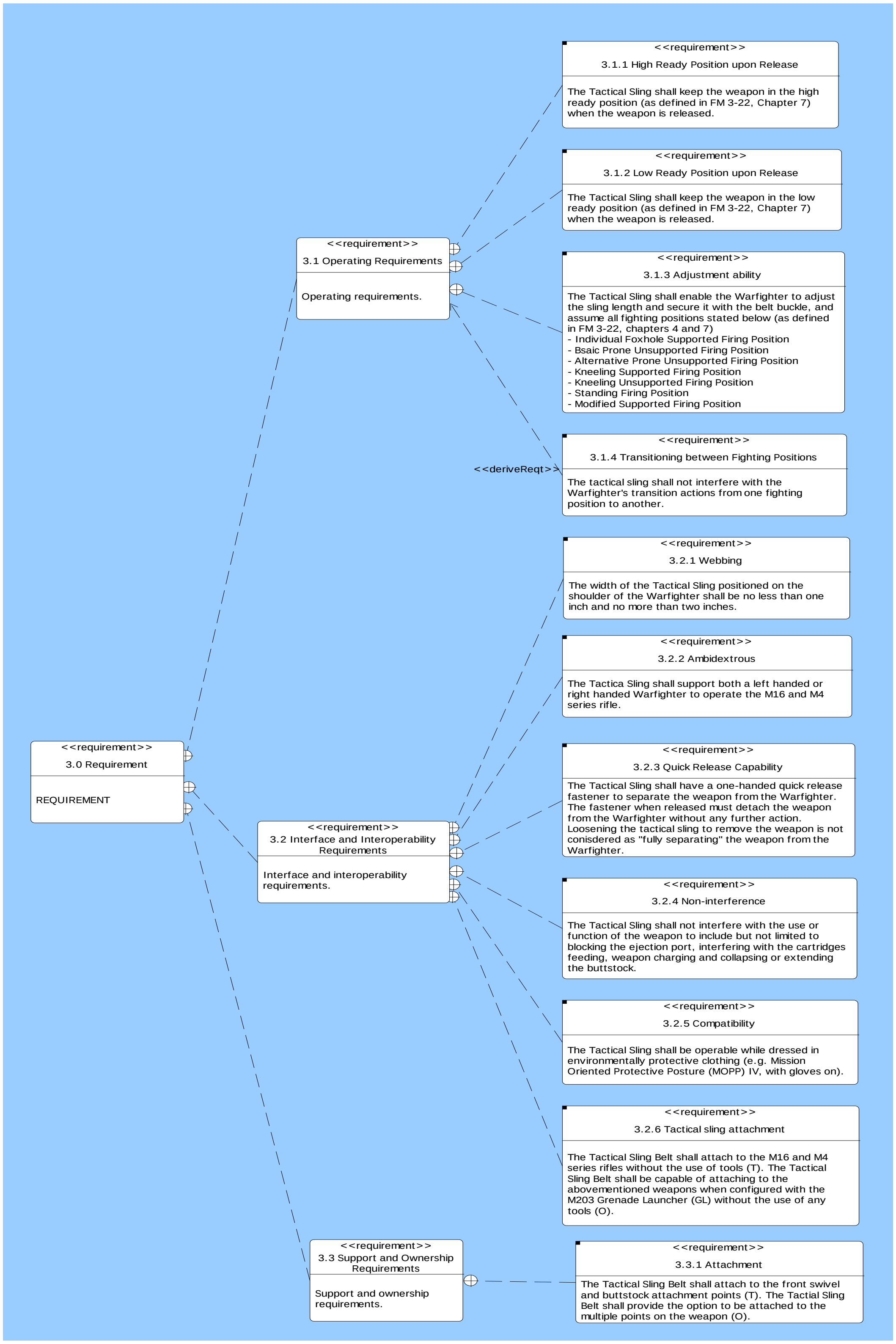

Figure 11. Requirements Diagram for Tactical Sling. Adapted from Defense Standardization Program Office (2009).

C. USE-CASE DIAGRAM

The use-case diagram was utilized to model the relationship between the systems (i.e., tactical sling and its actors). Based on the aforementioned requirements diagram, six use-cases were identified that represented the tactical sling operations involving the two main actors, (1) the Warfighter and (2) the Weapon. In addition, an extension from these six use-cases was derived for the operation in Mission Oriented Protective Posture (MOPP) IV Attire, with gloves on (see Figure 12). Through this diagram, the development team could visualize the required key operations and the relationships among the actors to achieve the system performance. With that, the use-case diagram also facilitated the creation of the EFFBD.

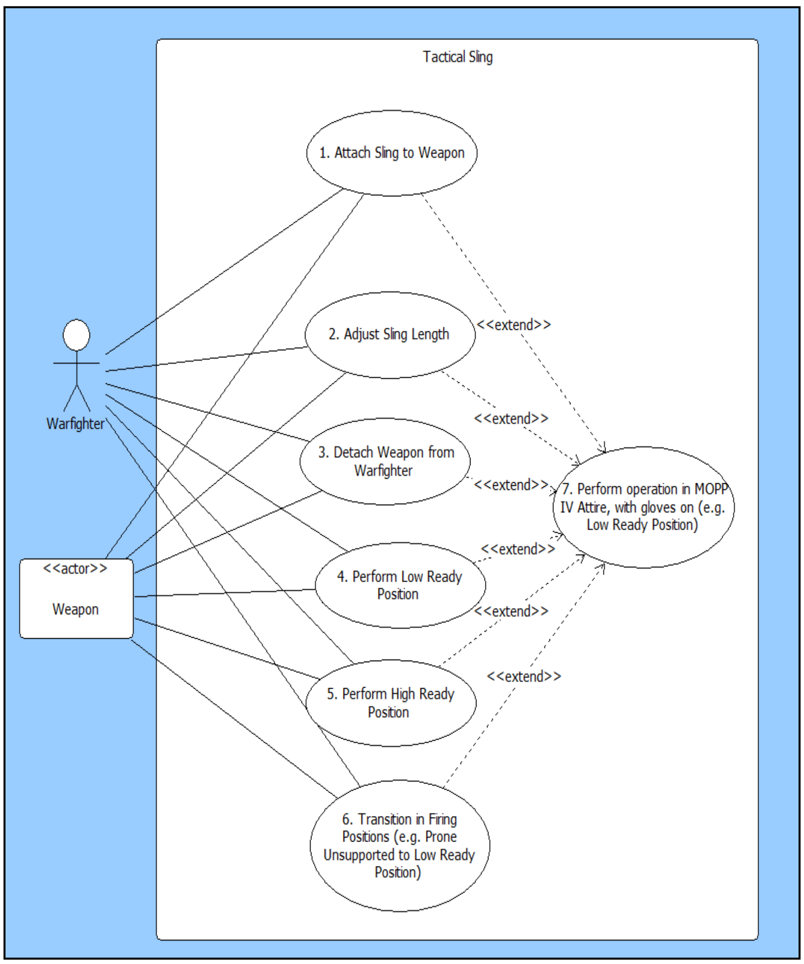

Figure 12. Use-Case Diagram for Tactical Sling

The EFFBD illustrated the behavior of the individual actors and components to complete a task. In this case, seven EFFBDs were created to illustrate the flow of functions performed by the specific actors or components to complete the seven key operations identified in Figure 12. During this process, the different types of methods to achieve the same goal were also explored and included using the "OR" gate, with consideration of the environmental factors and actors involved to perform the tasks.

Figure 13 shows the flow of functions required to attach the tactical sling to the weapon. As a whole, the Warfighter needs to perform three sequential functions. Based on the weapon design that comes with two different attachment methods (i.e., with or without attachment points) for both the front swivel and buttstock, the Warfighter will be able to choose any one of the four methods. In this process of creating the EFFBD, the stakeholders can visualize the steps and scrutinize the feasibility of the functions to perform the operations. See Appendix A-5 to A-8 for the remaining use-cases.

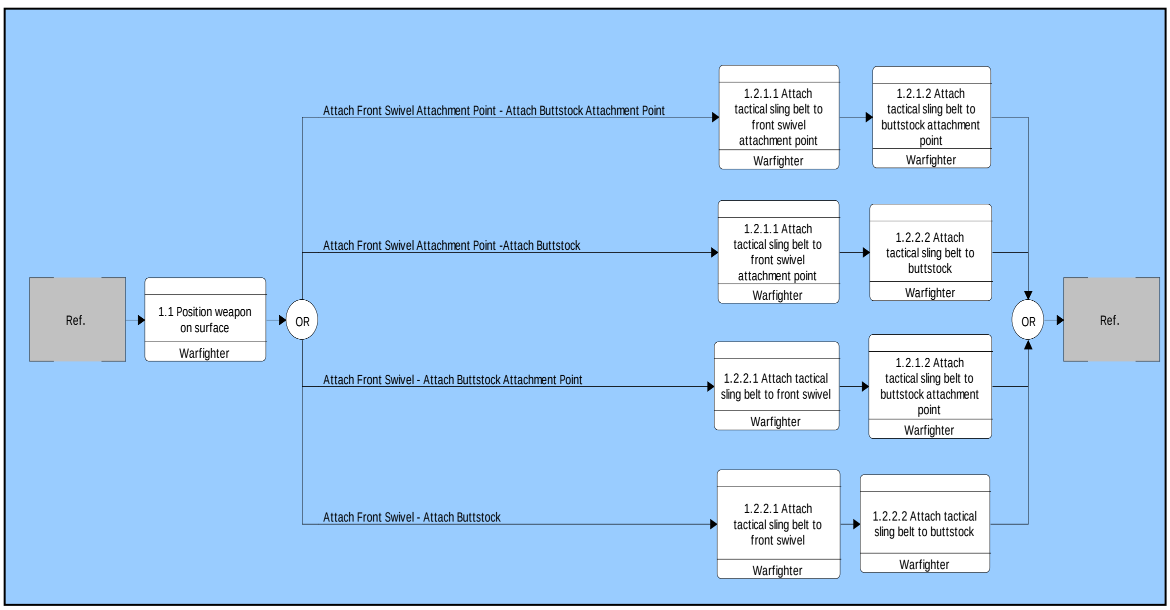

Figure 13. Use-Case: Attach Sling to Weapon

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IV. EXPERIMENTS

A. EXPERIMENTAL DESIGN

The following sections illustrates the experimental design and the methodology used to conduct the experiment and analyze the data.

1. Introduction

The tactical sling specification was selected as a majority of the experiment subjects can relate to the concept due to their military background. The main goal was to measure the subjects' comprehension of model-based versus text-based tactical sling specifications. The ability to comprehend the materials was based on the accuracy of the answers provided by the subjects in an online survey. This allowed us to evaluate the effectiveness of the SE process. Besides addressing the experiment goal, we also evaluated the efficiency of the SE process, and the usefulness and usability of the modeling language (see Figure 14). The targeted subjects were from a pool of 400 Naval Postgraduate School (NPS), Systems Engineering students—both resident and distance learning. Statistical power dictated that at least 100 participants were needed.

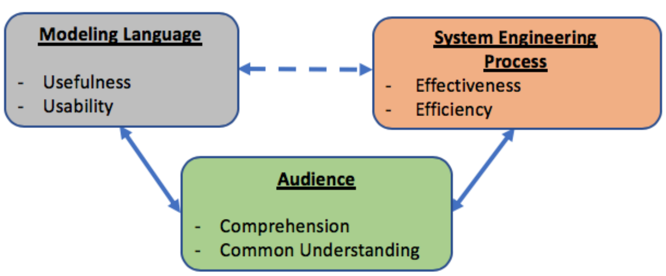


Figure 14. Research Model. Adapted from Giachetti et al. (2017).

The two-condition experimental setup consisted of two different test groups: (1) Model-Based Group and (2) Text-Based Group. Subjects were randomly assigned to one of these groups, where each test group was given either the model-based or text-based specifications (see Figure 15) derived from the *SD-15 Guide for Performance Specification—Appendix C: Item Specification for Sling, Tactical* (2009). See Appendix A and Appendix B for the models-based and text-based specifications, respectively. Noting that the functions of the tactical sling were generally user-centric, the thesis only selected specifications that illustrated these functions in the (1) operating requirements; (2) interface and interoperability requirements; and (3) support and ownership requirements.

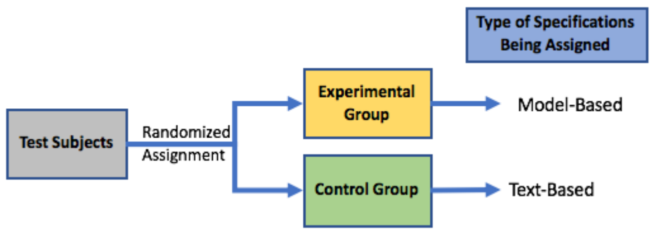


Figure 15. Experiment Design

Our dependent variable was the subjects' comprehension of the requirements in the specifications, and the independent variables were the languages (i.e., models or text-based) used to represent the tactical sling requirements. To test the subject's comprehension of requirements using each type of tactical sling specification, the subjects had to complete an online questionnaire of open-ended, numeric, and "yes or no" questions about the requirements The same set of questions were presented to both groups. There were two sections: Section 1: Requirements and Section 2: Reference materials and demographics.

Section 1 focused on the subject's comprehension of the requirements in the tactical sling's performance specifications. Based on the accuracy of their answers and the time taken to answer Section 1 questions correctly, we assessed the effectiveness and efficiency of using each type of specification to conduct SE analyses. The questions are listed in Table 1. For every question, the subjects had to answer the question and provide the supporting information they used to derive the solution.

Table 1. Questionnaire (Section 1)

S/N	Requirements
1	List the physical components of the tactical sling.
2	What is the minimum and maximum width of the tactical sling belt?
3	List the tactical sling's functions that require interactions between the warfighter, weapon, and tactical sling.
4	List and describe the ways to detach the weapon.
5	Does the tactical sling allow both a left handed and right handed warfighter to operate the M16 and M4 series rifle?
6	Does the tactical sling support operations while wearing Mission Oriented Protective Posture (MOPP) IV gear?
7	Does the warfighter require a tool to attach the tactical sling onto the weapon?
8	Do you foresee the tactical sling causing any interference when used?
9	Do you foresee the tactical sling posing any risk while crossing water obstacles?
10	List and describe the different ways to attach the tactical sling to the weapon.

Section 2 served to acquire inputs about the reference materials presented and demographics of the subjects. The responses from this section enabled us to assess the usefulness and usability of the language, coupled with the subjects' demographics (see Table 2). For the detailed design of the questionnaire, refer to Appendix C.

Table 2. Questionnaire (Section 2)

S/N	Reference Materials and Demographics
1	How many times did you refer to the performance specification document?
2	Was it easy to find the information in the performance specification document to help you answer the questions?
3	Overall, how easy was it to understand the information in the performance specification document?
4	How many times did you refer to the FM 3–22 document?
5	Did you use any other sources besides the references provided in this survey?
6	List all education degrees you have (e.g., BS in aerospace engineering).
7	How many years of systems engineering experience do you have?
8	How many years of modeling or model-based systems engineering (MBSE) experience do you have?
9	Rate your level of experience with either the M16 and/or M4 series rifle?
10	Have you ever used a tactical sling when shooting a rifle?
11	Any other comments?

In summary, the questionnaire was designed to facilitate two-fold evaluation. First, leveraging the GQM approach described in Chapter II, we used the responses from the first 14 questions to evaluate the experiment hypotheses listed in Table 3 (see Figure 16). Then, the demographics (i.e., Qn 15 to 20) responses were utilized to identify any correlation with the results from the first 14 questions.

Table 3. Experiment Hypotheses

H1: The average accuracy of answers for the Section 1 questions is the same for the model-based and text-based groups.
H2: The average time taken to answer Section 1 questions correctly is the same for the model-based and text-based groups.
H3: The usefulness of the performance specifications is the same for model-based and text-based groups.
H4: The usability of the performance specifications is the same for model-based and text-based groups.

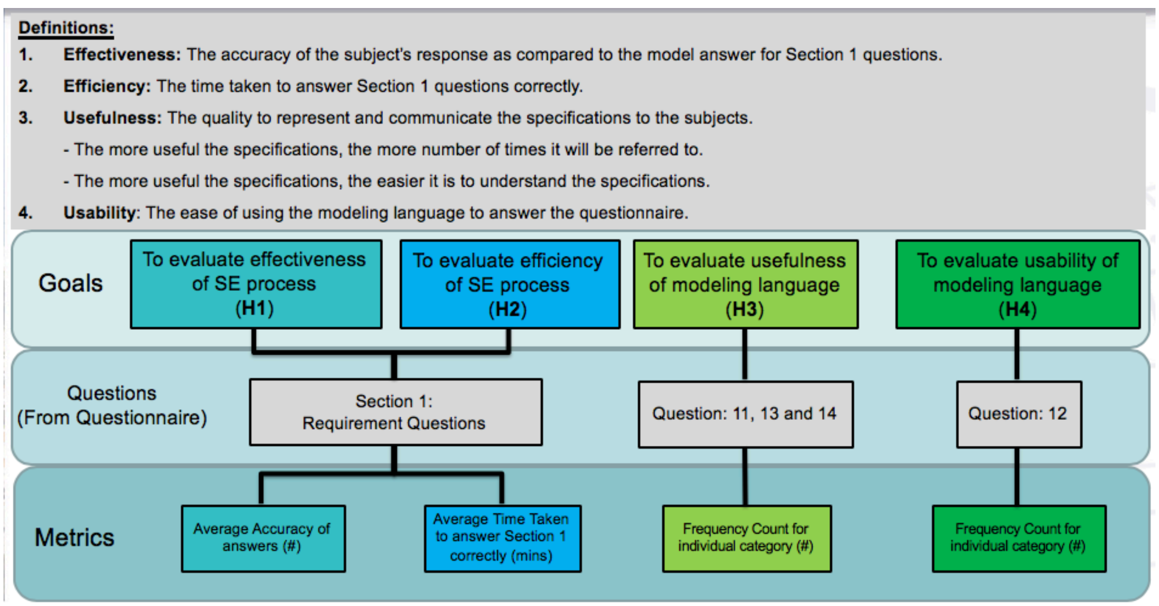


Figure 16. Goal-Question-Metric Matrix

2. Institutional Review Board Process

As the experiment involved NPS SE students as experiment subjects, an approval from the NPS Institutional Review Board was required. To achieve this, an initial review package was prepared. See Appendix D for details on the package.

This research was voluntary, with no incentive provided. Once the IRB's approval was obtained, recruitment emails were sent based on a student-student relationship via the NPS email to the resident students and the distance learning students through the Distance Learning Education Technician. The participants were assured in both the recruitment email and the consent form that participation was completely optional and all data collected would be anonymous. Finally, no time limit was imposed for the questionnaire to avoid any form of pressure on the subjects.

3. Conduct of Experiment

The experiment was performed online from June 2018 to August 2018. The link to the questionnaire was sent to the subjects through their NPS emails. In the first page, subject's consent to participate in the questionnaire was requested. Thereafter, subjects were advised to read either the model-based or text-based tactical sling specifications for 15 minutes before answering the questionnaire. To prevent any possible interaction between subjects, the requirement questions in Section 1 were randomized for different subjects. Then, Section 2 acquired the demographics data of the subjects. This questionnaire was administered using the NPS LimeSurvey platform, whereby all survey data files were stored on a server behind the NPS firewall.

4. Data Analysis Methodology

For data analysis, a three-step methodology was implemented, as is shown in Figure 17.

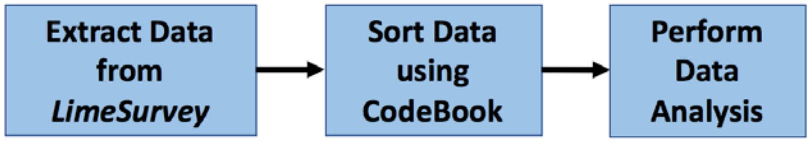


Figure 17. Data Analysis Methodology

a. Extract Data from LimeSurvey

First, raw data were extracted from the LimeSurvey application in the form of a Microsoft Excel worksheet. This worksheet comprised the subjects' responses and the time taken to perform the activities in the questionnaire. Next, incomplete responses that exhibited the following features were eliminated: (1) responses that are irrelevant to the question and (2) responses of subjects that exited the questionnaire part way through.

b. Sort Data using Codebook

Data were sorted into a coded Excel file. The coded file functions as a framework to guide the data analysis process. It contained (1) the questionnaire instrument (i.e., frequency count of different category); (2) the questionnaire questions, labels, and values (i.e., codebook); and (3) information on the questionnaire method (i.e., descriptive), characteristics, and outcomes.

Using the codebook, individual responses were sorted into different categories (i.e., value labels) based on the scope of question. For example, Figure 18 illustrates the code categories for question 1. For the Section 1 questions, if the questions contained multiple possible responses, subjects' responses were assessed and given a response code from 1 to 3, defined as follows: (1) Not correct; (2) Partial Correct; and (3) Correct. For some questions, there was only one possible correct response or expected answer (e.g. Yes or No, a number value). For these questions, responses were coded as either (1) Not correct or (2) Correct. With the coded responses, the frequency count of the categories for each question were tabulated. This enabled us to perform descriptive tests effectively and efficiently in the next step, especially when handling a large sample size. For the detailed codebook of the questionnaire, refer to Appendix E.

Variable Name	Variable Label	Range Variable	Variable Format	Format Name	Format Value	Value Label
Qn1[SQ001]	List the physical components of the tactical sling.	1-3	openended	1phycomp	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn1[SQ002]	Requirement # or any other information you used.	1-3	openended	1sptinfo	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)

Figure 18. Codebook for Question 1

c. *Perform Data Analysis*

To perform qualitative data analysis, descriptive tests were conducted to identify different key metrics (i.e., mean, standard deviation, frequency count, and percentage of different category) for the questionnaire. The purpose was to provide an overview of the responses that are sorted into the model-based and text-based conditions. Using this sorted data, we were able to evaluate the experiment hypotheses, and identify any possible correlation between the subjects' demographics and the results.

B. DATA ANALYSIS RESULTS

The following sections provides an overview of the questionnaire responses that were collected and summarizes the outcomes for the experiment hypotheses and additional insights gained.

1. Introduction

The experiment concluded with a total of 40 responses. There were 11 subjects completed the questionnaire and 29 subjects' responses were excluded due to incomplete data characteristics being portrayed. The subsequent section discusses the results and elaborate how the experiment goal is achieved.

Table 4. Summary of Questionnaire Responses

Total Responses	Completed	Incomplete Responses		
		Exited at Introduction Page	Exited at Consent Form	Exited Half Way
40	11	10	9	10

For the 29 subjects' responses that were excluded, we continued to investigate the data trend behind the incomplete responses to identify the possible contributing factors. The findings were as such:

a. Exit at Introduction Page

There were 11 subjects who clicked on the link from the recruitment email to access the questionnaire. However, there was no time recorded for these 11 subjects to indicate any form of interaction with the questionnaire.

b. Exit at Consent Form Page

There were nine subjects who exited the questionnaire after they provided their consent to participate in the questionnaire. However, there was no time taken to suggest any interaction between these subjects and the reference materials after the consent form page.

c. Exit Half Way

There were ten subjects who exited the questionnaire half way. While all of them provided the consent and read the reference materials, only three subjects made an attempt to answer at least one question. The other seven subjects exited the questionnaire without answering any questions.

2. Discussion of Results

This thesis selected Minitab, a statistical package, to present the statistical results and their corresponding analyses for the questionnaire. The objectives were to (1) evaluate the experiment goal (i.e., H1); (2) evaluate the additional experiment hypotheses (i.e., H2 to H4); and (3) identify any possible correlation between the subjects' demographics and the results. Noting that there was a variation in scope for the Section 1 questions and to conduct a fair evaluation, we broke these questions down further into either (1) Multiple Answers (MA) Questions, which were coded with a 1, 2, or 3; or (2) Single Answer (SA) Questions, which were coded with only a 1 or 2.

See Figure 19. For both H1 and H2, the hypotheses tested the MA and SA questions separately.

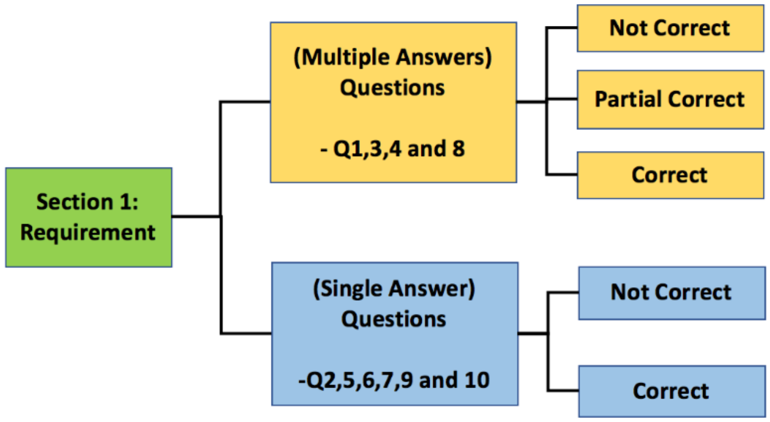
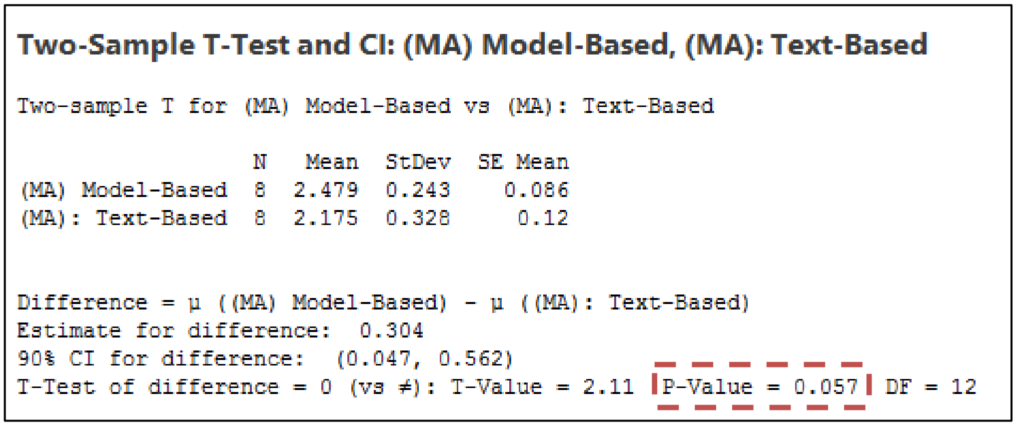


Figure 19. Breakdown of Section 1 Questions.

a. *H1: The Average Accuracy of Answers for Section 1 is the Same for the Model-based and Text-based Groups*

The aim of this hypothesis is to measure the subjects' comprehension of the materials and to compare between both groups. To examine this hypothesis, the subjects' responses to the Section 1 questions (i.e., Q1 to Q10) as stated earlier in Table 1 were consolidated. Using these data, two-sample t-tests were conducted to reject the null hypothesis H1, which is an appropriate test to explore results from two independent variables (i.e., model-based and text-based) with a small sample size (i.e., less than 30).

Figure 20 shows that we rejected $H1_{MA}$ ($p=0.057 < \alpha=0.1$), which indicated the average accuracy for MA questions differed significantly. Conversely, Figure 21 illustrates that we failed to reject $H1_{SA}$ ($p=0.623 > \alpha=0.1$), which showed the average accuracy for SA questions did not differ significantly. Table 5 summarizes the hypothesis test results and outcomes for H1.



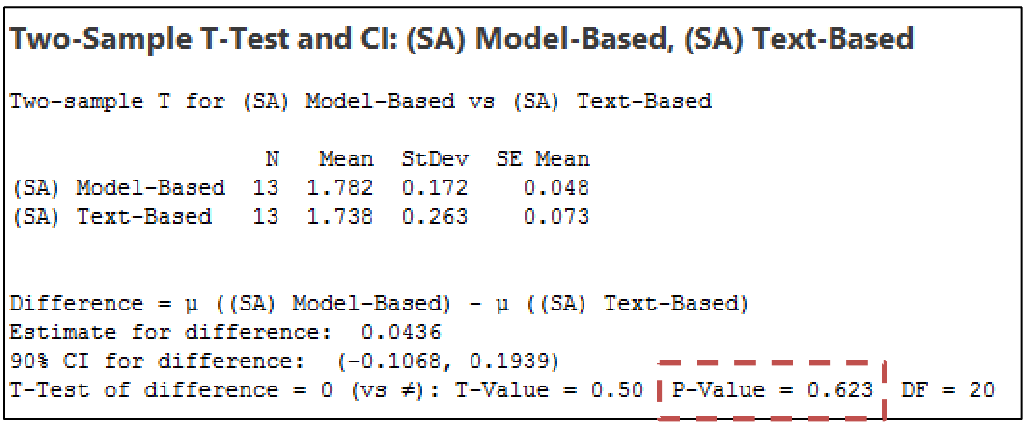
Two-Sample T-Test and CI: (MA) Model-Based, (MA): Text-Based

```
Two-sample T for (MA) Model-Based vs (MA): Text-Based

                     N   Mean  StDev  SE Mean
(MA) Model-Based     8  2.479  0.243    0.086
(MA): Text-Based     8  2.175  0.328     0.12


Difference = µ ((MA) Model-Based) - µ ((MA): Text-Based)
Estimate for difference:  0.304
90% CI for difference:  (0.047, 0.562)
T-Test of difference = 0 (vs ≠): T-Value = 2.11  P-Value = 0.057  DF = 12
```

Figure 20. Two Sample t-Test for MA Questions ($H1_{MA}$)



Two-Sample T-Test and CI: (SA) Model-Based, (SA) Text-Based

```
Two-sample T for (SA) Model-Based vs (SA) Text-Based

                     N   Mean  StDev  SE Mean
(SA) Model-Based    13  1.782  0.172    0.048
(SA) Text-Based     13  1.738  0.263    0.073


Difference = µ ((SA) Model-Based) - µ ((SA) Text-Based)
Estimate for difference:  0.0436
90% CI for difference:  (-0.1068, 0.1939)
T-Test of difference = 0 (vs ≠): T-Value = 0.50  P-Value = 0.623  DF = 20
```

Figure 21. Two Sample t-Test for SA Questions ($H1_{SA}$)

Table 5. Hypothesis Test Results and Outcomes for H1

Question Type	Hypothesis	Hypothesis Test Results	Outcome
Multiple Answers	$H1_{MA}$	Rejected	The average accuracy for MA questions differed significantly.
Single Answer	$H1_{SA}$	Failed to reject	The average accuracy for SA questions did not differ significantly.

With these results, we concluded the mean accuracy for MA questions for model-based (2.479) and text-based (2.175) showed a statistically significant difference, $p=0.057 < \alpha=0.1$. Conversely, the mean accuracy for SA questions for model-based

(1.782) and text-based (1.738) was not significantly different statistically, $p=0.623 > \alpha=0.1$.

Next, we further investigated the MA questions to identify what contributed to the difference in accuracy between both groups. Figure 22 shows the total correct percentage for the MA questions by both groups. The first notable result was the model-based group (in green) performed at least 25 percent better for Questions 1, 3, and 4 than did the text-based group (in blue). This suggests the strength of the model-based approach to represent specifications that entail more than one system characteristic. The expected responses for Questions 1, 3, and 4 (listed subsequently), were all clearly depicted in the model-based specifications. By contrast, subjects using the text-based specifications needed to review and correlate multiple requirement statements to formulate the expected response.

- Question 1: List the physical components of the tactical sling.
- Question 3: List the tactical sling's functions that require interactions between the warfighter, weapon, and tactical sling.
- Question 4: List and describe the ways to detach the weapon.

Note that for every question in Section 1, the subjects had to (1) answer the question, which is labeled as SQ001 in Figure 22; and (2) provide the supporting information they used to derive the solution, which is labeled as SQ002.

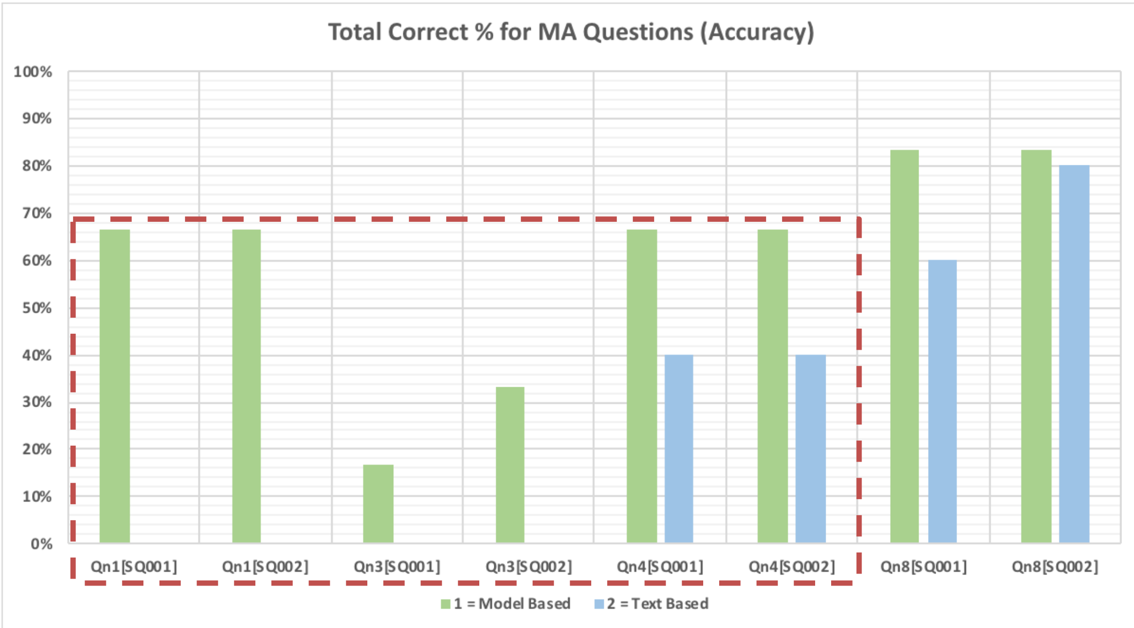


Figure 22. Total Correct Percentage for MA Questions

Figure 23 shows the total correct percentage for the SA questions by both groups. We discovered that both groups performed relatively the same for Questions 2, 5, 6, 7, and 10, each of which had only one possible correct answer. Therefore, we failed to reject the hypothesis ($H1_{SA}$). This implied that simple-to-comprehend specifications can be represented by both the model and the text form.

Next, we studied the global results and identified that there were two questions (i.e., Questions 3 and 10) for which both groups did not achieve more than 35 percent total correct. See Figure 24 for the global results. For the individual subject's accuracy of answers, refer to Appendix F

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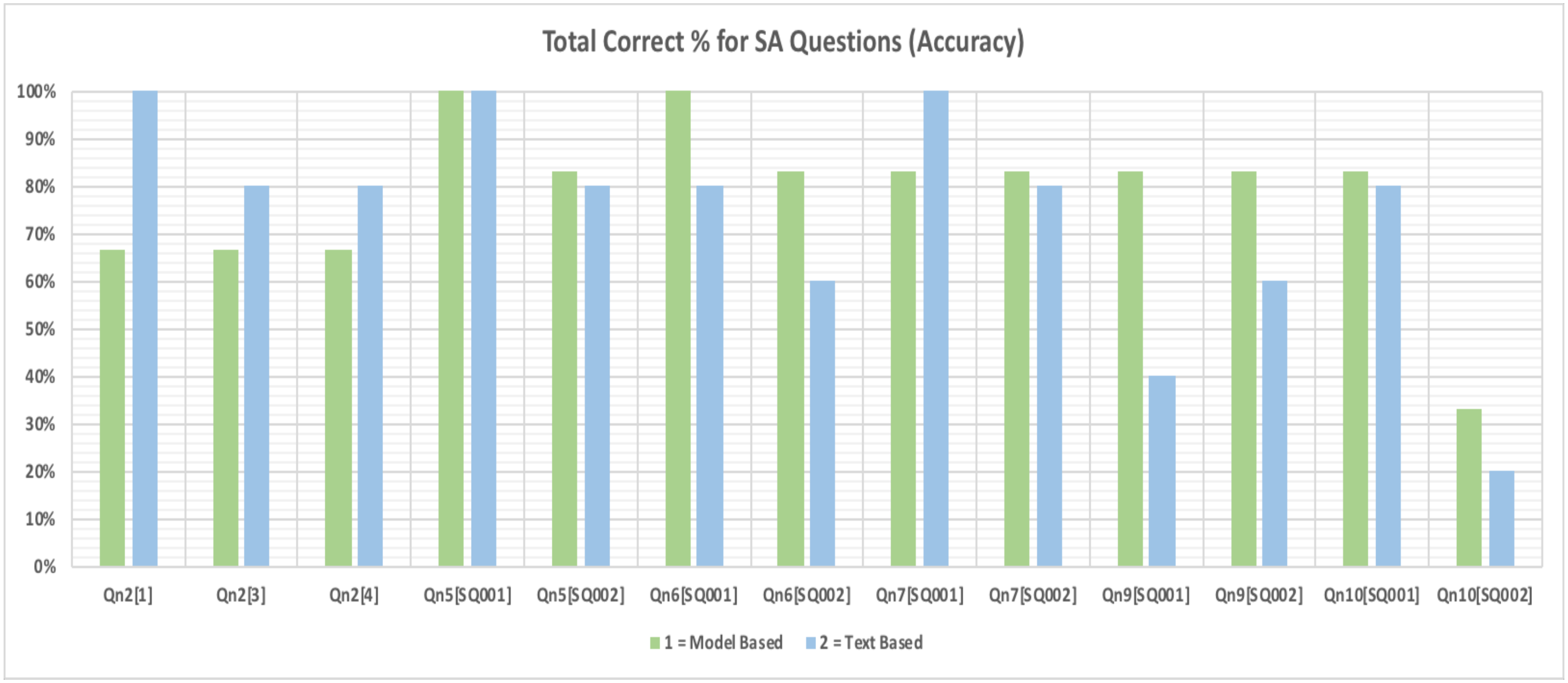

Figure 23. Total Correct Percentage for SA Questions

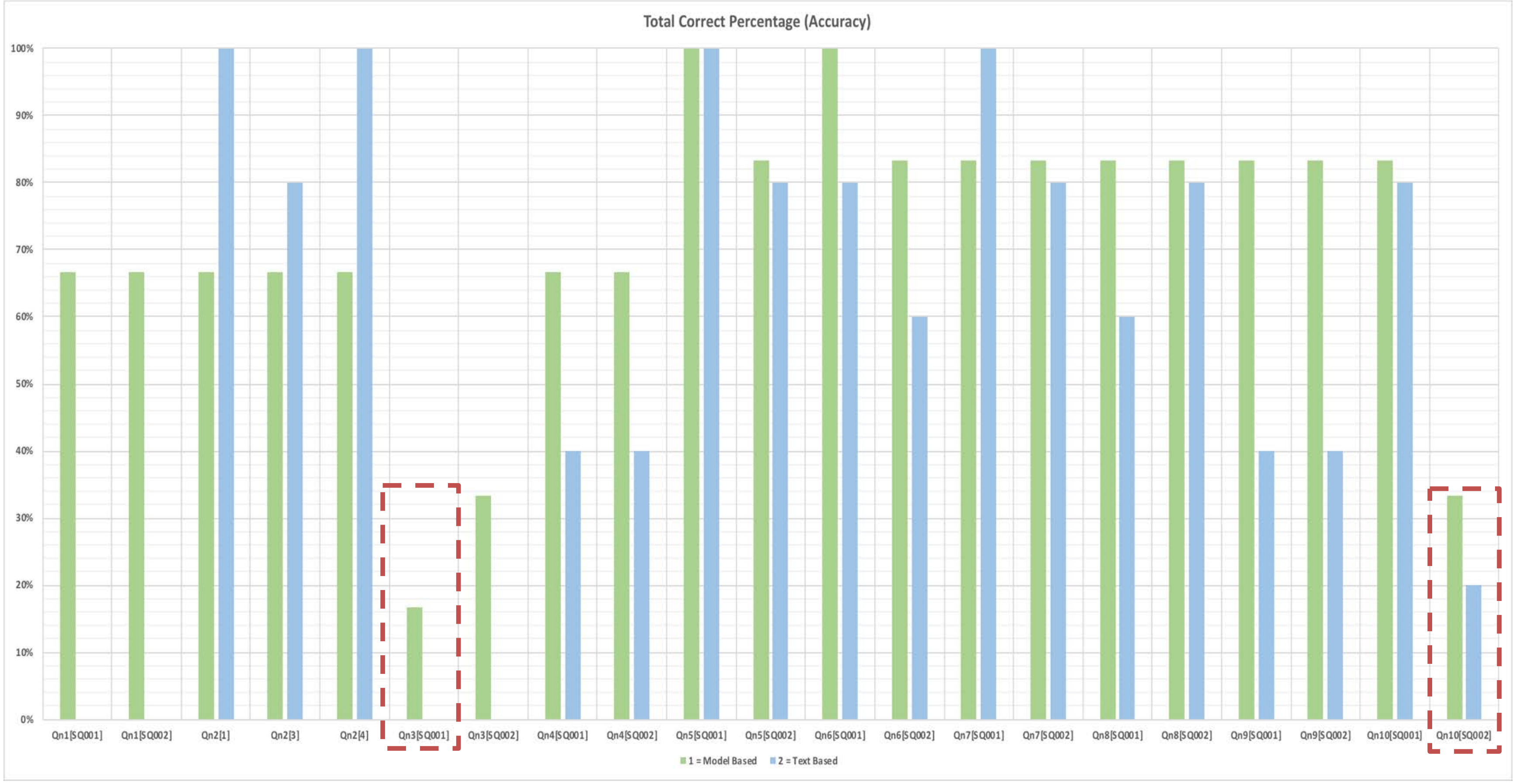

Figure 24. Global Results for Section 1

The results highlighted the inability of both groups to answer Questions 3 (Qn3[SQ001]) and 10 (Qn10[SQ002]) effectively. Question 3 [SQ001] posed the most challenge, as it requires seven distinct answers from the subjects; zero text-based and one model-based subject got "correct." The remaining ten subjects fell into the "partial correct" category, as shown in Figure 25. This was because subjects were expected to integrate information from multiple requirements statements (i.e., 3.11, 3.1.2, 3.1.3, 3.1.4, 3.23, 3.2.5, and 3.2.6/3.3.1). This suggests system requirements that are related to one another should not be dispersed to multiple locations in the performance specifications.

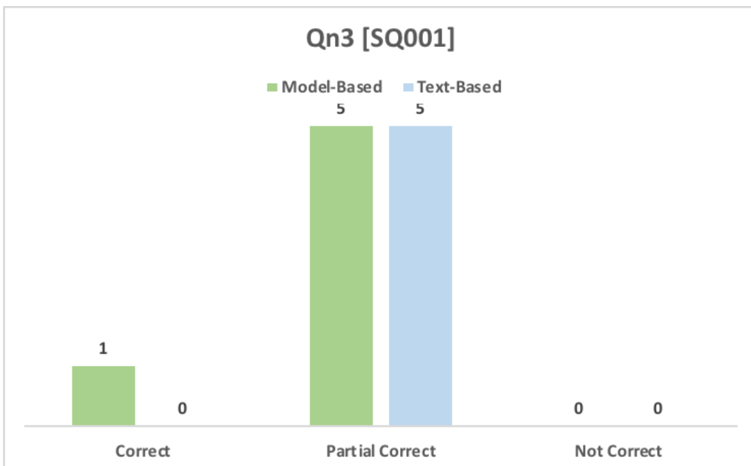

Figure 25. Number of Subjects in Each Category (Qn 3[SQ001])

For Question 10 (Qn10[SQ002]) (Do you foresee the tactical sling posing any risk while crossing water obstacles?), two model-based subjects and one text-based subject got "correct"; the remaining eight subjects got "not correct," as shown in Figure 26. This was because the subjects were expected to infer from either the 3.2.3: Quick Release Capability or the 3.2.4: Non-interference requirements that the tactical sling will not pose any risk while crossing water obstacles. The task of crossing water obstacles was not mentioned in the tactical sling specifications. Therefore, system requirements should not be represented in a way whereby subjects need to make inferences from other requirement statements.

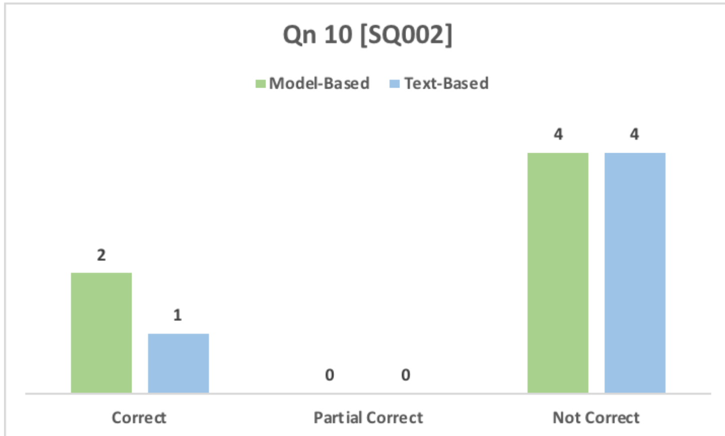

Figure 26. Number of Subjects in Each Category (Qn 10[SQ002])

Next, we investigated the demographics and identified subjects (highlighted in yellow) who achieved at least 75 percent of the answers correct for Section 1. See Figure 27. The findings were as such:

- Five out of six of them were assigned to the model-based condition.
- All of them have at least one year experience of systems engineering.
- All of them have a Bachelor Degree in one of these three programs: (1) Electrical Engineering, (2) Mechanical Engineering, or (3) Industrial Engineering.

ID	Condition 1 = Model Based 2 = Text Based	Qn 16	Qn17 (SE)	Overall Correct
14	1	BS in Control Systems Engineering	1	14%
12	1	BEng in Electrical Engineering	1	76%
21	1	B.S. Industrial Engineering	30	100%
36	1	BS in mechanical eng MS in system eng (student)	1	86%
37	1	Bachelors in Mechanical Engineering.	1	76%
44	1	BEng (Hons) - EEE MSc - ISE	4	76%
46	2	Degree in Electrical Engineering (EEE)	1	81%
9	2	BS in Civil Engineeing	1	52%
20	2	BS computer engineering	13	33%
32	2	BS Electrical and Computer Engineering	0	62%
42	2	BS in Aerospace Engineering	5	57%

Figure 27. Demographics of Subjects with at Least 75 Percent of Answers Correct.

b. H2: The Average Time Taken to Answer Section 1 Correctly is the Same for the Model-based and Text-based Groups

To achieve a more accurate interpretation of the subjects' comprehension, we chose only the time taken by individual subjects who answered Section 1 questions (i.e., Q1 to Q10) correctly. Recall from Figure 22, the text-based group had zero subjects who answered Questions 1 and 3 correctly. Therefore, the time taken to answer Questions 1 and 3 was omitted in the conduct of the two-sample t-tests to reject the null hypothesis H2.

Figure 28 shows that we failed to reject $H2_{MA}$ ($p=0.647 > \alpha=0.1$), which indicated the average time taken to answer MA questions did not differ significantly. Conversely, Figure 29 illustrates that we failed to reject $H2_{SA}$ ($p=0.159 > \alpha=0.1$), which showed that the average time taken to answer the SA questions did not differ significantly. Table 6 summarizes the hypothesis test results and outcomes for H2.

Two-Sample T-Test and CI: (MA) Model-Based Time, (MA) Text-Based Time

```
Two-sample T for (MA) Model-Based Time vs (MA) Text-Based Time

                       N  Mean  StDev  SE Mean
(MA) Model-Based Time  2  2.40   1.07     0.75
(MA) Text-Based Time   2  4.85   5.49      3.9


Difference = μ ((MA) Model-Based Time) - μ ((MA) Text-Based Time)
Estimate for difference:  -2.44
90% CI for difference:  (-27.40, 22.51)
T-Test of difference = 0 (vs ≠): T-Value = -0.62  P-Value = 0.647  DF = 1
```

Figure 28. Two-Sample t-Test for MA Questions ($H2_{MA}$)

Two-Sample T-Test and CI: (SA) Model-Based Time, (SA) Text-Based Time

```
Two-sample T for (SA) Model-Based Time vs (SA) Text-Based Time

                       N   Mean  StDev  SE Mean
(SA) Model-Based Time  6   1.60   1.63     0.66
(SA) Text-Based Time   6  0.484  0.261     0.11


Difference = μ ((SA) Model-Based Time) - μ ((SA) Text-Based Time)
Estimate for difference:  1.113
90% CI for difference:  (-0.244, 2.469)
T-Test of difference = 0 (vs ≠): T-Value = 1.65  P-Value = 0.159  DF = 5
```

Figure 29. Two Sample t-Test for SA Questions ($H2_{SA}$)

Table 6. Hypothesis Test Results and Outcomes for H2

Question Type	Hypothesis	Hypothesis Test	Outcome
Multiple Answers	$H2_{MA}$	Failed to reject	The average time taken for MA questions did not differ significantly.
Single Answer	$H2_{SA}$	Failed to reject	The average time taken for SA questions did not differ significantly.

With these results, we concluded the mean time taken for MA questions for model-based (2.4) and text-based (4.85) groups was not significantly different statistically, $p=0.647 > \alpha=0.1$). Conversely, the mean time taken for SA questions for the model-based (1.6) and text-based (0.484) groups was not significantly different statistically, $p=0.159 > \alpha=0.1$).

Next, we studied the time taken to answer each Section 1 question correctly. See Figure 30 for global time taken. After omitting Questions 1 and 3, we found that the time taken between both groups was relatively similar for Questions 2, 4, 5, 6, 7, and 9. Figure 31 shows that the spike in Question 8 was caused by one subject (subject ID:42). This suggests either the question was difficult to comprehend, or the subject was distracted by other activities while working on the question. From a broader perspective, this incident highlights the limitation of this experiment; the inability to verify whether the longer time taken could be attributed to the question itself or to some type of distraction.

Finally, we found that only two model-based and one text-based subjects answered Question 10 correctly. Subjects were expected to draw inferences about the system capability (i.e., crossing a water obstacle) based on the tactical sling specifications provided. The time taken for the model-based and text-based groups was 4.88 and 0.31 minutes, respectively. We discovered, however, that the time taken for the text-based group was attributed to only one subject (subject ID:46). Therefore, we recommend future work to monitor this finding to conclude in a purposeful way.

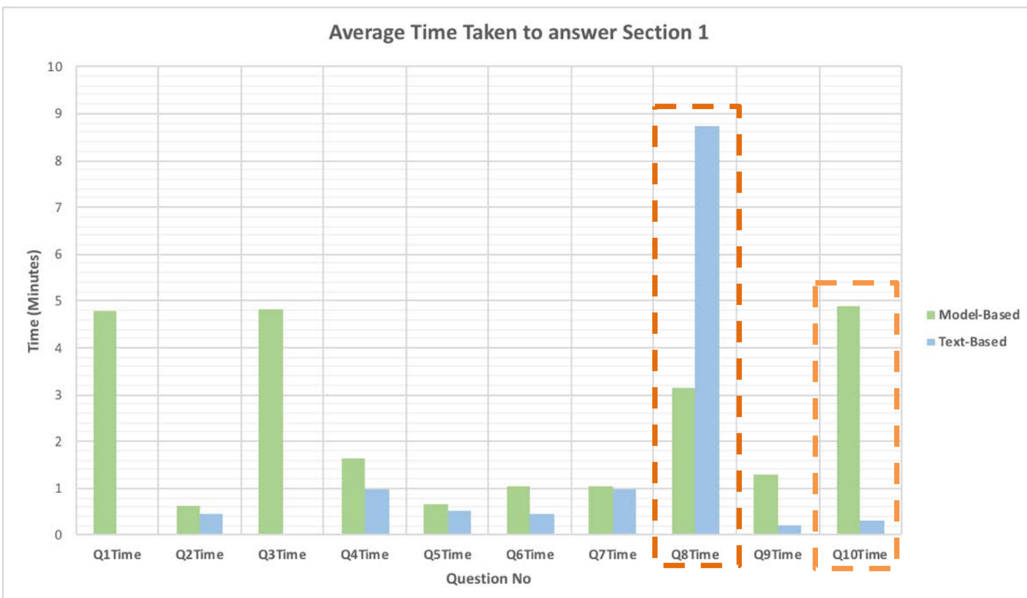

Figure 30. Summary of Average Time Taken for Each Question in Section 1

ID	Condition 1 = Model Based 2 = Text Based	Qn 8 Time (Minutes)
9	2	5.3
12	1	1.2
14	1	0.9
20	2	0.7
21	1	2.9
32	2	0.6
36	1	1.6
37	1	3.2
42	2	19.9
44	1	7.0
46	2	1.0

Figure 31. Time Taken for Question 8

c. *H3: The Usefulness of the Performance Specifications is the Same for Model-based and Text-based Groups*

To examine this hypothesis, we examined the subjects' responses from Questions 11, 13, and 14. Using these data, we conducted the Mann-Whitney test for each question to reject the null hypothesis H3, which is a suitable test to explore ordinal results (i.e., likert scale). Figure 32 shows that we failed to reject $H2_{11}$ ($p=1 > \alpha=0.1$) and $H2_{13}$ ($p=0.3443 > \alpha=0.1$). We omitted the results from Question 14 as Minitab could not perform the analysis as all the responses from the model-based group were identical. Table 7 illustrates the statistical outcomes for each question. See Appendix G for the summary of Questions 11, 13, and 14.

Mann-Whitney Test and CI: Q11: Model-Based, Q11: Text-Based

```
                  N  Median
Q11: Model-Based  6   3.000
Q11: Text-Based   5   3.000


Point estimate for η1 - η2 is -0.000
96.4 Percent CI for η1 - η2 is (-2.000,2.000)
W = 35.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 1.0000
The test is significant at 1.0000 (adjusted for ties)
```

Mann-Whitney Test and CI: Q13: Model-Based, Q13: Text-Based

```
                  N  Median
Q13: Model-Based  6   2.000
Q13: Text-Based   5   3.000


Point estimate for η1 - η2 is -1.000
96.4 Percent CI for η1 - η2 is (-3.001,0.999)
W = 30.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.3613
The test is significant at 0.3443 (adjusted for ties)
```

Figure 32. Mann-Whitney Tests for Q11 and Q13

Table 7. Hypothesis Test Results and Outcomes for H3

Question No.	Hypothesis	Hypothesis Test	Outcome
11	$H3_{11}$	Failed to reject	The number of times the subjects refer to the performance specification did not differ significantly.
13	$H3_{13}$	Failed to reject	The level of finding information in the performance specification did not differ significantly.
14	$H3_{14}$	Omitted	The number of times the subjects refer to the FM3-22 document did not differ significantly.

Using these results, we concluded the median usefulness for Question 11 for the model-based (i.e., 3) and the text-based (i.e., 3) specifications was not significantly different statistically, $p=1 > \alpha=0.1$. Additionally, the median usefulness for Question 13 for the model-based (i.e., 2) and the text-based (i.e., 3) specifications was not significantly different statistically, $p=0.3443 > \alpha=0.1$. Therefore, the usefulness of both the model-based and text-based specifications did not show any statistically significant difference.

Next, we investigated the demographics and identified subjects who referred to the performance specification more than ten times (highlighted in green for model-based and blue for text-based specifications). It was assumed that the more useful the specification, the greater the number of times the subjects will refer to it. See Figure 35. The findings were as follows:

- An equal number of subjects from both groups (i.e., model-based: 4; text-based: 4) referred to the specification more than ten times.
- They achieved at least 50 percent correct answers (highlighted in yellow); five out of these eight subjects achieved at least 75 percent correct (highlighted in orange).

ID	Condition 1 = Model Based 2 = Text Based	Qn11[SQ001]	Overall Correct
12	1	A-2	76%
14	1	A-1	14%
21	1	A-4	100%
36	1	A-3	86%
37	1	A-4	76%
44	1	A-3	76%
9	2	A-5	52%
32	2	A-3	62%
42	2	A-3	57%
46	2	A-3	81%
20	2	A-1	33%

Figure 33. Demographics of Subjects who Referred to the Performance Specification More than Ten Times

d. *H4: The Usability of the Performance Specification is the Same for Model-based and Text-based Groups*

We examined H4 using the subjects’ response from Question 12. Figure 34 shows that we failed to reject ($p=0.3478 > \alpha=0.1$), which indicated the usability of the performance specification did not differ significantly. See Appendix H for the summary for Question 12. Table 8 summarizes the hypothesis test results and outcomes for H4.

Mann-Whitney Test and CI: Q12: Model-Based, Q12: Text-Based

```
                   N  Median
Q12: Model-Based   6   2.500
Q12: Text-Based    5   3.000


Point estimate for η1 - η2 is -1.000
96.4 Percent CI for η1 - η2 is (-3.999,1.000)
W = 30.5
Test of η1 = η2 vs η1 ≠ η2 is significant at 0.3613
The test is significant at 0.3478 (adjusted for ties)
```

Figure 34. Mann-Whitney Test for H4

Table 8. Hypothesis Test Result and Outcome for H4

Question No.	Hypothesis	Hypothesis Test	Outcome
12	H4	Failed to reject	The usability of the performance specification for both model-based and text-based groups did not differ significantly.

To sum up, we concluded the median usability for Question 12 for the model-based (i.e., 2.5) and text-based (i.e., 3) groups was not significantly different statistically, $p=0.3478 > \alpha=0.1$.

Next, we investigated the demographics and found that all model-based subjects (highlighted in green) found it easy to find information in the performance specification. See Figure 35.

ID	Condition 1 = Model Based 2 = Text Based	Qn 12
12	1	Somewhat Easy (3)
14	1	Neither (4)
21	1	Very Easy (1)
36	1	Easy (2)
37	1	Somewhat Easy (3)
44	1	Easy (2)
9	2	Hard (6)
42	2	Somewhat Hard (5)
20	2	Very Easy (1)
32	2	Somewhat Easy (3)
46	2	Somewhat Easy (3)

Figure 35. Demographics of Subjects who Rated it Easy to Find Information in the Specification

3. Summary of Results

In summary, the experiment goal was achieved. Through the evaluation of H1, we were able to: (1) measure the subjects' comprehension of the individual questions; (2) compare the mean values between both groups; and (3) conclude the average accuracy for MA questions differs significantly. In other words, the models were more effective for MA questions. Next, the results showed that both types of specifications were similarly efficient (H2), useful (H3), and usable (H4). Table 9 summarizes the outcomes for the experiment hypotheses and additional insights gained.

Table 9. Experiment Summary

<table>
<tr><th>Hypothesis</th><th>Outcome</th><th>Model-Based</th><th>Text-Based</th><th>Additional Insights Gained</th></tr>
<tr><td rowspan="2">H1: The average accuracy of answers for Section 1 questions is the same for the model-based and the text-based groups.</td><td><u>MA Questions</u>
Reject</td><td>√</td><td>-</td><td rowspan="2">1. Model-based is to represent specification that entails more than one system characteristic.
2. Specifications that are simple to comprehend can be represented by both models and text form.
3. System specifications related to one another should not be dispersed into multiple different locations in the performance specifications.
4. System specifications should not be represented in a way whereby subjects need to draw inferences from other specifications.
5. The demographics of subjects who achieved at least 75 percent correct answers were as such:
• Five out of six of them were assigned to model-based condition.
• All of them have at least one year experience in systems engineering.
• All of them have a Bachelor’s degree in one of these programs: (1) Electrical Engineering; (2) Mechanical Engineering; or (3) Industrial Engineering.</td></tr>
<tr><td><u>SA Questions</u>
Failed to Reject</td><td colspan="2">Did not differ significantly</td></tr>
<tr><td rowspan="2">H2: The average time taken to answer Section 1 questions correctly is the same for the model-based and text-based groups.</td><td><u>MA Questions</u>
Failed to Reject</td><td colspan="2">Did not differ significantly</td><td rowspan="2">1. Results omission (i.e., time taken for Questions 1 and 3) can be conducted to achieve a fair comparison between the independent variables (i.e., model-based and text-based).
2. Experiment Limitation: The inability to verify whether the time taken could be attributed to the question itself or to distractions.</td></tr>
<tr><td><u>SA Questions</u>
Failed to Reject</td><td colspan="2">Did not differ significantly</td></tr>
<tr><td rowspan="2">H3: The usefulness of the performance specifications is the same for model-based and text-based groups.</td><td><u>Q11</u>
Failed to Reject</td><td colspan="2" rowspan="2">Did not differ significantly</td><td rowspan="2">1. Results omission (i.e., Q14 responses) can be conducted in the event that the statistical package is unable to perform the Mann-Whitney test due to identical responses in model-based group.
2. The demographics of subjects who refer more than ten times to the specifications were as such:
• An equal number of subjects from both groups (i.e., Model-based: 4; Text-based: 4) referred more than ten times.
• They achieved at least 50 percent correct answers; five out of these eight subjects achieved at least 75 percent correct.</td></tr>
<tr><td><u>Q13</u>
Failed to Reject</td></tr>
<tr><td>H4: The usability of the performance specifications is the same for model-based and text-based groups.</td><td>Failed to Reject</td><td colspan="2">Did not differ significantly</td><td>1. Based on the demographics, all model-based subjects find it easy to find information.</td></tr>
</table>

V. CONCLUSION AND RECOMMENDATION

A. CONCLUSION

Due to the low number of participants, the study could not definitively show whether systems engineers using models understand system requirements in the same way or differently from systems engineers using text-based versions. Nevertheless, it did substantiate that models were more effective for multiple-answer questions that corresponded to more complex requirements. The study suggests that systems engineers and stakeholders can comprehend complex system requirements better in an MBSE environment.

Our work clearly has some limitations. Specifically, insufficient data points hindered us from conducting inferential statistics to draw inferences about the population. Furthermore, the study was unable to verify whether the time taken to answer the questionnaire for H2 could be attributed to the question itself or to some type of distraction. Nevertheless, we believe our work could be a springboard to engage the SE community with these findings, educate them with the relevant knowledge to overcome possible pitfalls; and enhance their experiences during the transition to MBSE across the relevant areas.

B. RECOMMENDATION FOR FUTURE WORK

Several challenges arose during this study that can point to areas for future work. First, one could conduct a factor analysis to identify questions that are relevant to measure comprehension by analyzing their similarities and then group them together. Next, researchers could make a more deliberate effort to recruit at least 100 participants, which would achieve the statistical power per GPower 3.0. Lastly, one could construct a controlled environment in which to conduct the experiment to attain a more accurate assessment of the time taken to complete the questionnaire.

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APPENDIX A. MODEL-BASED SPECIFICATION

NAVAL

POSTGRADUATE

SCHOOL

MONTEREY, CALIFORNIA

PERFORMANCE SPECIFICATION

FOR TACTICAL SLING BELT

For Research Experiment Purpose Only

Prepared by

CHIA, YONG JIE

1

Figure 36. Model-Based Specification for Tactical Sling (1/8). Adapted from U.S. Army Armament Research, Development and Engineering Center (ARDEC) (2007).

1.0 SCOPE

1.1 Scope. This specification prescribes the performance requirements for the Tactical Sling. The Tactical Sling allows the Warfighter's weapon to remain in a ready position while conducting non-weapon firing-related tasks.

1.2 Requirement levels. This specification lists two values for certain performance parameters. The threshold (T) is the minimum acceptable level. The objective (O) is the desired level at which performance of the Tactical Sling results in an operationally significant increase in capabilities. When only one requirement is stated, it is the threshold requirement.

2.0 APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3 of this specification. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 of this specification, whether or not they are listed.

2.2 Government Document. The following specifications and standards form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitations or contract.

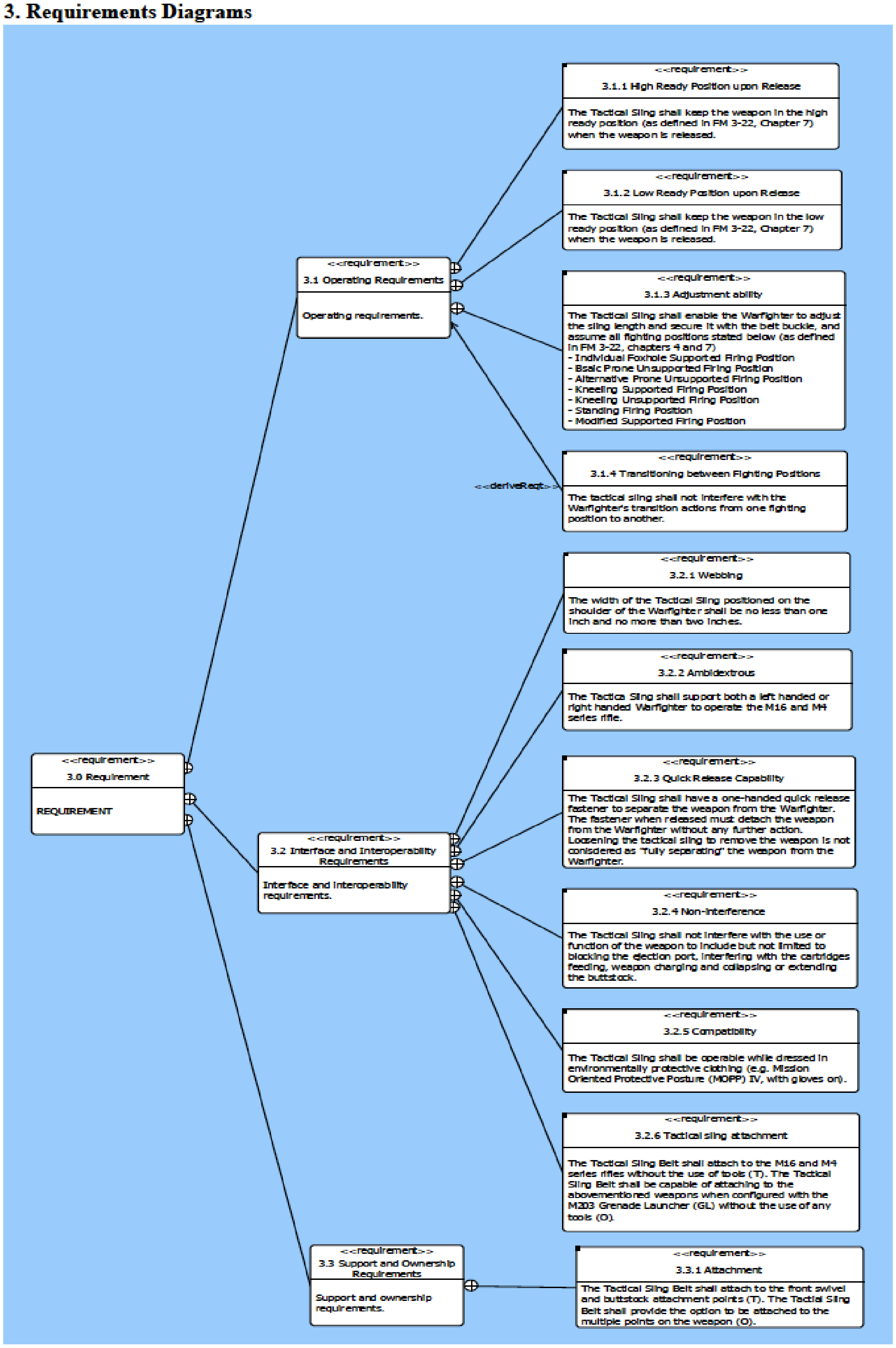
ARMY FIELD MANUAL

FM 3-22 Rifle marksmanship M16A1, M16A2/3, M16A4, and M4 Carbine

2

Figure 37. Model-Based Specification for Tactical Sling (2/8). Adapted from U.S. Army Armament Research, Development and Engineering Center (ARDEC) (2007).

3. Requirements Diagrams



3

Figure 38. Model-Based Specification for Tactical Sling (3/8). Adapted from U.S. Army Armament Research, Development and Engineering Center (ARDEC) (2007).

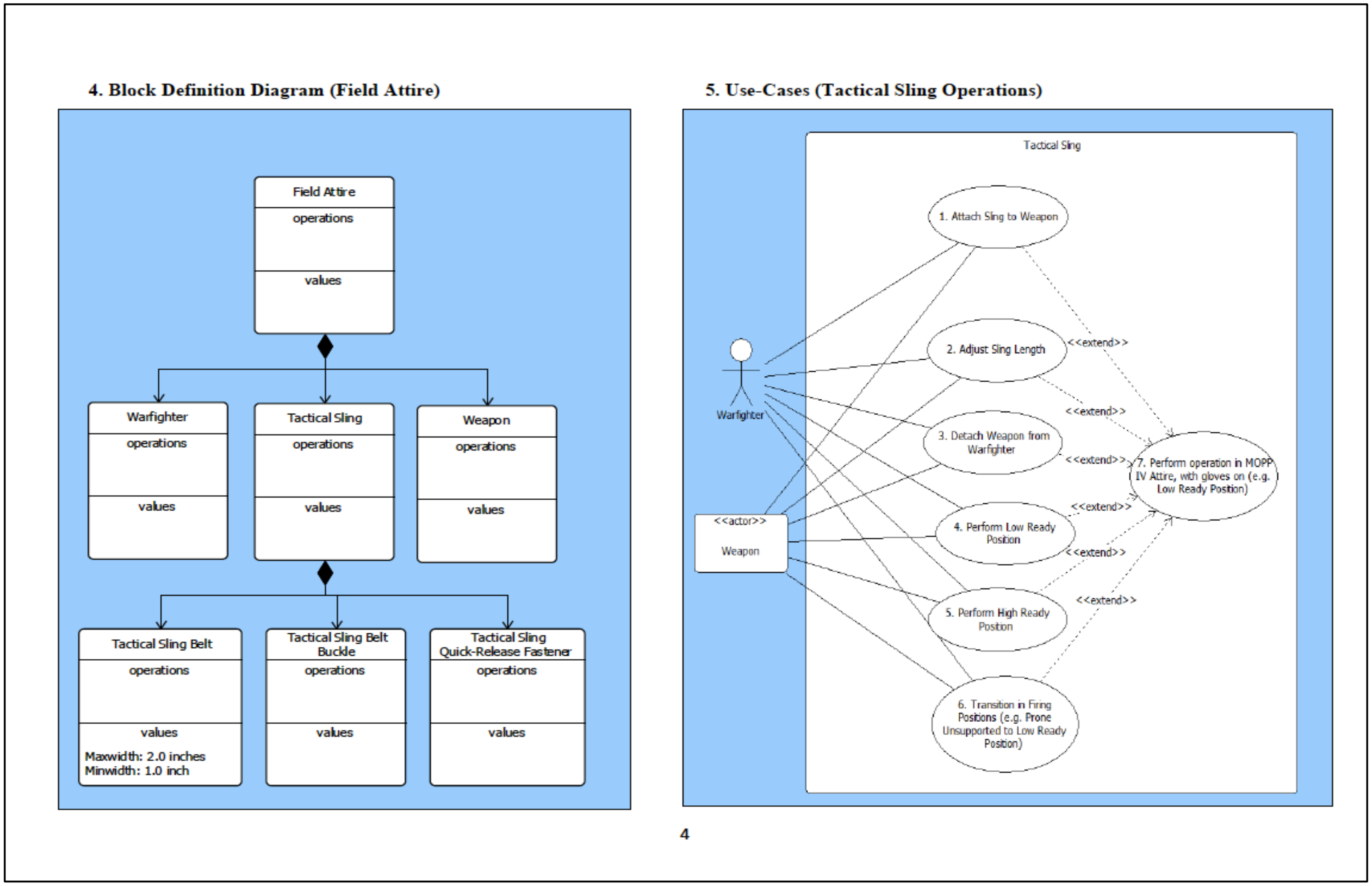


Figure 39. Model-Based Specification for Tactical Sling (4/8). Adapted from U.S. Army Armament Research, Development and Engineering Center (ARDEC) (2007).

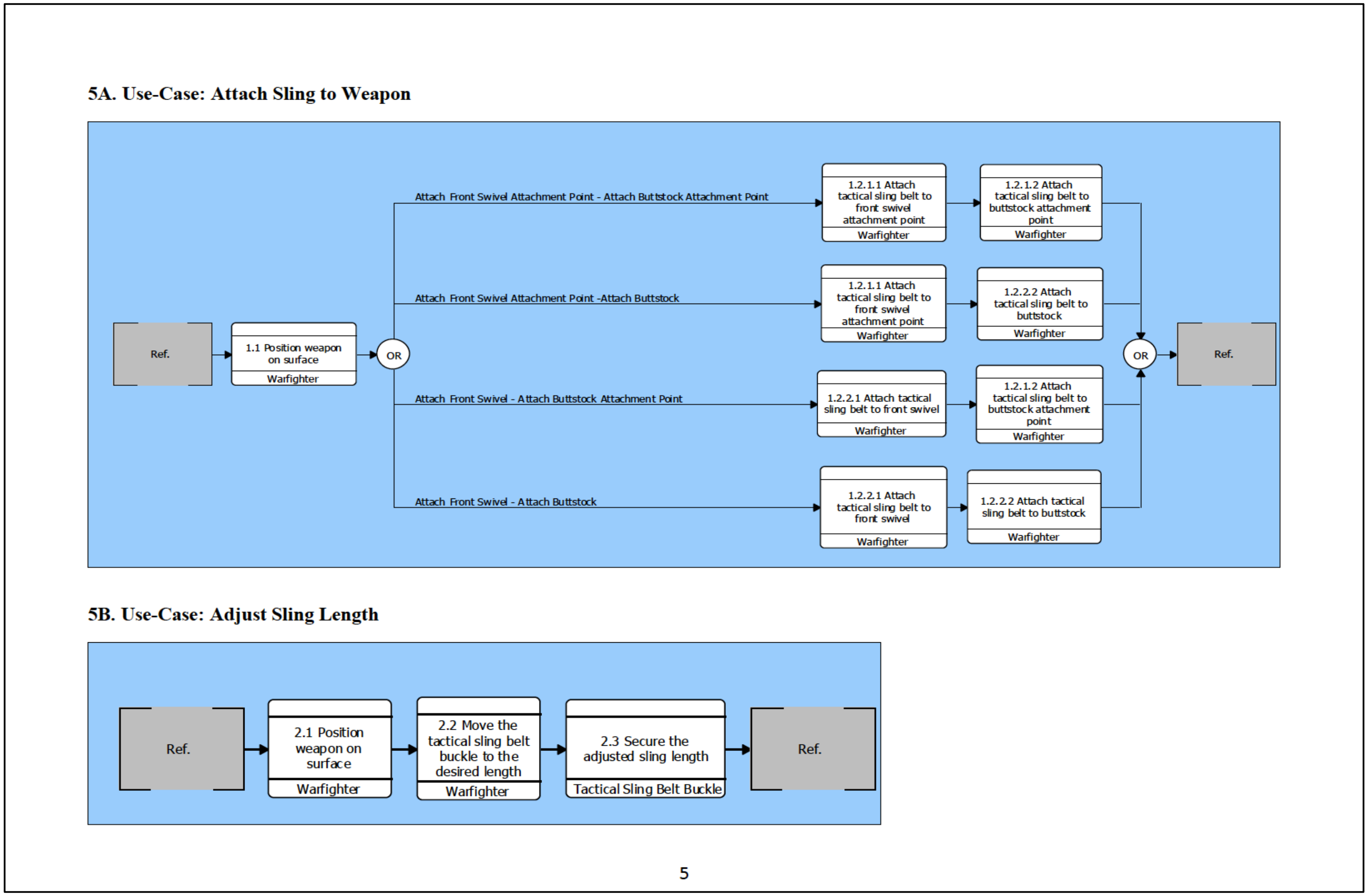


Figure 40. Model-Based Specification for Tactical Sling (5/8). Adapted from U.S. Army Armament Research, Development and Engineering Center (ARDEC) (2007).

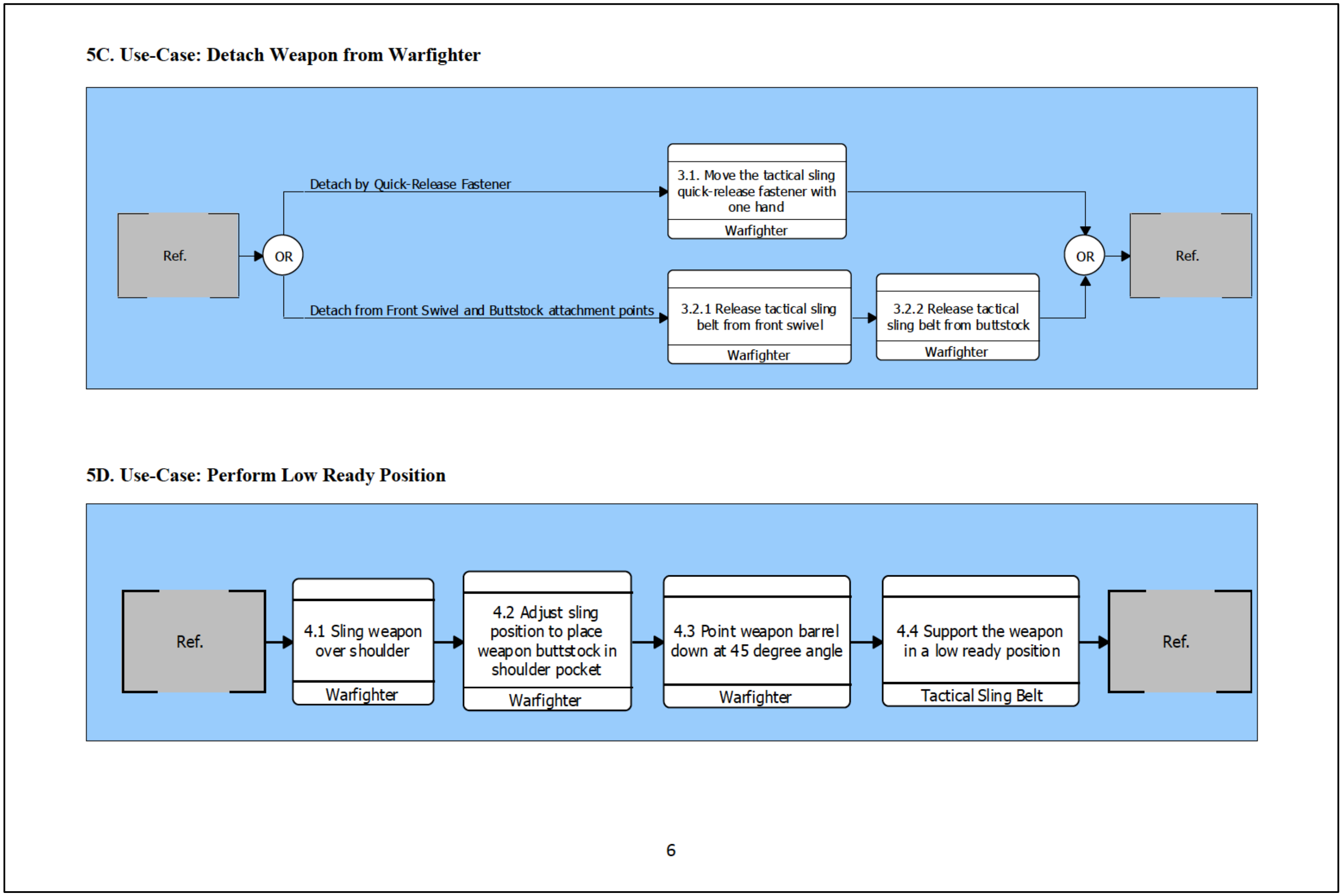


Figure 41. Model-Based Specification for Tactical Sling (6/8). Adapted from U.S. Army Armament Research, Development and Engineering Center (ARDEC) (2007).

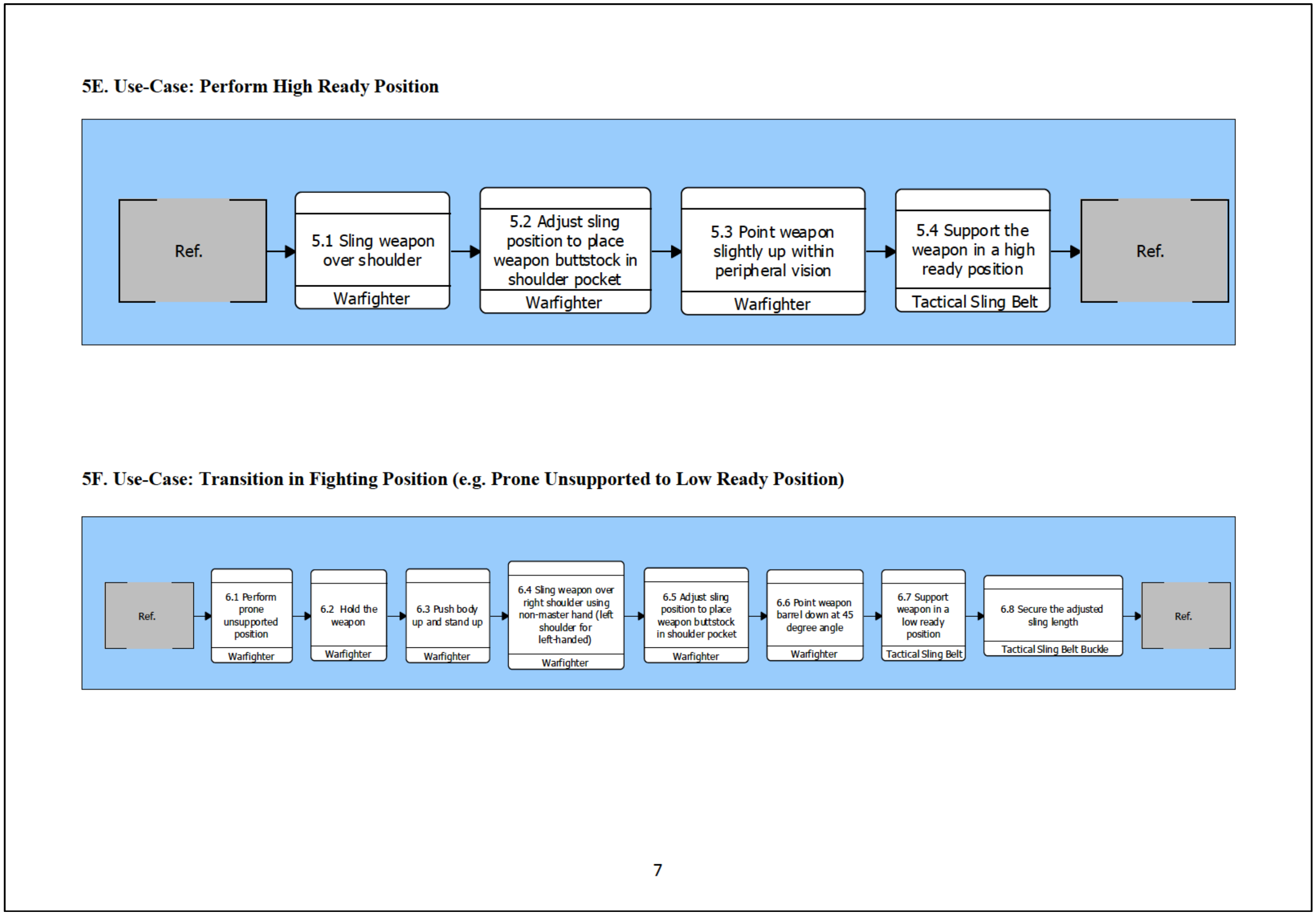
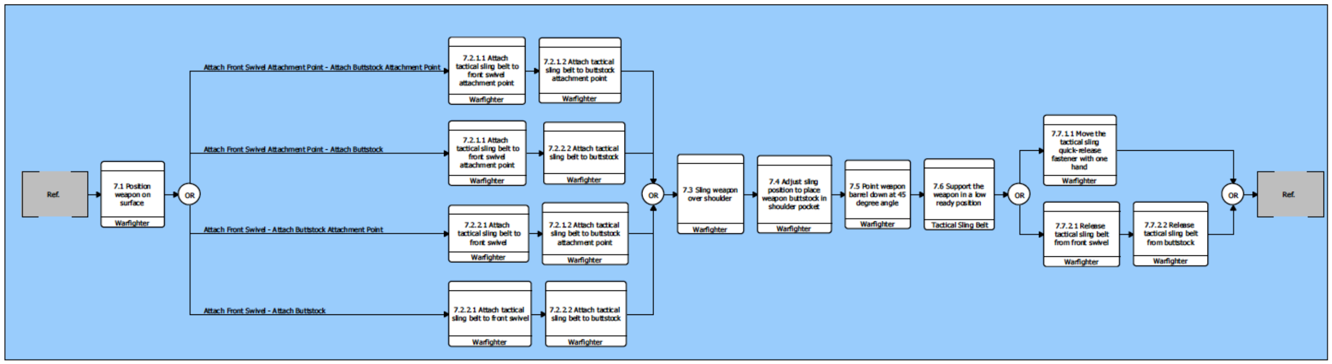


Figure 42. Model-Based Specification for Tactical Sling (7/8). Adapted from U.S. Army Armament Research, Development and Engineering Center (ARDEC) (2007).

5G. Use-Case: Perform Operation in MOPP IV attire, with gloves on (Low Ready Position)



8

Figure 43. Model-Based Specification for Tactical Sling (8/8). Adapted from U.S. Army Armament Research, Development and Engineering Center (ARDEC) (2007).

APPENDIX B. TEXT-BASED SPECIFICATION

NAVAL

POSTGRADUATE

SCHOOL

MONTEREY, CALIFORNIA

PERFORMANCE SPECIFICATION

FOR TACTICAL SLING

For Research Experiment Purposes Only

Prepared by

CHIA, YONG JIE

1

Figure 44. Text-Based Specification for Tactical Sling (1/3). Adapted from U.S. Army Armament Research, Development and Engineering Center (ARDEC) (2007).

1.0 SCOPE

1.1 Scope. This specification prescribes the performance requirements for the Tactical Sling. The Tactical Sling allows the Warfighter's weapon to remain in a ready position while conducting non-weapon firing-related tasks.

1.2 Requirement levels. This specification lists two values for certain performance parameters. The threshold (T) is the minimum acceptable level. The objective (O) is the desired level at which performance of the Tactical Sling results in an operationally significant increase in capabilities. When only one requirement is stated, it is the threshold requirement.

2.0 APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3 of this specification. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents cited in sections 3 of this specification, whether or not they are listed.

2.2 Government Document. The following specifications and standards form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitations or contract.

ARMY FIELD MANUAL

FM 3-22 Rifle marksmanship M16A1, M16A2/3, M16A4, and M4 Carbine

3.0 REQUIREMENT

3.1 Operating Requirements.

3.1.1 High Ready Position upon Release. The Tactical Sling shall keep the weapon in the high ready position (as defined in FM 3-22, Chapter 7) when the weapon is released.

3.1.2 Low Ready Position upon Release. The Tactical Sling shall keep the weapon in the low ready position (as defined in FM 3-22, Chapter 7) when the weapon is released.

3.1.3 Adjustment Ability. The Tactical Sling shall enable the Warfighter to adjust the sling length and secure it with the belt buckle, and assume all fighting positions stated below (as defined in FM 3-22, chapters 4 and 7).

- Individual Foxhole Supported Firing Position
- Basic Prone Unsupported Firing Position
- Alternative Prone Unsupported Firing Position
- Kneeling Supported Firing Position
- Kneeling Unsupported Firing Position
- Standing Firing Position
- Modified Supported Firing Position

3.1.4 Transitioning between Fighting Positions. The Tactical Sling shall not interfere with the Warfighter's transition actions from one fighting position to another.

2

Figure 45. Text-Based Specification for Tactical Sling (2/3). Adapted from U.S. Army Armament Research, Development and Engineering Center (ARDEC) (2007).

3.2 Interface and Interoperability Requirements.

3.2.1 Webbing. The width of the Tactical Sling positioned on the shoulder of the Warfighter shall be no less than one inch and no more than two inches.

3.2.2 Ambidextrous. The Tactical Sling shall support both a left handed or right-handed Warfighter to operate the M16 and M4 series rifle.

3.2.3 Quick Release Capability. The Tactical Sling shall have a one-handed quick release fastener to separate the weapon from the Warfighter. The fastener when released must detach the weapon from the Warfighter without any further action. Loosening the tactical sling to remove the weapon is not considered as “fully separating” the weapon from the Warfighter.

3.2.4 Non-interference. The Tactical Sling shall not interfere with the use or function of the weapon to include but not limited to blocking the ejection port, interfering with the cartridges feeding, weapon charging and collapsing or extending the buttstock.

3.2.5 Compatibility. The Tactical Sling shall be operable while dressed in environmentally protective clothing (e.g. Mission Oriented Protective Posture (MOPP) IV, with gloves on).

3.2.6 Tactical sling attachment. The Tactical Sling Belt shall attach to the M16 and M4 series rifle without the use of tools (T). The Tactical Sling Belt shall be capable of attaching to the abovementioned weapons when configured with the M203 Grenade Launcher (GL) without the use of any tools (O).

3.3 Support and ownership requirements.

3.3.1 Attachment. The Tactical Sling Belt shall attach to the front swivel and buttstock attachment points (T). The Tactical Sling Belt shall provide the option to be attached to multiple points on the weapon (O).

3

Figure 46. Text-Based Specification for Tactical Sling (3/3). Adapted from U.S. Army Armament Research, Development and Engineering Center (ARDEC) (2007).

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APPENDIX C. QUESTIONNAIRE

INTRODUCTION. You are invited to participate in a research study entitled "Requirement understanding for defense acquisition." The purpose of the research is to compare participant's understanding of system requirements based on whether they are presented model-based or text- based descriptions (Naval Postgraduate School 2018).

PROCEDURES.

-For this survey, you will be randomly assigned to either the model-based or text-based condition.
- You will be asked to open and read through the provided reference materials about the system and its requirements.
- After reviewing the reference materials, you will be asked to answer a series of questions about the system requirements. You will also be asked to provide some demographic information.
- This survey is expected to take thirty minutes to an hour to complete.
- Approximately 400 subjects will be invited to participate in this study.
- Survey participants will not be compensated.

LOCATION. The survey will take place online.

VOLUNTARY NATURE OF THE STUDY. Your participation in this study is strictly voluntary. If you choose to participate you can change your mind at any time and withdraw from the study. You will not be penalized in any way or lose any benefits to which you would otherwise be entitled if you choose not to participate in this study or to withdraw.

POTENTIAL RISKS AND DISCOMFORTS. The potential risk of participating in this study is a minor risk of breach of confidentiality. This risk is addressed under the "Confidentiality & Privacy Act" section.

ANTICIPATED BENEFITS. Anticipated benefit from this study is to determine whether replacing traditional documentation of system requirements will have an effect on a program's ability to specify, document, understand, and communicate system requirements. You will not directly benefit from your participation in this research.

CONFIDENTIALITY & PRIVACY ACT. Any information that is obtained during this study will be kept confidential to the full extent permitted by law. All efforts, within reason, will be made to keep your personal information in your research record confidential but total confidentiality cannot be guaranteed. To increase the confidentiality of the survey responses, all surveys will be anonymous. No one on the survey team will be able to determine the identity of any individual participant. All data will be stored on secure, password protected DoD servers or computers. The data collected will be used for the purpose of this study only and will only be accessible to the student, the Principal and Co-Investigators identified for this study.

POINTS OF CONTACT. If you have any questions or comments about the research, or you experience an injury or have questions about any discomforts that you experience while taking part in this study please contact me at ychia@nps.edu or the Co-Investigator, Dr. Mollie McGuire, 831–656-2995, mrmcguir@nps.edu. Questions about your rights as a research subject or any other concerns may be addressed to the Navy Postgraduate School IRB Chair, Dr. Larry Shattuck, 831-656-2473, lgshattu@nps.edu.

STATEMENT OF CONSENT. I have read the information provided above. I have been given the opportunity to ask questions and all the questions have been answered to my satisfaction. I understand that all results will be aggregated and I will not be identified in any results reported or presented. I understand that by agreeing to participate in this research I do not waive any of my legal rights.

Yes ☐ No ☐

Thank you for taking time to participate in this survey to assess requirement understanding for defense acquisition.

Before beginning the survey, please take 15 minutes to read the reference material:

1. Tactical Sling Performance Specifications
2. Rifle Marksmanship M16/M4 Series Weapons

You can refer to the reference material when needed throughout the survey.

Once you are ready, you can start the survey.

Click Next to begin!

NEXT

1. List the physical components of the tactical sling. Include the requirement # or any other information you used to derive the solution. (e.g., 3.8.1)

Physical Components	
Requirement # and any other information you used	

2. What is the minimum and maximum width of the tactical sling belt? Include the requirement # or any other information you used to derive the solution. (e.g., 3.8.1)

Minimum width (inches)	
Maximum width (inches)	
Requirement # and any other information you used	

3. List the tactical sling's functions that require interactions between the warfighter, weapon, and tactical sling. Include the requirement # or any other information you used to derive the solution. (e.g., 3.8.1)

Tactical Sling's Function	
Requirement # and any other information you used	

4. List and describe the ways to detach the weapon. Include the requirement # or any other information you used to derive the solution. (e.g., 3.8.1)

Ways to detach the weapon	
Requirement # and any other information you used	

5. Does the tactical sling allow both a left handed and right handed warfighter to operate the M16 and M4 series rifle? Include the requirement # or any other information you used to derive the solution. (e.g., 3.8.1)

Yes/ No	
Requirement # and any other information you used	

6. Does the tactical sling support operations while wearing Mission Oriented Protective Posture (MOPP) IV gear? Include the requirement # or any other information you used to derive the solution. (e.g., 3.8.1)

Yes/ No	
Requirement # and any other information you used	

7. Does the warfighter require a tool to attach the tactical sling onto the weapon? Include the requirement # or any other information you used to derive the solution. (e.g., 3.8.1)

Yes/ No	
Requirement # and any other information you used	

8. List and describe the different ways to attach the tactical sling to the weapon. Include the requirement # and any other information you used to derive the solution (e.g., 3.8.1)

M16 Weapon

M4 Weapon with Grenade Launcher and Accessories

Ways to attach tactical sling	
Requirement # and any other information you used	

9. Do you foresee the tactical sling causing any interference when used? If yes, explain below. Include the requirement # or any other information you used to derive the solution. (e.g., 3.8.1)

Yes/No	
Requirement # and any other information you used	

10. Do you foresee the tactical sling posing any risk while crossing water obstacles? If yes, explain below. Include the requirement # or any other information you used to derive the solution. (e.g., 3.8.1)

Yes/No	
Requirement # and any other information you used	

Section 2: Reference materials and demographics

The following section contains questions about the reference material you just used, and requests some demographic information. The data you shared with us will not be used to personally identify you

11. How many times did you refer to the performance specification document?

0 to 5	6 to 10	11 to 15	16 to 20	More than 20
*	*	*	*	*

12. Was it easy to find the information in the performance specification document to help you answer the questions?

Very Easy (1)	Easy (2)	Somewhat Easy (3)	Neither (4)	Somewhat Hard (5)	Hard (6)	Very Hard (7)
*	*	*	*	*	*	*

13. Overall, how easy was it to understand the information in the performance specification document?

Very Easy (1)	Easy (2)	Somewhat Easy (3)	Neither (4)	Somewhat Hard (5)	Hard (6)	Very Hard (7)
*	*	*	*	*	*	*

14. How many times did you refer to the FM 3–22 document?

0 to 5	6 to 10	11 to 15	16 to 20	More than 20
*	*	*	*	*

15. Did you use any other sources besides the references provided in this survey? (If yes, please list them below. Otherwise indicate “Not Applicable” below). Rest assured, you will not be penalized if you used other sources.

16. List all education degrees you have: (e.g., BS in aerospace engineering)

17. How many years of systems engineering experience do you have?

18. How many years of modeling or model-based system engineering (MBSE) experience do you have?

19. Rate your level of experience with either the M16 and/or M4 series rifle?

None	**Very Little**	**Little**	**Moderate**	**Experience**	**Extensive**
*	*	*	*	*	*

20. Have you ever used a tactical sling when shooting a rifle?
Yes ☐ No ☐

21. Any other comments?

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APPENDIX D. INITIAL REVIEW PACKAGE

The initial review package encompasses the completion of the following documents:

a. Initial Review Application

The initial review application serves as the master checklist for the initial review package. Comprehensive details such as the (1) Protocol Basics; (2) Research Summary; (3) Subject Population & Recruitment; (4) Risk & Benefits; (5) Data Security & Monitoring; (6) Consent Procedure need to be provided.

b. Scientific Review Form

As part of U.S. Navy regulations, an independent review of research for scientific merit is required prior to IRB review. The scientific reviewer must meet the Collaborative Institutional Training Initiative (CITI) Ethics training requirements to be eligible.

c. Conflict of Interest Disclosure Form

The purpose is to identify and evaluate potential conflicts of interest in research that may affect the rights and welfare of human subjects. The principal investigator will identify each person involved with the project who qualifies as an "investigator" and insure each investigator had been advised of the conflict of interest disclosure policy.

d. Consent Form

The consent form is to obtain approval from the subjects to participate in this research. First, an overview of what the subjects will experience and perform for the research is presented. Then, provide assurance to the subjects on how the information will be kept confidential. Finally, the point of contact for any questions on the research will be provided.

e. Collaborative Institutional Training Initiative

The course is to ensure the research community understands the regulations of the "Federal Policy for the Protection of Human Subjects." Every member of the research team is to complete the CITI Program and score a minimum 8 for a total of 12 required, elective, and supplemental modules.

f. Recruitment Script

The recruitment script will be used to recruit the participants via the NPS email platform. A summarized version of what the subjects will experience and perform for the research will be illustrated. Subsequently, the link to the online survey will be provided.

g. Questionnaire

The questionnaire is to allow IRB to review the type of questions and information that will be acquired from the subjects. This allows IRB to identify any potential risk and discomfort that will be imposed on the subjects.

h. Research Proposal (Approved)

The research proposal is to provide the rationale behind the conduct of IRB for this research by elaborating on the overall aim and structure of the research. This allows IRB to understand the need for the human subject research.

APPENDIX E. CODEBOOK

Section 1: Requirements

Variable Name	Variable Label	Range Variable	Variable Format	Format Name	Format Value	Value Label
Qn1[SQ001]	List the physical components of the tactical sling.	1-3	openended	1phycomp	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn1[SQ002]	Requirement # or any other information you used.	1-3	openended	1sptinfo	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn2[1]	Minimum width of tactical sling.	1-2	numeric/ordinal	2minwid	1	Did not provide expected response (Not Correct)
					2	Provided expected response (Correct)
Qn2[3]	Maximum width of tactical sling.	1-2	numeric/ordinal	2maxwid	1	Did not provide expected response (Not Correct)
					2	Provided expected response (Correct)
Qn2[4]	Requirement # or any other information you used.	1-3	openended	2sptinfo	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn3[SQ001]	List the Tactical sling's functions that require interactions between warfighter, weapon and	1-3	openended	3functions	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn3[SQ002]	Requirement # or any other information you used.	1-3	openended	3sptinfo	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn4[SQ001]	List and describe ways to detach the weapon.	1-3	openended	4detwpn	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn4[SQ002]	Requirement # or any other information you used.	1-3	openended	4sptinfo	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn5[SQ001]	Does the tactical sling allow both a left-handed and right-handed Warfighter to operate the M16?	1-2	yesno	5leftright	1	Did not provide expected response (Not Correct)
					2	Provided expected response (Correct)
Qn5[SQ002]	Requirement # or any other information you used.	1-3	openended	5sptinfo	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn6[SQ001]	Does the tactical sling support operations that involve Mission Orientd Protective Posture (MOPP) IV, with gloves on?	1-2	yesno	6mopp	1	Did not provide expected response (Not Correct)
					2	Provided expected response (Correct)
Qn6[SQ002]	Requirement # or any other information you used.	1-3	openended	6sptinfo	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn7[SQ001]	Does the warfighter require a tool to attach the tactical sling onto the weapon?	1-2	yesno	7tool	1	Did not provide expected response (Not Correct)
					2	Provided expected response (Correct)
Qn7[SQ002]	Requirement # or any other information you used.	1-3	openended	7sptinfo	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn8[SQ001]	How many ways can the tactical sling be attached to the weapon?	1-3	openended	8attach	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn8[SQ002]	Requirement # or any other information you used.	1-3	openended	8sptinfo	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn9[SQ001]	Do you foresee the tactical sling to cause any interference when in used?	1-2	yesno	9interfere	1	Did not provide expected response (Not Correct)
					2	Provided expected response (Correct)
Qn9[SQ002]	Requirement # or any other information you used.	1-3	openended	9sptinfo	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)
Qn10[SQ001]	Do you foresee the tactical sling posing any risk while crossing water obstacle?	1-2	yesno	10waterobs	1	Did not provide expected response (Not Correct)
					2	Provided expected response (Correct)
Qn10[SQ002]	Requirement # or any other information you used.	1-3	openended	10sptinfo	1	Did not provide expected response (Not Correct)
					2	Provided part of the expected response (Partial Correct)
					3	Provided expected response (Correct)

Section 2: Reference Materials and Demographics

Qn11[SQ001]	How many times did you refer to the performance specification document?	A1 to A5	likertscale	11timesreferperf	A1	0 to 5
					A2	6 to 10
					A3	11 to 15
					A4	16 to 20
					A5	More than 20
Qn12[SQ001]	Do you find the information easy to find in the performance specification document?	A1 to A7	likertscale	12infoeasyperf	A1	Very Easy
					A2	Easy
					A3	Somewhat Easy
					A4	Neither
					A5	Somewhat Hard
					A6	Hard
					A7	Very Hard
Qn13[SQ001]	Overall, how easy or hard was it to understand the information in the performance specification document?	A1 to A7	likertscale	13easyhardundperf	A1	Very Easy
					A2	Easy
					A3	Somewhat Easy
					A4	Neither
					A5	Somewhat Hard
					A6	Hard
					A7	Very Hard
Qn14[SQ001]	How many times did you refer to the FM 3-22 docun	A1 to A5	likertscale	14timesreferfm322	A1	0 to 5
					A2	6 to 10
					A3	11 to 15
					A4	16 to 20
					A5	More than 20
Qn15	Did you use any other sources beside the attached ones to complete this survey? If yes, list them, else indicate "Not Applicable".	-	openended	15othersource	-	Subject's input
Qn16	List all education degrees	-	openended	16edudeg	-	Subject's input
Qn17	How many years of systems engineering experience do you have?	-	numeric/interval	17seexp	-	Subject's input
Qn18	How many years of modeling or model-based system engineering (MBSE) experience do you have?	-	numeric/interval	18mbseexp	-	Subject's input
Qn19[SQ001]	Rate your experience with either the M16 and/or M4	A-1 to A-6	likertscale	19wpnexp	A1	None
					A2	Very Little
					A3	Little
					A4	Moderate
					A5	Experienced
					A6	Extensive
Qn20	Have you ever used a tactical sling when shooting a	1-2	yesno	20slingshootrifle	1	Yes
					2	No
Qn21	Any other comments	-	openended	21othercomment	-	Subject's input
Qn1Time	Time Taken to answer Qn 1	-	numeric/interval	Q1time	-	
Qn2Time	Time Taken to answer Qn 2	-	numeric/interval	Q2time	-	
Qn3Time	Time Taken to answer Qn 3	-	numeric/interval	Q3time	-	
Qn4Time	Time Taken to answer Qn 4	-	numeric/interval	Q4time	-	
Qn5Time	Time Taken to answer Qn 5	-	numeric/interval	Q5time	-	
Qn6Time	Time Taken to answer Qn 6	-	numeric/interval	Q6time	-	
Qn7Time	Time Taken to answer Qn 7	-	numeric/interval	Q7time	-	
Qn8Time	Time Taken to answer Qn 8	-	numeric/interval	Q8time	-	
Qn9Time	Time Taken to answer Qn 9	-	numeric/interval	Q9time	-	
Qn10Time	Time Taken to answer Qn 10	-	numeric/interval	Q10time	-	
Qn11Time	Time Taken to answer Qn 11	-	numeric/interval	Q11time	-	Provided by LimeSurvey
Qn12Time	Time Taken to answer Qn 12	-	numeric/interval	Q12time	-	
Qn13Time	Time Taken to answer Qn 13	-	numeric/interval	Q13time	-	
Qn14Time	Time Taken to answer Qn 14	-	numeric/interval	Q14time	-	
Qn15Time	Time Taken to answer Qn 15	-	numeric/interval	Q15time	-	
Qn16Time	Time Taken to answer Qn 16	-	numeric/interval	Q16time	-	
Qn17Time	Time Taken to answer Qn 17	-	numeric/interval	Q17time	-	
Qn18Time	Time Taken to answer Qn 18	-	numeric/interval	Q18time	-	
Qn19Time	Time Taken to answer Qn 19	-	numeric/interval	Q19time	-	
Qn20Time	Time Taken to answer Qn 20	-	numeric/interval	Q20time	-	
Qn21Time	Time Taken to answer Qn 21	-	numeric/interval	Q21time	-	

APPENDIX F. ACCURACY OF ANSWERS IN SECTION 1 FOR INDIVIDUAL SUBJECTS

Max Format Value for the question		3	3	2	2	2	3	3	3	3	2	2
ID	Condition 1 = Model Based 2 = Text Based	Qn1[SQ001]	Qn1[SQ002]	Qn2[1]	Qn2[3]	Qn2[4]	Qn3[SQ001]	Qn3[SQ002]	Qn4[SQ001]	Qn4[SQ002]	Qn5[SQ001]	Qn5[SQ002]
12	1	2	2	2	2	2	2	2	3	3	2	2
14	1	2	1	1	1	1	2	1	1	1	2	1
21	1	3	3	2	2	2	3	3	3	3	2	2
36	1	3	3	2	2	2	2	3	3	3	2	2
37	1	3	3	2	2	2	2	2	2	1	2	2
44	1	3	3	1	1	1	2	2	3	3	2	2
9	2	2	2	2	1	2	2	2	2	2	2	2
20	2	2	1	2	2	2	2	1	2	1	2	1
32	2	2	2	2	2	2	2	2	3	3	2	2
42	2	2	2	2	2	2	2	2	2	2	2	2
46	2	2	2	2	2	2	2	2	3	3	2	2

Figure 47. Accuracy of Answers for Individual Subjects (Q1 to Q5).

Max Format Value for the question		2	2	2	2	3	3	2	2	2	2
ID	Condition 1 = Model Based 2 = Text Based	Qn6[SQ001]	Qn6[SQ002]	Qn7[SQ001]	Qn7[SQ002]	Qn8[SQ001]	Qn8[SQ002]	Qn9[SQ001]	Qn9[SQ002]	Qn10[SQ001]	Qn10[SQ002]
12	1	2	2	2	2	3	3	2	2	2	1
14	1	2	1	1	1	2	1	2	1	1	1
21	1	2	2	2	2	3	3	2	2	2	2
36	1	2	2	2	2	3	3	1	2	2	1
37	1	2	2	2	2	3	3	2	2	2	1
44	1	2	2	2	2	3	3	2	2	2	2
9	2	1	1	2	2	3	3	1	1	2	1
20	2	2	1	2	1	2	1	2	1	2	1
32	2	2	2	2	2	2	3	1	2	1	1
42	2	2	2	2	2	3	3	1	1	2	1
46	2	2	2	2	2	3	3	2	2	2	2

Figure 48. Accuracy of Answers for Individual Subjects (Q6 to 10).

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APPENDIX G. SUMMARY OF Q11, 13, AND 14

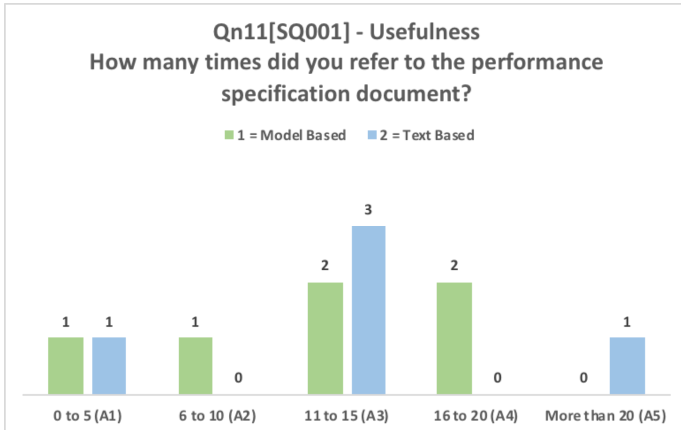

Figure 49. Summary of Qn 11 (H3).

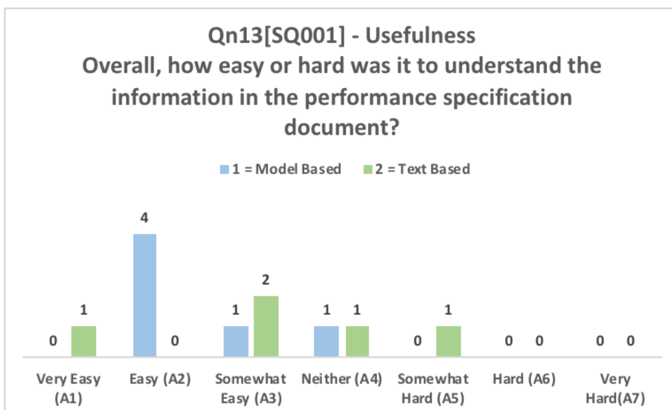

Figure 50. Summary of Qn 13 (H3).

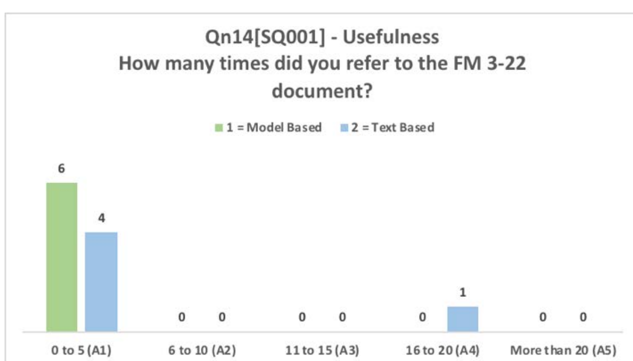

Figure 51. Summary of Qn 14 (H3).

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APPENDIX H. SUMMARY OF Q12

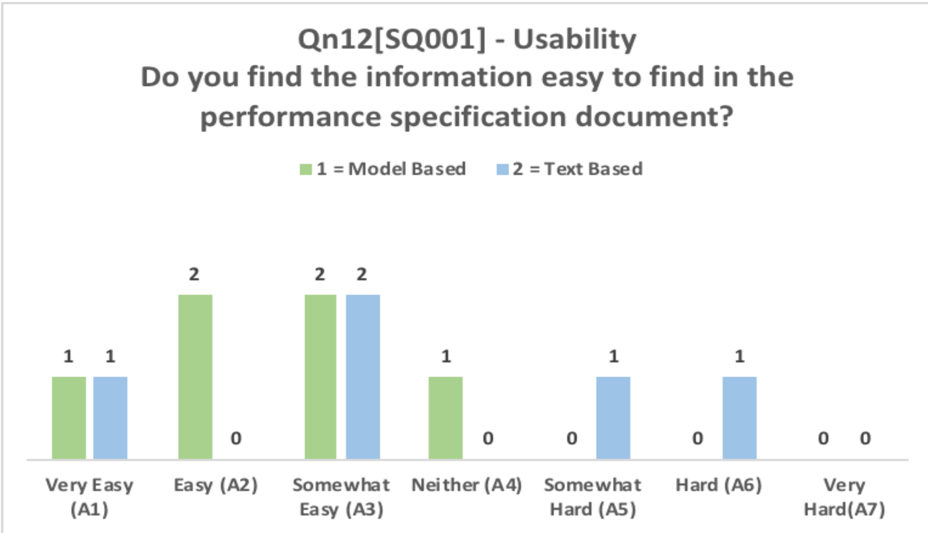

Figure 52. Summary of Qn 12 (H4).

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