Identifying Variance Between Materiel and Non-Materiel Solution Requirement Attributes

By Justin Rettaliata

B.S. Mechanical Engineering, May 2003, Lehigh University
Masters in Business Administration, May 2008, College of William and Mary

A Dissertation submitted to
the Faculty of
The School of Engineering and Applied Science
of The George Washington University
in partial satisfaction of the requirements
for the degree of Doctor of Philosophy

July 22, 2014

Dissertation directed by

Thomas A. Mazzuchi,
Professor of Operations Research and of Engineering Management
and
Shahram Sarkani
Professor of Engineering Management and Systems Engineering

The School of Engineering and Applied Science of The George Washington University certifies that Justin Rettaliata has passed the Final Examination for the degree of Doctor of Philosophy as of April 4, 2014. This is the final and approved form of the dissertation.

Identifying Variance Between Materiel and Non-Materiel Solution Requirement Attributes

Justin Rettaliata

Dissertation Research Committee:

Shahram Sarkani, Professor of Engineering Management and Systems Engineering

Thomas Andrew Mazzuchi, Professor of Engineering Management and Systems Engineering & of Decision Sciences

John Bischoff, Professorial Lecturer in Engineering Management and Systems Engineering, Committee Member

Jason Dever, Professorial Lecturer in Engineering Management and Systems Engineering, Committee Member

E. Lile Murphree, Professor of Engineering Management, Committee Member

Dedication

My dissertation is dedicated to my loving wife, Sheena, my son Jackson, my parents, Marilyn and Stephen, and my grandparents, Michael and Millie Ruggiero, for their continued love and support when undertaking this endeavor. Their constant encouragement and belief in me made this possible.

Abstract

Identifying Variance Between Materiel and Non-Materiel Solution Requirement Attributes

In 2008, the Government Accountability Office (GAO) performed a study on 11 Department of Defense (DoD) programs and compared how requirements were developed between DoD and private industry. The study found that the DoD did not follow good Systems Engineering practices when developing requirements, resulting in program cost and schedule overruns. With 2011 Defense spending at approximately $711B, it is undeniable that significant portions of these resources are spent on programs that meet their demise due to poorly developed requirements documentation. Such requirements are poorly written, lack clear traceability and threaten the viability of the programs.

The question arises whether these issues are due to poor training during the requirements definition process, lack of sufficient information and expertise available at program initiation, or a decrease in emphasis on establishing quality attributes for requirements. This study evaluates requirement attributes for materiel and non-materiel solution sets, and whether these attributes are the same or different. A case study example is presented identifying a selected set of requirement attributes and, with the aid of expert practitioner knowledge, these attributes are ranked in order of preference for materiel and non-materiel solutions sets.

Table of Contents

List of Figures

List of Tables

1 INTRODUCTION

“A requirement is a statement that identifies a capability or function needed by a system in order to satisfy a customer need.” (Bahill, et al., 2009) Scott Berkun (2009) provides an excellent example of a poorly written requirement, "... Make a $5 car that goes 500 miles per hour, weighs 10 lbs, and is invisible. Those are very clear requirements. They’re also impossible. No matter how well defined these requirements are, or how happy the customer and the VP is with them, the project is set up to fail. ... Requirements are not a product. The product is the product. A requirement is best seen as a way to help the design/engineering team succeed in making the product." (Berkun, S., 2009).

Despite continued reform on requirements development, even prominent current programs have been plagued with the consequences of poorly written requirements, including programs that have applied a disciplined Systems Engineering approach. The US Navy’s Organic Airborne Surface Influence Sweep (OASIS) system's poor requirements were one of the reasons that led to its demise. The OASIS program, a materiel solution for sweeping and detonating underwater mines, was cancelled after over $112M of research, development and testing dollars were invested because of its shock requirement (necessary to withstand the blast from detonating mines) being mismanaged, untraceable, untestable, and irrational among other things. (Sanders, N., 2012; Inspector General US DoD, 2012) The Joint Strike Fighter (JSF), a materiel solution for an advanced fighter jet, has also suffered the wrath of poorly written requirements when in testing it was realized the heat blast from the jet engine literally melted

the deck upon which it was to land. The JSF program required a redesign of the heat shielding paint on the deck of the host ship, a costly mitigation. (Titcomb, 2012)

Unlike a material solution approach where requirements can be traced to system level components and the results of developmental testing, it is very difficult to trace non-materiel solutions that have struggled due to poorly written requirements. Moreover, it is also very easy to perceive the impact of unreliable components on operational availability requirements, yet not so easy to perceive how modifying our training process will provide us a more effective fleet or squadron. After a thorough literature review, two examples were identified. First, the United States Coast Guard (USCG) identified many problems with how their doctrine was established, accounted for, cataloged, disseminated, and modified. This resulted in the USCG to conduct a deep dive assessment of how their non-materiel requirements for doctrine were established and understood by their personnel. (Doctrine Study Group, 2008) Secondly, the Joint Staff also had poorly defined doctrine causing the United States Senate to direct them to re-evaluate how their non-materiel requirements for doctrine were managed and disseminated. (Furr, 1991) A notable comment by Furr (1991) was that personnel who were available and not necessarily trained in requirements and doctrine writing were developing Joint Staff doctrine and requirements(Furr, 1991) . The lack of properly trained or experienced requirements writers is a frequent occurrence that was also noted by Hooks (1993), where she stated that

“the primary reason that people write poor requirements is that they have had no training or experience in writing good requirements.” (Hooks, 1993)

It is important to first define materiel and non-materiel solutions. These definitions will establish the groundwork for why their respective requirement attributes may differ.

A materiel solution is “a new item (including ships, tanks, self-propelled weapons, aircraft, etc., and related spares, repair parts, and support equipment, but excluding real property, installations, and utilities) developed or purchased to satisfy one or more capability requirements (or needs) and reduce or eliminate one or more capability gaps.” (Manual, JCIDS, 2012) By selecting this type of solution, the decision makers are agreeing that there is no existing capability that can be altered or enhanced to satisfy the requirements. In contrast, a non-materiel solution alters areas of existing programs to answer the capability requirements. These areas where change can be made include: doctrine, organization, training, (existing) materiel, leadership and education, personnel, facilities, and/or policy (DOTmLPF-P) (Manual, JCIDS, 2012). Definitions for each of these areas are shown in Table 1-1.

Table 1-1 – DOTmLPF-P Definitions (Manual, JCIDS, 2012)

Area of Change	Definition
Doctrine	Fundamental principles that guide the employment of US military forces in coordinated action toward a common objective.
Organization	A joint unit or element with varied functions enabled by a structure through which individuals cooperate systematically to accomplish a common mission and directly provide or support joint warfighting capabilities.
Training	Training, including mission rehearsals, of individuals, units, and staffs using joint doctrine or joint tactics, techniques, and procedures to prepare joint forces or joint staffs to respond to strategic, operational, or tactical requirements considered necessary by the CCMDs to execute their assigned or anticipated missions.
Materiel	All items (including ships, tanks, self-propelled weapons, aircraft, etc., and related spares, repair parts, and support equipment, but excluding real property, installations, and utilities) necessary to equip, operate, maintain, and support joint military activities without distinction as to its application for administrative or combat purposes. The letter “m” in the acronym is usually lower case since Joint DCRs do not advocate new materiel development, but rather advocate increased quantities of existing materiel capability solutions or use in alternate applications.
Leadership and Education	Professional development of the joint leader is the product of a learning continuum that comprises training, experience, education, and self-improvement.
Personnel	The personnel component primarily ensures that qualified personnel exist to support joint capability requirements.
Facilities	Real property consisting of one or more of the following: buildings, structures, utility systems, associated roads and other pavements, and underlying land.
Policy	Any DOD, interagency, or international policy issues that may prevent effective implementation of changes in the other seven DOTmLPF-P elemental areas.

By analyzing the DOTmLPF-P change areas, decision makers are able to determine what can be altered within an existing program, enabling them to provide an efficient and effective solution. This can be compared to a much less efficient and more expensive process of developing a materiel solution through the costly acquisition process.

The determination of whether a program is a materiel or non-materiel solution is a critical step prior to identifying a solution to fulfill a capability gap within the DoD. This determination is made within the Joint Capabilities Integration and Development System (JCIDS) process, mandated by United States Law under Title 10, United States Code, outlining the roles for Armed Forces, which plays a key role in identifying the capabilities required by the warfighters to support the National Defense Strategy (NDS), the National Military Strategy (NMS), and the

National Strategy for Homeland Defense. (CJCSI 3170.01H, 2012) The entire JCIDS process consists of the analysis of four main documents during the acquisition cycle: Capabilities Based Assessment (CBA), Initial Capabilities Document (ICD), Capability Development Document (CDD), and Capabilities Production Document (CPD). Each of these documents supports the determination of program requirements for answering a capability gap; however, this research will focus solely on the CBA portion of the process where the determination is made whether a materiel or non-materiel solution will be selected.

The CBA is conducted during the Gap Analysis Phase of the Requirements and Acquisition Process Flow (DoDI 5000.02, 2008). The CBA accomplishes the following (JCS J-8, 2009):

- Define the mission;
- Identify capabilities required;
- Determine the attributes/standards of the capabilities;
- Identify gaps;
- Assess operational risk associated with the gaps;
- Prioritize the gaps;
- Identify and assess potential non-materiel solutions;
- Provide recommendations for addressing the gaps.

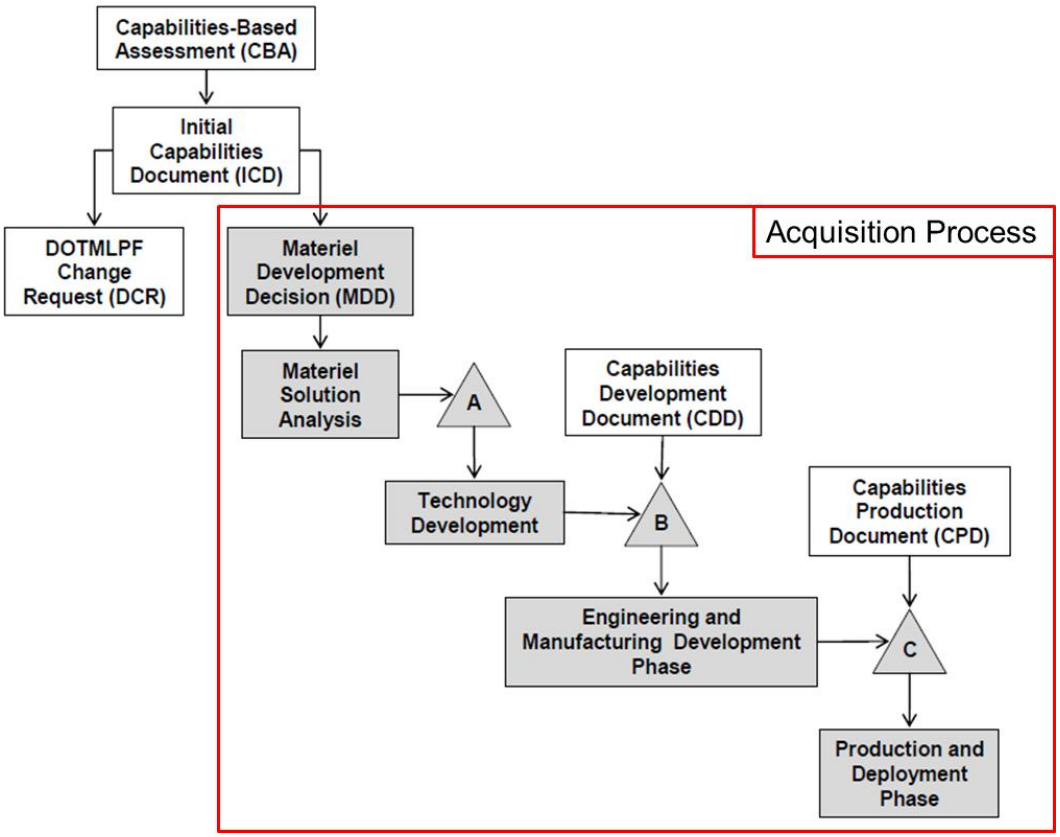

Figure 1-1 – Capabilities Based Assessment Process (JCS J-8, 2009)

As shown in Figure 1-1, the CBA feeds into the ICD and creates a recommendation for a materiel or a non-materiel solution. Depending on the recommendation, a materiel solution will enter the acquisition process at milestone A or B as depicted by DODI 5000.02, while a non-materiel solution will be addressed by a DOTMLPF Change Request (DCR).

The Defense Acquisition University (DAU) provides training for requirement authors. Courses offered include, "*Introduction to JCIDS"* (CLR101), *"Defining Requirements"* (CLR252), and *"Core Concepts for Requirements Management (CCRM)"* (RQM110). These courses are part of the Level B certification process for a Requirements Manager Certification and Training (RMCT) process. After a

thorough review, it was determined that the coursework of these classes fail to address the important attributes of requirements for non-materiel solutions. Each course treats materiel and non-materiel solution requirements the same. In addition, the DoDI 5000.02, JCIDS Manual does not provide guidance when writing requirements for non-materiel solutions. This research, with the assistance of expert practitioner judgment, determines if requirement attributes should vary when considering materiel or non-materiel solutions.

1.1 Statement of Problem

The development of requirements for any solution set is never an easy endeavor. The difficulty is increased when the requirements manager is not adequately trained in how to properly develop a requirement, or how to determine which requirement attributes are important to a materiel or non-materiel solution set. The specific problem this research addresses is that, despite being trained requirements managers, DoD does not adequately train its requirements managers in how to select and prioritize requirement attributes for a materiel or non-materiel solution set. Additionally, at the time of this dissertation, the DoD treats requirements writing for each solution set the same.

1.2 Approach

The goal of this research was to take an existing requirement attribute writing guide and develop a prioritized list of requirement attributes for materiel and non-materiel solution sets to aid in the development of requirements for both solution sets. The objectives of this research include: identify attributes for a well-written

requirement for materiel and non-materiel solutions; develop and conduct a case study to determine the ranking of the attributes and compare the selected attributes with those used in military and scholarly institutions. This research is not intended to be an authoritative list of requirement attributes, but a suggested prioritized list that may be utilized in developing requirements.

1.3 Organization of Document

This document outlines and describes a quantitative research study. Chapter 1 introduces the topic and problem being considered and provides background, purpose, scope and the limitations of the study. Chapter 2 provides a literature review on Requirements Writing Guides that define requirement attributes. Chapter 3 will describe the research methodology and provide different ranking methods and discrete choice models that can be utilized in evaluating the collected data. Chapter 4 will describe the research plan, data collection procedures, and analysis procedures. Chapter 5 will provide a review of the findings and results of the analysis, in addition to providing a conclusion and recommendations from this study. Chapter 6 will provide a conclusion and future research possibilities.

1.4 Background

Over the last two plus decades, issues with writing requirements are far from a new topic. Hanks, et al (2005) documented 28 separate reform initiatives that revolved around requirements generation (Hanks, et al., 2005). Table 1-2 lists out these reform initiatives.

When analyzing these initiatives, it can be seen that they touch on many aspects of requirement development including how to write a requirement, as well as how to improve the requirements based actions and decisions in the acquisition process.

These initiatives are just a part of the efforts that are undertaken to improve upon the acquisition process. Unfortunately, regardless of what initiatives are implemented, without properly training personnel on the different aspects of what it takes to develop a well-written requirement, the initiatives will not be fully realized. DAU is responsible for developing the curriculum for DoD requirements managers so that they can fully implement lessons learned from the past and learn the skill sets to help develop the requirements for future acquisition programs.

DoD has guidance on how requirements are to be written for programs of record. These documents are basis for which the DAU curriculum is developed. In the DAU curriculum, requirements managers are taught how to determine whether the capability gaps can be answered by a materiel or non-materiel solution. Unfortunately, after determining the solution set for the program, the curriculum is more focused on the materiel solution (which is managed through the acquisition process) than the non-materiel solution. This leaves a gap in requirements development for creating requirements for non-materiel solutions. It is hypothesized by the author that DAU treats the requirements attributes for non-materiel solutions the same as materiel solutions, as DAU offers no additional training on developing requirements for non-materiel solutions.

Table 1-2 – Requirements Reform Initiatives (Hanks, et. al, 2005)

Requirements Reform Initiative	Implementation Date	Description
Performance-Based Service Acquisition	Sep-91	For service provision contracts, contract is to specify the “what” and not the “how”. Aim is to reduce contract costs, improve quality of service and increases access to commercial sector. DoD has a goal to have 50% of all contracts for services be performance based by 2005
Improved Pre-Solicitation Phase Communication	Jan-93	To improve the quality of bids and reduce bid and proposal costs, by improving pre-bid discussions to enhance the bidders’ understanding of the requirement and DoD’s understanding of suppliers’ capabilities and any potential problems.
Elimination of Mil Specs and Mil Standards	Feb-94	A Secretary Perry policy to use performance specifications and commercial standards for defense systems acquisition solicitations and contracts, in preference to design-specific specifications and standards, the use of which would require a waiver from the component acquisition executive or a designee. Intention was to reduce time taken both to place, and to fulfill, a contract, and to improve access to commercial market
Multi-Year Contracting	Feb-94	Allows more stable, longer-term relationships between DoD and a supplier than are enabled by traditional annual commitments. Multi-year contracting has been possible for a long time, but its use was limited by restrictive implementation guidance and return on investment criteria.
Integrated Product and Process Development (IPPD)	Feb-94	IPPD is cooperative working among key stakeholders from all relevant disciplines from the earliest design phase to deliver a cost-effective producible, high quality, supportable and “right the first time” design.
Program Stability	Feb-94	The Perry proposals emphasized the need to provide more funding stability and flexibility to manage programs in the best manner possible. They encouraged the development of innovative funding methods that would alleviate inappropriate impact on program management, and urge the need to reduce unexpected program budget changes. The intention was to reduce cost and cycle time by avoiding “stop-go” program management.
Contractor-Maintained Design Configuration	Mar-94	Use of performance based acquisition reduces oversight of contractor configuration management practices and allows technology updates and other changes without extensive contract amendment. The aim is to reduce contract schedule and cost and improve quality while increasing access to the commercial sectore
Single Process Initiative (SPI)	Jun-94	SPI allows a single process for both commercial and military products, to reduce contract schedule and cost, increase quality, and improve access to the commercial sector. Removing government-unique requirements make it easier and cheaper for contractors to produce military products by using existing commercial processes and production lines, and hence increases govn’t access to the commercial sectior. Base standards on commercial standards such as ANSI/NISC 2 540-1, ISO 10012-1 or equivalent
Concurrent Developmental/Operational Testing	Nov-94	Test and Evaluation (T&E) Plans are to be structured so as to allow the maximum possible concurrent developmental and operational testing throughout the acquisition process. Bring together all relevant testing agencies.The aim is to reduce contract schedule and cost. The goal of integrated T&E is to provide early operational insights into developmental process. This early operational insight should reduce the scope of the integrated operational test and eval, thereby contributing to reduced cycle time and total ownership costs (TOC).
Rapid Prototyping for Software Development	Nov-94	Intent is to speed up development (hence reducing contract schedule) and improve product quality by creating a working model of a software module to demonstrate feasibility, then refining it for inclusion in final product
Open Systems Approach	Nov-94	Designing open systems and specifying interface standards enhances operability, both among the us armed services and with allies. Applying widely used interface standards in weapon systems will enable multiple sources of supplying and technology insertion and allow for upgrading in service.
Advanced Concept Technology Demonstration (ACTD)	1994	Allow operational forces to experiment with new technology in the field to evaluate potential changes to doctrine, operational concepts, tactics, modernization plans, and training. After ACTD, the system can enter the acquisition process at an appropriate point. The aim is to expedite the movement of maturing technologies from the developer to the user as quickly as possible, providing the warfighter with a prototype capability and supporting him in its evaluation.

Table 1-2 – Requirements Reform Initiatives (Hanks, et. al, 2005) (cont)

Streamlined ECP Review/Approval	Feb-95	Restricts the use of ECPs in performance-based acquisition to those affecting DoD's performance requirements. The aim is to reduce contract schedule and ECP costs
RFP Streamlining	Mar-95	Cut both government and contractors' costs by reducing the size and complexity of RFPs. Essentially avoid unnecessary Statement of Work complexity and contract clauses, and to focus on output based requirements rather than detailed specifications. Cost as a military requirement allows the warfighter to judge what a system is worth in comparison with other needed capabilities and their costs. The ORD must contain cost objectives to allow an affordability determination to be made early in proposed acquisition program
Commercial Sourcing: FAR Part 12 Procurements	Jun-95	Reduces restrictive laws and domestic source restrictions that limited contractors from using commercial sources. The aim is to reduce contract cost and schedule, and to improve access to the commercial market.
Survivability/Lethality Below End-Item Level	Jun-95	The aim is to reduce contract costs by allowing the Secretary of Defense to issue waivers permitting survivability/lethality testing at the system and subsystem level instead. This authority is required in such circumstances to certify to Congress that the testing of the full weapon system would be unreasonably expensive and impractical.
Joint Government/Industry IPTs	Oct-95	IPTs including both government and industry are placing the traditional adversarial relationships among key players (users, acquirers, testers, funds managers, contractors, etc) with cooperation and teamwork to achieve targets. The intention is to eliminate functional stovepiping by bringing all relevant functions together in an integrated decision team with all the necessary expertise to address and resolve problems at the earliest moment and lowest level possibile, thus reducing time, cost, and a part of the oversight overhead, and improving solution/product quality. IPTs: Overarching, working-level, program management office – level and below
Cost as an Independent Variable (CAIV)	Dec-95	Used to develop strategies for acquiring and operating affordable systems by getting aggressive achievable cost objectives and managing achievement of these objectives. Key stakeholders help set and achieve cost objectives, identifying potential tradeoffs, eg, through participation of cost performance IPTs. As system performance and cost objectives are decided (on the basis of cost-performance tradeoffs), the requirements and acquisition processes will make cost more of a constraint and less of a variable, while nonetheless obtaining the required military capability. The aim is to achieve life-cycle cost savings through repeated tradeoff analysis at all stages
Best Value Contracting: Consideration of Cost/Performance Tradeoffs	Mar-96	Contracts are awarded on the basis of "best value" not "lowest cost". All relevant factors- cost, performance, quality, schedule, considered and potential tradeoffs – are taken into account. Contracts are to minimize the number of critical performance criteria so as to allow contractors maximum flexibility to innovate to meet overall program objectives. Reduce contract award schedule and reduce contract costs.
Simulation-Based Acquisition	Mar-96	Process in which DoD and industry are enabled by the robust, collaborative use of simulation technology integrated across acquisition phases and programs. Modeling techniques test and evaluate design without the need for hardware prototypes, and may allow earlier systems engineering decisions, concurrent evaluations throughout the project, and a better balancing of life cycle costs. Intended to improve dramatically the acquisition process by the application of advanced information technology, by reducing contract schedule and costs and improving quality.
Evolutionary Acquisition	Jun-96	DoDINST 5000.2 provides for a flexible process for rapid acquisition of mature technology, with evolutionary acquisition strategies and time-phased requirements that allow early fielding of a usable warfighting capability, with block upgrades to full capability over time.

Table 1-2 – Requirements Reform Initiatives (Hanks, et. al, 2005) (cont)

Other Transaction Authority	Dec-96	Allowed certain projects to be based on arrangements other than contracts, grants, or cooperative agreements, under authority of 10 USC 2371 and outside the normal regulator environment of FAR/DFARS. Intent is to reduce contract schedule and cost while improving both quality and access to the commercial market, but allowing tremendous flexibility to negotiate appropriate terms and conditions.
Alpha Contracting	Oct-97	Also known as IPT pricing and one pass contracting – involves all government participants in a contract negotiation getting together as a team and staying in continuous communication with the contractor while the contractor develops the proposal. The team concurrently evaluates, analyzes and resolves issues during proposal development. The intention is to improve communication with the contractor, improve the quality of the proposal, reduce the time needed to negotiate a proposal by avoiding successive iterations, and creat a no surprises culture on proposal delivery.
Modernization Through Spares	1997	The goals of the Commercial Operations and Support Savings Initiative (COSSI) are to improve readiness and reduce operations and support costs by inserting commercial items or technology into military legacy systems. The Army program is known as “Modernization Through Spares” 9MTS) and emphasizes the rapid development of prototypes and fielding of production items based on current commercial technology.
Reduction in Total Ownership Cost (RTOC)	Apr-98	Aims to ensure that investment decisions are made on the basis of the through-life costs of an acquisition program, and not just the basis of the initial acquisition cost. In respect of savings efforts, it aims to ensure that any savings identified are equally considered on a whole-life basis, so that short-term gains are not outweighed by higher downstream costs. The pilot programs were encouraged to focus on three types of actions: reliability and maintainability improvements; reduced supply chain response times; and competitive sourcing of product support
Logistics Transformation	1998	Transforming DoD’s mass logistics system into a highly agile, reliable system that delivers logistics on demand. Logistics reform will move towards performance-based support nd link modern warfighting and modern business practice. Logistics transformation aims to apply the commercial world’s focus on the customer service, integrated supply chains, rapid transportation, and ecommerce techniques to military logistics, emphasizing readiness and rapid service to the warfighter. “just-in-case to just-in-time mindsets
Contractor Total system Performance Responsibility (TSPR)	1998	Used as a contract condition that obligated the prime to be totally responsible for all integration of entire weapon system. This ensured that the government received an integrated system that would meet the performance requirements as defined in the system specification. Evolved as a new approach to sustaining programs – focus is on management responsibility vs. development responsibility. Generally involves the ID of core government functions. All non-core government functions become the responsibility of the contractor, and the government retains the core functions Core government functions: Program Direction, Budgeting/Financial execution, Product/service acceptance, requirements determination, contract management and security. Outside these core functions, TSPR concept involves a single contractor assuming complete responsibility for overall performance in the weapon system’s field of operations and sustainment.
Oral Presentations	1999	Industry proposals with intent to reduce the contractor’s time and cost in submitting proposals and to improve the dialogue between government and industry, thus reducing cycle time and costs and improving the quality of both the eventual agreement and the communication between government and industry throughout the life of program

1.5 Purpose

The purpose of the study is to identify a fixed list of requirement attributes for both materiel and non-materiel solution sets and determines if there is a difference in rankings between the attributes for each solution. By providing a prioritized list for each solution set, this will aid requirements managers in creating a well-written requirement that will be clear and achievable.

1.6 Significance

In light of current fiscal pressures and across the board cuts, especially in the DoD, leaders are under increased scrutiny on how they are spending and executing programs. With approximately $711B sent on Defense spending in 2011 (SIPRI Military Expense Database, 2013), it is increasingly more difficult to defend programs that are plagued by cost overruns and schedule slips due to the inability to develop system level requirements in accordance with sound systems engineering and requirements guidance.

The significance of this study in requirements writing is extremely important when considering the current pressures on government spending and execution of military programs. Without properly training requirements managers on how to identify attributes to both a materiel and non-materiel solution, as well as how to write a proper requirement, the DoD will be unable to develop sound requirements. This study will provide a prioritized list of requirement attributes for both solution sets that might be used to help improve upon the development of requirements.

1.7 Scope and Limitations

For the purposes of this study, the scope was limited to analyzing the requirement attributes for materiel and non-materiel solutions. Due to the many variations of published requirement attribute lists, Davis' 13 Attributes to a Well Written Requirement (Davis, 1993) were chosen as the basis for the requirement attribute list utilized in this study.

This research focused solely on the requirement attribute portion of the requirement writing process, and does not elaborate on the other pieces required for the final development of a requirement, such as identifying customer needs, identifying project goals, defining business needs defining system capabilities and scope, concepts of operations, determining stakeholders, or identifying key decisions (Bahill, et al., 2009). This study is not meant to be an authoritative source for which requirement attributes are to be used when developing requirements for each solution set, but a demonstration of which requirement attributes could be adopted based on expert judgment.

2 LITERATURE REVIEW

Requirements determination only accounts for an estimated 2% of the acquisition life cycle of a program (Georgiadis, et al, 2013). With the other remaining 98% of the program costs relying on these requirements, it is even more critical to ensure a requirement is properly developed. As demonstrated by Hanks, et al, (2005), finding ways to improve requirements generation to reduce schedule slips and cost overruns is far from a new undertaking. Despite these efforts, there are still many documented programs, government and private

industry, that experience overages that lead to not only delays, but potential cancellations as well. According to Hull, et al (2011), 13.1% of all projects are cancelled due to inadequate or incomplete requirements (Hull, et al., 2011). The literature review demonstrates many different theories on what attributes best define a requirement, though is far from an exhaustive search of all theories. What is not discussed in this literature review is the determination of how to apply these attributes to a program. As mentioned by Rajnish, et al (2010), it is not as easy as choosing a standard notion of requirements quality, such as the IEEE Standards (1998), and applying them (Rajnish, et al, 2010). Depending on the application, not all requirement specifications meet these qualities. So while these attributes can be used as a guideline for developing a well-written requirement, they need the experience of a well-trained requirements manager to implement them. As cited by Hooks (1993), primary reasons that requirements are poorly written are because people are not properly trained or have no experience in requirements writing (Hooks, 1993).

2.1 Requirements Writing Guides

Table 2-1 provides a list of requirement writing guides that were researched in this literature. This list is not an all-inclusive list of guides, but is an extension of an earlier paper (Rettaliata, et al, 2013). The study within this research was limited to utilizing only one requirements writing guide (Davis' 13, 1993) and provide a comparison to other guides. Applications of each individual guide were not within the scope of this research.

Table 2-1 – Requirements Writing Guide List

Requirements Writing Guide	Reference
Attributes to a Well Written Requirement	Davis, 1993
Properties of a Requirement	IEEE Guide for Developing System Requirements Specifications, 1998
Characteristics of a Good Requirement	IEEE Recommended Practice for Software Requirements, 1998
MIL Standard 961E	DoD Standard Practice, 2008
INCOSE Guide for Writing Requirements	Dick, et al, 2012
Characteristics of a Quality Requirement	Rajnish, et al., 2010
Criteria for Writing Requirements Statements	Hull, et al., 2011
Criteria for Requirements	Hood, et al., 2008
Attributes of Good Requirements	DAU, 2001
Criteria of a Good Requirement	Young, 2004
Qualities of a Good Requirement	Bahill, et al., 2009
Attributes for a Requirement Specification	Westfall, 2005
Requirements Characteristics	Robertson, et al., 1999
Characteristics of a Well-Written Requirement	Hooks, et al., 2001
Attributes to Quality Requirements	Davis, et al., 1993
Requirements Characteristics	Basili, et al., 1981
Requirements Characteristics	Celko, et al., 1983
Characteristics of Realistic User Requirements	ESA BSSC, 1995
Attributes to Requirements	Rombach, 1989
Requirement Quality Factors	Lamsweerde, 2009
Characteristics of Quality Requirement Statements	Wiegers, 1999

2.1.1 Davis' 13 Attributes to a Well Written Requirement

According to Davis (1993), Table 2-2 depicts requirement attributes that can be utilized to define the perfect software requirement specification. These attributes touch on important aspects that help create a requirement that is both realistic and achievable.

Table 2-2 – Davis' 13 Attributes to a Well-Written Requirement (Davis, 1993)

Attribute	Definition
Correct	Represents something required of the system
Unambiguous	Can have only one interpretation
Complete	All aspects are accounted for, and no gaps are left
Verifiable	Finite way of determining if requirement meets intended purpose
Consistent	Does not conflict or present inconsistency other requirements
Understandable by customer	Explainable by non-subject matter experts
Modifiable	Structure allows alterations to be made without compromising intent
Traced	Origin is clear
Traceable	Process can be followed back to origin
Design Independent	Does not rely on a single architecture
Annotated	Rank in order to determine importance to the end user
Concise	Short and to the point
Organized	Structured to be easily found

2.1.2 IEEE Standard 1233 Properties of a Requirement (1998)

A well-formed requirement defines a systems capability that needs to be validated. In order to properly form a requirement, the IEEE Standards Association (IEEE SA) defines the key properties of a requirement, as shown in Table 2-3, for System Specifications.

Table 2-3 – Properties of a Requirement (IEEE Guide for Developing System Requirements Specifications, 1998)

Attribute	Definition
Abstract	Each requirement should be implementation independent. – i.e. should not already have a solution in mind
Unambiguous	Each requirement should be stated in such a way so that it can be interpreted in only one way.
Traceable	For each requirement it should be feasible to determine a relationship between specific documented customer statement(s) of need and the specific statements in the definition of the system given in the SyRS as evidence of the source of a requirement.
Validatable	Each requirement should have the means to prove that the system satisfies the requirements

2.1.3 IEEE Standard 830 Characteristics of a Good Requirement (1998)

Japenga (2003) references the IEEE Standard 830-1998 as an excellent source for Software Specifications. Table 2-4, defines the key properties of a requirement as defined by the IEEE SA for Software Specifications. By following these guidelines, requirements writers are able to properly define a product to meet consumer needs, while also reducing development efforts, creating estimates for cost and schedules, and overall give a solid outline of what the project is to accomplish and how it will accomplish it.

Table 2-4 – Characteristics of a Good Requirement (IEEE Recommended Practice for Software Requirements, 1998)

Attribute	Definition
Correct	Requirement meets all needs specified to the system
Unambiguous	Requirement has only one interpretation
Complete	Requirement meets all that is needed by developers
Consistent	Requirement does not conflict with other requirements listed
Ranked for Importance	Requirement importance is indicated compared to other requirements
Verifiable	Requirement can be tested, within reasonable means, to perform as intended
Modifiable	Requirement structure can be altered easily
Traceable	Requirement can be traced back to its origin

2.1.4 MIL Standard 961E

Table 2-5 depicts the criteria that a requirement must meet in order to be deemed acceptable, per DoD standards. These criteria are the standardized basis in which DoD uses to build its requirements.

Table 2-5 - MIL Standard 961E Paragraph 5.8 (DoD Standard Practice, 2008)

Definition
Each requirement shall be stated in such a way that an objective verification can be defined for it.
Each requirement should be cross-referenced to the associated verification.
Only requirements that are necessary, measurable, achievable, and verifiable shall be included.
Requirements shall be worded to provide a definitive basis for acceptance or rejection.
Requirements shall be described in a manner to encourage competition.
Requirements shall be worded such that each paragraph only addresses one requirement or topic.

2.1.5 INCOSE Guide for Writing Requirements

According to Dick, et al. (2012), the characteristics listed in Table 2-6 are critical in appropriately developing a requirement. By utilizing these characteristics, a requirements writer would be able to create a better-defined requirement statement.

Table 2-6 - INCOSE Guide for Writing Requirements (Dick, et al., 2012)

Attribute	Definition
Necessary	Requirement is important and is not met by other requirements, has appropriate reasoning for being established, and problem cannot be satisfied without this requirement present
Implementation Independent	Requirement should not state how the requirement is met – i.e. should not already have a solution in mind
Unambiguous	Requirement should have a single interpretation and be understood by the writer, the designer and those doing verification and validation
Complete	Requirement can be understood with an individual statement and not depend on other statements or requirements
Singular	Requirement shall address a single thought, and not combine several requirements into one statement
Feasible	Requirement can be achieved and properly/realistically quantified
Verifiable	Requirement can be tested to tell if it has been satisfied
Correct	Requirement satisfies expression of stakeholder expectations
Conforming	Requirements are written to a set standard so that they are easier to write, understand and review

2.1.6 Rajnish et al. 8 Characteristics of a Quality Requirement (2010)

Rajnish et al (2010) state that the requirement characteristics demonstrated in Table 2-7 are examples of important attributes for software development

projects. Despite being based on software programs, these characteristics can easily be expanded to other non-software based programs as well. These characteristics along with following better requirements engineering steps, per Rajnish et al (2010), will help in improving requirements and lead to project success. (Rajnish et al, 2010)

Table 2-7 –8 Characteristics of a Quality Requirement (Rajnish, et al.,2010)

Attribute	Definition
Correct	To ensure that SRS correctly reflects the actual needs.
Unambiguous	An SRS is unambiguous if, and only if, every requirement stated has only one interpretation.
Complete	All conditions under which the requirement applies are stated and it expresses a whole idea or statement
Consistent	Refers to internal consistency, and must ensure that it does not conflict with other documents such as system requirement specification.
Verifiable	An SRS is verifiable if, and only if, every requirement stated therein is verifiable, i.e. if there exists some finite cost-effective process with which a person or machine can check that the software product meets the requirements.
Traceable	An SRS is traceable if the origin of each of its requirements is clear and if it facilitates the referencing of each requirement in future development or enhancement document.
Modifiable	An SRS is modifiable if, and only if, its structure and style are such that any changes to the requirements can be made easily, completely, and consistently while retaining the structure and style.
Ranked for importance and/or stability	Each requirement in an SRS must be ranked for importance and/or stability.

As stated by Rajnish et al, “there is no formulaic way to write excellent requirements.” The ability to write a great requirement is based on experience and education, both academic and real life. (Rajnish et al, 2010)

2.1.7 Hull, et al Criteria for Writing Requirements Statements (2011)

According to Hull, et al (2011), there are certain criteria that every requirement should meet. They summarized these criteria as seen in Table 2-8

Table 2-8 – Criteria for Writing Requirements Statements (Hull, et al, 2011)

Attribute	Definition
Atomic	Each statement carries a single traceable element
Unique	Each statement can be uniquely identified
Feasible	Technically possible within cost and schedule
Legal	Legally possible
Clear	Each statement is clearly understandable
Precise	Each statement is precise and concise
Verifiable	Each statement is verifiable, and it is known how
Abstract	Does not impose a solution of design specific to the layer below
Complete	All requirements are present
Consistent	No two requirements are in conflict
Non-redundant	Each requirement is expressed once
Modular	Requirements statements that belong together are close to one another
Structured	There is a clear structure to the requirements document
Satisfied	The appropriate degre of traceability coverage has been achieved
Qualified	The appropriate degree of traceability coverage has been achieved

In addition to these criteria, Hull, et al claim that in order to have a properly written requirement statement, one must create a requirement using direct language, ensure the requirements are testable, maintain the same terminology and develop each requirement one at a time (Hull, et al, 2011).

2.1.8 Hood, et al Criteria for Requirements (2008)

According to Hood, et al (2008), Table 2-9 depicts the necessary criteria that define a quality requirement. By following these criteria, Hood, et al suggest that requirements managers will be able to develop more organized and thought out requirements statements.

Table 2-9 Criteria for Requirements (Hood, et al, 2008)

Attribute	Definition
Complete	Requirement contains all the information necessary to be understood
Free of Contradiction	Does not contradict or go against other requirements
Unambiguous	Clear and only one interpretation
Feasible	Achievable and realistic
Understandable	Must be understood by the contractor as well as the consumer
Testable	Capable of being tested to ensure it's achievable
Identifiable	Need for requirement can be identified, as well as owner and consumer
Atomic	A requirement should not be easily broken into smaller requirements. There should be once concept per requirement.
Free of Duplication	Does not repeat what another requirement says
Correctly Derived	Capable of being interpreted correctly, with only one meaning
Tracable to Source	Requirement can be traced back to its origination to aid in understanding why its needed

Unfortunately, these criteria do not represent a cut and dry solution, and require measurement through reviews to perfect the requirements. These criteria provide an outline to follow. (Hood, et al, 2008)

2.1.9 DAU Attributes of Good Requirements (2001)

In the Requirements Analysis chapter of their Systems Engineering Guide, DAU (2001) determined that an important aspect of the systems engineering process inputs was defining attributes of a good requirement. These attributes are shown in Table 2-10.

Table 2-10 – Attributes of Good Requirements (DAU, 2001)

Attribute	Definition
Achievable	Must reflect need or objective for which a solution is technically achievable at costs considered affordable
Verifiable	The expected performance and functional utility must be expressed in a manner that allows verification to be objective, preferably quantitative
Unambiguous	Must have but one possible meaning
Complete	All information necessary to understand the customer's need must be there
Implementation Independent	Expressed in terms of need, not solution; address the "why" and "what" of the need, not how to do it
Consistent	Does not conflict with other requirements
Appropriate for level of system hierarchy	Should not be too detailed that it constrains solutions for the current level of design.

2.1.10 Young Criteria of a Good Requirement (2004)

Daniels, et al believed that the criteria listed in Table 2-11 by Young represented good list of criteria for specifying a requirement, but are far from a "one size fits all" method for developing a requirement (Daniels, et al, 2004). Daniels, et al went on to mention that, despite being a good list, "whether these criteria are met is largely independent of the method used to capture the requirement and more dependent on the subject of the requirement" (Daniels, et al, 2004).

Table 2-11 – Criteria of a Good Requirement (Young, 2004)

Attribute	Definition
Necessary	If the system can meet prioritized real needs without the requirement, it isn't necessary.
Feasible	The requirement is doable and can be accomplished within budget and schedule.
Correct	The facts related to the requirement are accurate, and it is technically and legally possible.
Concise	The requirement is stated simply.
Unambiguous	The requirement can be interpreted in only one way.
Complete	All conditions under which the requirement applies are stated, and it expresses a whole idea or statement.
Consistent	It is not in conflict with other requirements.
Verifiable	Implementation of the requirement in the system can be proved.
Nonredundant	It is not a duplicate requirement.
Traceable	The source of the requirement can be traced, and it can be tracked throughout the system
Allocated	The requirement is assigned to a component of the designed system.
Design independent	It does not pose a specific implementation solution.
Written using the standard construct	The requirement is stated as an imperative using "shall."
Assigned a unique identifier	Each requirement shall have a unique identifying number.
Devoid of escape clauses	Language should not include such phrases as "if," "when," "but," "except," "unless," and "although." Language should not be speculative or general (i.e., avoid wording such as "usually," "generally," "often," "normally," and "typically").

2.1.11 Qualities of a Good Requirement (Bahill, et al, 2009)

According to Bahill, et al. (2009), in order to create a good requirement, one must base the requirement on qualities that best define a requirement. These qualities can be seen in Table 2-12.

Table 2-12 – Qualities of a Good Requirement (Bahill, et al., 2009)

Attribute	Definition
Describes What, not How	A good requirement defines what a system must do, but does not specify how to do it. A statement of a requirement should not be a preconceived solution to the problem that is to be solved.
Atomic	A requirement should not be easily broken into smaller requirements. There should be once concept per requirement.
Allocation	Each requirement should be allocated to a single entity. Don't assign one requirement to two physical components
Unique	Avoid repeating requirements
Documented and Accessible	A requirement must be documented via text, equations, images, etc and documentation must be accessible, regardless of confidentiality, etc.
Identifies Its Owner	Owner must be identified, so they can approve of changes, etc.
Identifies Its Target	A good requirement identifies for whom it is a requirement, i.e. the system, the process, the company, or the customer
Approved	A requirement must be approved by its owner
Traceable	It should be possible to trace each requirement back to its source.
Necessary	Answers: Can the system meet the customer's real needs without it? If yes, then the requirement is not necessary.
Complete	All conditions under which the requirement applies should be stated
Is Not Written Negatively	"Do not use…" is not utilized in limiting requirement
Unambiguous	Ensures that the requirement can only be interpreted in one way
Is Not Always Written	"Commonsense" requirements, that will not be written, are acceptable as long as the requirements really are common sense.
Verifiable	Quantitative values must be given in requirements. Each requirement must be verifiable by test, demonstration, inspection, logical argument, analysis, modeling, or simulation.

Table 2-12 – Qualities of a Good Requirement (Bahill, et al., 2009) Cont'd

Attribute	Definition
States Its Units of Measurement	Must define what units are being utilized (i.e. English vs. SI units)
Identifies Applicable States	Some requirements only apply when the system is in certain states or modes. If the requirement is only to be met sometimes, the requirement statement should reflect when
State Assumptions	All assumptions should be stated.
Usage of Shall, Should, and Will	A A mandayory requirement should be expressed using 'shall;' a trade-off requirement can be expressed using 'should;' and 'will' is used to express a delcaration of intent of the agency
Avoids Certain Words	The words 'optimize, maximize, and minimize' should not be used in stateing requirements, because we could never prove that we had achieved them
Might Vary in Level of Detail	The amoun of detailtquirements depends on the intended supplier.
Contains Date of Approval	Nave of the approver and the date of approval should be included in each requirement.
States ilts Rationale	Each requirement states why it was written and what it was supposed to ensure
Respects the Media	It is important to write each requirement so that it cannot spark undue public criticism of your customer or their project
Distinguishes Number	Ensure not to remove number distinctions
Consistent	Requirements should not contain contradictory statements or conditions
Uses Parameters	Using parameters rather than fixed numbers will make requirements more reusable.

It can be noted that these qualities extend well past the scope of many of the other suggested attributes to a well-written requirement. Nonetheless, according to Bahill, et al, these are important qualities that must be recognized when developing requirements (Bahill, et al., 2009).

2.1.12 Westfall Attributes for a Requirement Specification (2005)

According to Westfall (2005), during the peer review process in the requirements validation phase, the reviewers should ensure that the requirements specifications satisfy the attributes shown in Table 2-13

Table 2-13 Attributes for a Requirement Specification (Westfall, 2005)

Attribute	Definition
Complete	The requirements document includes all of the necessary requirements information.
Consistent	Internal conflicts do not exist between requirements in the document that result in the requirements contradicting each other. The requirements also do not conflict with higher-level requirements including business, user, or system level requirements. Terminology should also be used consistently within the document: o A word has the same meaning every time it is used. o Two different words are not used to mean the same thing.
Modifiable	The requirements document is organized and written in a manner that will facilitate making future change: o Nonredundant: Each requirement is stated in only one place. o Changeable: Each requirement can be changed without excessive impact on other requirements.
Unambiguous	Each requirement statement should have only one interpretation, and each requirement should be specified in a coherent, easy-to-understand manner.
Concise	Each requirement should be stated in short, specific, action-oriented language.
Finite	The requirement should not be stated in an open-ended manner.
Measurable	Specific, measurable limits or values should be stated for each requirement as appropriate.
Feasible	The requirement can be implemented using available technologies, techniques, tools, resources, and personnel within the specified cost and schedule constraints.
Testable	There exists a reasonably cost-effective way to determine that the software satisfies the requirement.
Traceable	Each requirement should be traceable back to its source. It should also be specified in a manner that allows traceability forward into the design, implementation, and tests.

2.1.13 Robertson & Robertson Tests to Formalize Potential Requirements (1999)

According to Robertson, et al. (1999), the only way to test if a requirement characteristic is adequate for that requirement is to “consistently identify those characteristics” (Robertson, et al., 1999). By identifying these characteristics, as shown in Table 2-14, it enables requirements managers to identify defects as they write the requirements.

Table 2-14 – Requirement Characteristics (Robertson, et al., 1999)

Attribute	Definition
Completeness	Identifies all components and parts that produce a functional requirement
Traceability	Ensuring that requirement can be traced back to its origin, verifying that the requirement specified is the requirement being implemented
Consistency	Ensure that requirements are written in the same language, allowing the requirement to be understood the same way by everyone
Relevancy	Ensure that requirement contributes to the purpose of the product
Correctness	Ensuring that the criterion that make a requirement are valid
Ambiguity	Ensure that the meaning of the requirement is defined
Viability	Ensuring that the requirements can be met
Solution-Bound	Ensure that the requirement is not indicating a specific solution
Gold-Plated	Ensure that a requirement is necessary, and not a "nice to have"
Creep	Ensure that requirements are not added after a set list of requirements was developed

2.1.14 Hooks and Farry Characteristics of a Well-Written Requirement (2001)

According to Hooks, et al (2001), in order to avoid project changes, one must follow a well-constructed requirements definition process, coupled with training in requirements development. Despite following these criteria and process to

developing a requirement, Hooks, et al state that “these steps do not always form a tidy little waterfall in which the output of each step flows neatly to the next; rather, this is often an iterative process.” (Hooks, et al, 2001).

Table 2-15 – Characteristics of a Well-Written Requirement (Hooks, et al, 2001)

Attribute	Definition
Necessary	The requirement must be needed for the product to function
Verifiable	The requirement must be verified via inspection, analysis, testing, modeling, demonstrations, etc
Attainable	The requirement must be feasible - do not write a requirement that cannot be met
Unambiguous	The requirement must be clear and understood
Consistent	The requirement must follow the same standard terminology
Concise	The requirement should be express a single thought and be short and to the point
State Positively	The requirement must not be negative, as it's hard to test something that should not happen
Correct	The requirement must be factually and grammatically correct
Traceablilty	The requirement can be traced back to its origin
Non-Contradictory	The requirement cannot contradict another requirement

2.1.15 Davis, et al. Attributes to Quality Requirements (1993)

According to Davis, et al (1993), in order to develop a quality requirement, one must have the appropriate attributes, as shown in Table 2-16. Without following these attributes, requirement writers will be unable to develop a requirement that contributes to a successful and cost-effective project (Davis, et al, 1993).

Table 2-16 – Attributes to Quality Requirements (Davis, et al, 1993)

Attribute	Definition
Unambiguous	Requirement has only one possible interpretation
Complete	Requirement satisfies all aspects, and nothing is left to be determined
Correct	Requirement represents something required of the system
Understandable	Requirement meaning is easily comprehended by all readers with minumal explanation
Verifiable	Requirement can be tested/verified with cost effective techniques
Internally Consistent	Requirement does not conflict with any individual requirement listed
Externally Consistent	Requirement does not conflict with baseline project documentation
Achievable	Requirement can be successfully implemented with system design
Concise	Requirement is short without affecting quality
Design Independent	Requirement is not dependent on a single system design
Traceable	Requirement can be referenced to its origin
Modifiable	Requirement is structured so that changes can be made easily
Electronically Stored	Requirement has been stored in a word processor and generated from a requirements database or other form therein
Executable/ Interpretable	Requirement can be satisfied if a tool can provide a dynamic behavioral model
Annotated by Relative Importance	Requirement importance/priority can be easily determined
Annotated by Relative Stability	Requirement can be determined for most likely to change
Annotated by Version	Requirement can be easily determined by which versions of product
Not Redundant	Requirement is not stated multiple times
At Right Level of Detail	Requirement is not too abstract, but not too detailed, but representative of how product will be used

Table 2-16 – Attributes to Quality Requirements (Davis, et al, 1993) cont'd

Attribute	Definition
Precise	Requirement uses numeric quantities to define need
Reusable	Requirement content can be adapted for use in other requirements
Traced	Requirement origin is clear
Organized	Requirements are arranged for ease of locating information and relationships
Cross-Referenced	Requirements are linked to other requirements needed to fulfill this requirement

2.1.16 Basili et al. Requirements Characteristics (1981)

According to Basili, et al (1981), Table 2-17 depicts characteristics for requirements of early software projects. While this data is over 30 years old, these characteristics are still found important today.

Table 2-17 – Requirements Characteristics (Basili, et al, 1981)

Attribute	Definition
Correct	Requirement must be correct
Complete	Requirement must specify necessary constraints, etc for implementation
Verifiable	Requirement should be able to be tested for errors, etc
Necessary	Requirement must be useful
Modifiable	Requirement must be easy to change
Unambiguous	Requirement is easily understood with one interpretation
Traceable	Requirement must be capable of being referenced

2.1.17 Celko, et al. Requirements Characteristics (1983)

During their review of requirements tools used by the US Air Force, Celko, et al (1983) identified requirements characteristics, as shown in Table 2-18. By utilizing these types characteristics when developing a requirements

writing/developing tool, Cleko, et al determined that fewer errors would occur during the requirements writing process (Cleko, et al., 1983).

Table 2-18 – Requirements Characteristics (Celko, et al, 1983)

Attribute	Definition
Unambiguous	Requirement must be easily understood and have on interpretation
Complete	Requirements must be fully defined for system
Understandable	Requirement must be understood by user and developer
Verifiable	Requirement must be capable of testing for errors, etc
Consistent	Requirement must be consistent with remainder of requirements and not have several different definitions
Traced	Requirement needs to be capable of being traced back to its source

2.1.18 ESA BSSC Characteristics of Realistic User Requirements (1995)

According to the ESA BSSC (1995), in order to successfully establish a program, its requirements must be realistic. Table 2-19 describes the characteristics they believe are essential in order to capture a realistic user requirement.

Table 2-19 – Characteristics of Realistic User Requirements (ESA BSSC, 1995)

Attribute	Definition
Clear	Requirement must not be ambiguous and have only one interpretation
Verifiable	Requirement must be able to be tested
Complete	Requirement must define user needs completely
Accurate	Requirement must meet the user needs
Feasible	Requirement must be achievable

2.1.19 Rombach Attributes to Requirements (1989)

Rombach states that a specification for a project can be broken down into aspects and attributes of the product (Rombach, 1989). For each aspect, certain attributes can be utilized to best describe them. Table 2-20 lists the attributes that requirements specifications should have in order to define a well-written requirement.

Table 2-20 – Attributes to Requirements (Rombach, 1989)

Attribute	Definition
Correctness	Requirements must be satisfied
Completeness	Requirements contain all relevant information
Consistency	Requirements have no internal or external conflicts
Feasibility	Requirements are satisfied within the constraints of the program
Non-ambiguity	Requirements have no other interpretations
Clarity	Requirements are easily understood
Preciseness	Requirements meaning are exact
Formality	Requirements demonstrate formal syntax
Abstractness	Requirements have proper amount of information/description
Structuredness/Modularity	Requirements demonstrate systematic structure
Traceability	Requirements can be related to other corresponding products or processes
Modifiability	Requirements can be changed easily when needed
Executability	Requirements must be able to be validated
Verifiability	Requirements can be tested for consistency

2.1.20 Lamsweerde Requirement Quality Factors (2009)

Lamsweerde (2009) states that, while difficult, in order to produce a good requirement one must account for multiple and diverse quality factors. These quality factors, as shown in Table 2-21, enable requirements writers to have a basis to evaluate the requirements being written.

Table 2-21 – Requirement Quality Factors (Lamsweerde, 2009)

Attribute	Definition
Completeness	Requirement must be sufficient to ensure that the system -to-be will satisfy all its objectives
Consistency	The requirements, assumptions and domain properties must be compatible with each other
Adequacy	Requirement must address the actual needs for a system
Unambiguity	The requirements, assumptions and domain properties must be formulated in a way that there is only one interpretation. Every term must be defined and used consistently
Measurability	Requirement must be formulated in such a way that enables analysts to evaluate alternative options against them, developers to test/verify them, and user to determine whether they are met or not under operation
Pertinence	The requirements and assumptions must all contribute to the satisfaction of one or several objectives of the system-to-be
Feasibility	The requirements must be realizable in current budget, schedule and technology constraints
Comprehens-ibility	The requirements, assumptions, and omain properties must be comprehensible by user
Good Structuring	The requirements document should be organized in a way that highlights the structural links among its elements
Modifiability	The requirements should be capablie of being revised, adapted, or extended as necssary
Traceability	The context in which an item of the requirements document was created, modified or used should be easy to retrieve

Lamsweerde (2009) went on to highlight that completeness, adequacy and pertinence are relatively defined in accordance with the system they are intended to describe. This makes the defining of these qualities very difficult to fully enforce because there is no absolute measurement to compare them to. (Lamsweerde, 2009)

2.1.21 Wiegers Writing Quality Requirements (1999)

In order to identify problematic requirement statements, according to Wiegers (1999), the attributes listed in Table 2-22 are very important in distinguishing between a good and bad requirement. These characteristics form a baseline for the development of the requirement, and can provide guidance for testing to determine if the requirement is adequate.

Table 2-22 Characteristics of Quality Requirement Statements (Wiegers, 1999)

Attribute	Definition
Correct	Each requirement must accurately describe the functionality to be delivered
Feasible	It must be possible to implement each requirement within the known capabilities and limitations of the system and its environment
Necessary	Each requirement should document something the customers really need or something that is required for conformance to an external requirement, an external interface, or a standard
Prioritized	Assign an implementation priority to each requirement, feature or use case to indicate how essential it is to include it in a particular product release
Unambiguous	The reader of a requirement statement should be able to draw only one interpretation of it
Verifiable	See whether you can devise tests or use other verification approaches to determine whether each requirement is properly implemented in the product
Complete	No requirements or necessary information should be missing
Consistent	Consistent requirements do not conflict with other requirements
Modifiable	Must be able to revise the requirement when necessary and maintain the history of changes made to each requirement
Traceable	You should be able to link each requirement to its source, which could be a higher-level system requirement, a use case, or a voice-of-the-customer statement

2.2 Requirements Writing Guide Comparisons

As demonstrated in Section 2.1, there are many different lists of attributes, and each author uses the attributes they feel most strongly define a requirement. It is not the intent of this research to create a definitive list of requirement attributes, but utilize one list as the baseline for the study. Davis' 13 Attributes to a Well-Written Requirement (1993) were utilized in this study as the basis for the attributes to materiel and non-materiel solution sets.

In order to demonstrate that Davis' 13 is an adequate representation of requirement attributes, a comparison of these attributes was made to other requirements writing guides. A working group of requirements subject matter experts was utilized to determine linkages between the various lists of attributes. Participants in the working group had a minimum of three years experience in requirements writing/systems engineering. There were no limitations on education level or positions held, though participants were required to be in the acquisition field (either private or government) or government resource sponsors. Table 2-23 is the result of these linkages. It can be noted that not all attributes found in Section 2.1 are mentioned in this table. While they are considered important for requirements writing, the purpose of this comparison was to demonstrate that Davis' 13 encompasses similar attributes to various other guides.

Table 2-23 – Requirements Writing Guide Comparison List

Attribute / Requirement Guide	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Davis, 1993	X	X	X	X	X	X	X	X	X	X	X	X	X
IEEEGuide for Developing System Requirements Specifications, 1998		X		X					X				
IEEE Recommended Practice for Software Requirements, 1998	X	X	X	X	X		X		X		X		
DoD Std Practice, 2008	X		X	X	X				X	X		X	
Dick, et al, 2012	X	X	X	X	X							X	
Rajnish, et al., 2010	X	X	X	X	X		X		X		X		
Hull, et al, 2011		X	X	X	X								
Hood, et al., 2008	X	X	X	X	X	X			X				X
DAU, 2001		X	X	X	X					X			
Young, 2004	X	X	X	X	X				X	X	X	X	X
Bahill, et al., 2009	X	X	X	X	X				X				X
Westfall, et al.,		X	X	X	X		X		X			X	
Roberston, et al., 1999	X	X	X	X	X				X				
Hooks, et al., 2001	X	X		X	X				X			X	
Davis, et al., 1993	X	X	X	X	X	X	X	X	X	X	X		X
Basili, et al., 1981	X	X	X	X			X		X				
Celko, et al., 1983		X	X	X	X	X		X					
ESA BSSC, 1995	X	X	X	X									
Rombach, 1989	X	X	X	X	X		X		X			X	X
Lamsweerde, 2009		X	X		X	X	X		X				X
Wiegers, 1999	X	X	X	X	X		X		X		X		

Table 2-23 demonstrates that Davis' 13 utilizes similar attributes to the requirements guides that were referenced, though it does not include all the attributes that were deemed important by all the authors. With this information, it is shown that utilizing Davis' 13 in this study is a fair representation of attributes for a well-written requirement.

3 RESEARCH METHODOLOGY

The data collected in this research was done so via a discrete choice model. By utilizing a multinomial discrete choice model, the researcher is able to define and differentiate between two or more discrete alternatives and, based on

participants' preferences, produce a ranking of importance of these alternatives (Agresti, A., 2002).

A discrete choice model, per its definition, is only meant to analyze a finite number of alternatives. These models can be used in a wide array of different studies relating to economics, user preference such as car selection (Train, 1986), which college to attend (Fuller et al, 1982), or even new product development (Moore, et al, 1999) and health services deployment (Hall et al, 2002). There is no real limit where discrete choice models can be applied, which provides a diverse range of studies where it can be utilized.

With the data collected, there are different methods in which it can be analyzed. This section covers various analysis methods that are used to analyze and rank data and analyze pairwise comparisons.

3.1 Kruskall-Wallace One-Way Analysis of Variance by Ranks (KW)

The KW method is utilized for rank-order data where two or more independent factors are being compared. In order to utilize this method, the data being collected must be rank-order format, or the data has been transformed into a rank-order format from an interval/ratio format (Sheeskin, 2000). The latter is the case when samples taken were originally to be analyzed by ANOVA, but one or more assumptions have been violated and can't be used.

Prior to using KW, four assumptions must be satisfied (Sheskin, 2000):

1) Samples must be randomly selected from the population it represents;

2) The *k* samples are independent of one another;

3) The dependent variable is a continuous random variable. Per Sheskin, "…this assumption, which is common to many nonparametric tests, is often not adhered to, in that such tests are often employed with a dependent variable that represents a discrete random variable." (Sheskin, 2000)

4) "The underlying distributions from which the samples are derived are identical in shape. The shapes of the underlying population distributions, however, do not have to be normal." (Sheskin, 2000)

If any of these assumptions are not followed, the calculations performed will be compromised.

After verifying that the assumptions are met, the following steps are followed to perform KW (Sheskin, 2000):

1. Develop a Null Hypothesis and Alternative Hypotheses, using equation (3-1) and (3-2):

Null - $H_0: \mu_1 = \mu_2 = \ldots = \mu_k$ (3-1)

Alternative - $H_1: Not\ H_0$ (3-2)

Where k = number of attributes and μ_k = Attribute k

In order to reject the null hypothesis, the H value calculated (equation (3-5)) must be equal to or greater than the chi-squared (χ^2) table depending on the confidence level chosen (.95 or .99) or calculated using software such as XLSTAT in Microsoft Excel.

2. Determine the total number of data points, using equation (3-3):

$$N = n_1 + n_2 + \cdots + n_k \quad (3\text{-}3)$$

Where n = number of participants in survey

3. Determine the sum of ranks (R_k) for each attribute, using equation (3-4):

$$\Sigma R_k = r_1 + r_2 + \cdots + r_n \tag{3-4}$$

Where r_n = the rankings for Attribute k by *n* participants

4. Calculate the KW test statistic (*H*), using equation (3-5)*:*

$$H = \frac{12}{N(N-1)} \sum_{j=1}^{k} \left[\frac{(\sum R_j)^2}{n_j} \right] - 3(N+1) \tag{3-5}$$

5. In order to find the χ^2 value, the degree of freedom must be calculated, using equation (3-6):

$$df = k - 1 \tag{3-6}$$

6. Determine the Tie Correction (*C*), using equation (3-7), if there are an excessive amount of ties in the overall distribution of *N* scores (Sheskin, 2000):

$$C = 1 - \frac{\sum_{i-1}^{s} (t_i^3 - t_i)}{N^3 - N} \tag{3-7}$$

Where: *s* = The number of sets of ties

t_i = The number of tied scores in the i^{th} set of ties

7. Determine H tie-corrected (H_C), using equation (3-8):

$$H_C = \frac{H}{C} \tag{3-8}$$

By using KW, the researcher is able to reduce or eliminate the impact of outliers that might compromise the data and provide an accurate means of determining rankings with non-normally distributed data. (Sheskin, 2000)

The KW method can be applied to many different problems. In literature, this ranged from applications in calculating statistical differences in biomedical research (Theodorsson-Norheim, 1986) to analyzing the performance of Japanese postal services (Sueyoshi, et al, 2000). Another study that analyzes similar aspects to the current research was undertaken by Hui, et al. (1995),

where they utilized KW to analyze attributes to the meat industry to rank the attributes to determine which attribute was the biggest cause to the declining consumption of meat in the 90s (Hui, et al., 1995). When comparing all these studies, a linkage can be drawn to the analysis undertaken during this research, which is further expanded up in Section 4.3.3.3.1.

3.2 The Single-Factor Between-Subjects Analysis of Variance (ANOVA)

The Single-Factor Between-Subjects Analysis of Variance (ANOVA) is a statistical tool that is utilized to determine if there is a difference between at least two means in a set of data where two or more means are being compared.

Prior to using ANOVA, three assumptions must be satisfied (Sheskin, 2000):

1) Samples must be randomly selected from the population it represents;

2) Distribution of data in the population from which the samples are derived is normal;

3) Ensure homogeneity of variance – "Variances of the k underlying populations represented by the k samples are equal to one another." (Sheskin, 2000)

If any of these assumptions are not followed, the calculations performed will be compromised.

After verifying that the data collected is an accurate, normalized representation, the following steps are followed to perform ANOVA (Sheskin, 2000):

1. Develop a Null Hypothesis and Alternative Hypotheses, using equations (3-9) and (3-10):

$$\text{Null} - H_o: \mu_1 = \mu_2 = \cdots = \mu_k \tag{3-9}$$

Alternative $-H_1: Not\ H_0$ (3-10)

Where k = number of attributes and μ_k = Attribute k

In order to reject the null hypothesis, the F value calculated (equation ((3-21) must be greater than the F value (F_V) retrieved from the F value table depending on the confidence level chosen (.95 or .99) or calculated using software such as XLSTAT in Microsoft Excel.

2. Determine the total number of data points, using equation (3-11):

$$N = n_1 + n_2 + \cdots + n_k \quad (3\text{-}11)$$

Where n = number of participants in survey

3. Determine the total sum of scores (X_T) of N subjects who participated in survey, using equation (3-12):

$$\Sigma X_T = \Sigma X_1 + \Sigma X_2 + \cdots + \Sigma X_k \quad (3\text{-}12)$$

Where X_k = the sum of rankings for Attribute k

4. Determine the total sum of squared scores of N subjects who participated in survey using equation (3-13):

$$\Sigma X_T^2 = \Sigma X_1^2 + \Sigma X_2^2 + \cdots + \Sigma X_k^2 \quad (3\text{-}13)$$

5. Determine the total variability (SS_T), equation (3-14). Total variability is broken into the variability between groups (SS_{BG}), equation (3-15), and variability within groups (SS_{WG}), equation (3-16), and can be explained as follows:

$$SS_T = SS_{BG} + SS_{WG} \quad (3\text{-}14)$$

$$SS_{BG} = \sum_{j=1}^{k} \left[\frac{(\Sigma X_j)^2}{n_j}\right] - \frac{(\Sigma X_T)^2}{N} \quad (3\text{-}15)$$

$$SS_{WG} = \sum_{j=1}^{k} \left[\Sigma X_j^2 - \frac{(\Sigma X_j)^2}{n_j}\right] \quad (3\text{-}16)$$

6. Determine the Mean Square of the variance between-groups (MS_{BG}), equation (3-17), and variance within-groups (MS_{WG}), equation (3-19):

$$MS_{BG} = \frac{SS_{BG}}{df_{BG}} \tag{3-17}$$

where the between groups degrees of freedom (df_{BG}) is found using equation (3-18):

$$df_{BG} = k - 1 \tag{3-18}$$

$$MS_{WG} = \frac{SS_{WG}}{df_{WG}} \tag{3-19}$$

where the within groups degrees of freedom (df_{WG}) is:

$$df_{WG} = N - k \tag{3-20}$$

7. Determine the $F_{CALCULATED}$ ratio, using equation (3-21):

$$F_{CALCULATED} = \frac{MS_{BG}}{MS_{WG}} \tag{3-21}$$

It is important to note Assumption 2 for ANOVA: all data to be normally distributed. This means that this method cannot be utilized for determining variances of ranked data, because participant ranked data is not normally distributed. This is an important assumption to follow, because a researcher is unable to utilize ANOVA when analyzing ranked data, and must rely on other analysis methods such as KW.

As stated by Gelman, “ANOVA is an extremely important method in exploratory and confirmatory data analysis (Gelman, 2005),” and as suggested by the title of his paper, is more important than ever. The use of this analysis method for analyzing data ranges from political preferences (Gelman, 2005), to ecological studies (Shaw, et al., 1993), to ranking of attributes for successors to a

family business (Chrisman, et al., 1998). The study undertaken by Chrisman, et al. (1998) was very similar to this study, where participants were asked to provide weights of importance for attributes, but the data collected by Chrisman was normally distributed, while the ranked data in this study was non-normally distributed. It is important to note that ANOVA is very versatile, but only as long as the assumptions are followed. If any of these assumptions are compromised, then this method is not appropriate for use.

3.3 Bradley-Terry

The Bradley-Terry model (Bradley, et al., 1952) was introduced as a method in which to analyze paired comparisons and develop an estimation of rankings or preferences of the evaluator. The origination of this development was actually to compare food-tasting preferences among users. The Bradley-Terry (BT) Method consists of three main parts: expert judgment analysis – determining circular triads, a coefficient of agreement metric and coefficient of concordance metric; probability statement used for determining the rankings of importance of items being compared; and a goodness of fit metric to determine the appropriateness of the data. By combining these three parts, this makes the Bradley-Terry model a very powerful statistical tool for determining participant preferences when analyzing pairwise comparisons.

Due to the actual complexities of performing Bradley-Terry calculations for a pairwise comparison example, the actual derivations are not expounded upon. These derivations are covered extensively in literature (Agresti, 2002; Bradley, R. A., & Terry, M. E. 1952; Cooke, R. M. 1991; Davidson, R. R. 1970; Hunter, D. R.

2004 to name a few) and not necessary for the scope of this publication. Instead, a high level overview will be done to explain the different parts of the model and their function.

1. Expert Judgment Analysis:

When collecting data from expert practitioners, there is always a risk that the experts answer at random instead of providing a true preference into the selection of their criteria. In order to determine if this is not the case, circular triads must be analyzed in their comparisons. The actually analysis of the experts is done in three sections: Identification of circular triads – i.e. did the expert answer at random or truthfully, coefficient of agreement among experts and coefficient of concordance among experts.

1.1 Defining Circular Triads

As stated by Mazzuchi, et al (2008), a circular triad can be defined as when the expert suggests that $E_1 > E_2 > E_3$ and $E_3 > E_1$, which violates the transitivity property. Despite this occurrence, when comparing a large number of items, etc, a few circular triads do in fact exist. (Mazzuchi, et al, 2008)

Prior to performing an in depth analysis of circular triads amongst the expert judgment, two hypotheses need to be developed (equation (3-22) and (3-23)).

$$H_0 = Expert\ answered\ randomly \quad (3\text{-}22)$$

$$H_1 = Expert\ answered\ form\ an\ actual\ preference\ structure \quad (3\text{-}23)$$

In order to determine the number of circular triads found in expert preferences, David (1963) developed equation (3-24).

$$c(r) = \frac{n(n^2-1)}{24} - \frac{1}{2}\sum_{i=1}^{n}\left(N_r(i) - \frac{1}{2}(n-1)\right)^2 \quad (3\text{-}24)$$

In this equation, David provides a procedure for testing the hypothesis that each preference is determined at random (Cooke, 1991).

Additionally, Kendall (1962) developed probability tables that defined certain values of *c(r)* that are exceeded under the null hypothesis that the expert answered in a random fashion for *n* = 2 through 10. In order to demonstrate this, Kendall developed equation (3-25) to compare *n* items in a random fashion.

$$c'(r) = \frac{n(n-1)(n-2)}{(n-4)^2} + \left(\frac{8}{n-4}\right) * \left[\left(\frac{1}{4}\right)\binom{n}{3} - c(r) + \frac{1}{2}\right] \quad (3\text{-}25)$$

When *n*>7, *c'(r)* has approximately a chi-squared distribution with (*n*(*n*-1)(*n*-2))/(*n*-4)^2 degrees of freedom.

By using *c'(r)*, the researcher is able to test the null hypothesis that an expert answered randomly. If the null hypothesis for any expert cannot be rejected at the 5% level of significance, the expert should be dropped from the analysis. By performing this step, this ensures that the researcher is using the best data for the analysis they are performing.

1.2 Coefficient of Agreement

In order to determine a coefficient of agreement, the following hypotheses are made (equation (3-26) and (3-27)):

$$H_0 = All\ agreements\ of\ experts\ are\ due\ to\ chance \tag{3-26}$$

$$H_1 = Not\ H_0 \tag{3-27}$$

The term coefficient of agreement is defined by Kendall (1962) as shown in equation (3-28), which tests the null hypothesis for small values of *n* and *e*. When *u* attains its maximum, 1, there is complete agreement (Cooke, 1991).

$$u = \frac{2\sum_{i=1}^{t}\sum_{j=1,j\neq i}^{t}\left(\frac{N(i,j)}{2}\right)}{\binom{e}{2}\binom{n}{2}} \tag{3-28}$$

Where *N(i,j)* denotes the number of times experts ranked *Ei* more severe than *Ej* (Mazzuchi, et al, 2008).

For larger values of *n* and *e*, Kendall (1962) tests the null hypothesis utilizing equation (3-29).

$$u' = \frac{4\left[\sum_{i=1}^{n}\sum_{j=1,j\neq i}^{n}\binom{N(i,j)}{2} - \frac{1}{2}\binom{e}{2}\binom{n}{2}\frac{(e-3)}{(e-2)}\right]}{e-2} \tag{3-29}$$

Where *u'* has a chi squared distribution with $\binom{n}{2}e(e\text{-}1)(e\text{-}2)^2$ degrees of freedom.

By using *u'*, the researcher is able to test the null hypothesis that all agreements of experts are due to chance. If the null hypothesis for any expert

cannot be rejected at the 5% level of significance, the expert should be dropped from the analysis.

1.3 Coefficient of Concordance

In order to determine a coefficient of concordance, the following hypotheses are made (equation (3-30) and (3-31)):

$$H_0 = Expert\ preferences\ are\ at\ random \tag{3-30}$$

$$H_1 = Not\ H_0 \tag{3-31}$$

The term coefficient of concordance is defined by Siegel (1956) as shown by equation (3-32).

$$w = \frac{\sum_{i=1}^{n}\left[\sum_{r=1}^{e} R(i,j) - \frac{\sum_{j=1}^{n}\sum_{r=1}^{e} R(j,r)}{n}\right]^2}{\frac{1}{12}e^2(n^3 - n)} \tag{3-32}$$

Siegel (1956) further tests the null hypothesis for values $3 \leq n \leq 7$ and $3 \leq e \leq 20$ by utilizing equation (3-33).

$$w' = \frac{\sum_{i=1}^{n}\left[\sum_{r=1}^{e} R(i,j) - \frac{\sum_{j=1}^{n}\sum_{r=1}^{e} R(j,r)}{n}\right]^2}{\frac{1}{12}en(n+1)} \tag{3-33}$$

Where $R(i,j)$ denotes the rank of E_j obtained through expert r's responses (Mazzuchi, et al, 2008). Similar to u in the coefficient of agreement, when w is equal to 1, the experts are in complete agreement.

By using *w'*, the researcher is able to test the null hypothesis that all preferences of experts are at random. If the null hypothesis for any expert cannot be rejected at the 5% level of significance, the expert should be dropped from the analysis.

2. Determining the Probability Statement:

Once the researcher performs the analysis of experts on the data collected, thus removing any outlying experts that failed the 5% level of significance, the actual probability statement can be formed and executed. According to Bradley, et al., (1952), this method develops two hypotheses (equations (3-34) and (3-35)):

$$H_0 = Ratings\ of\ subjects\ being\ compared\ are\ equal \tag{3-34}$$

$$H_1 = Ratings\ oare\ not\ assumed\ equal\ for\ all\ subjects\ being\ compared \tag{3-35}$$

Once the hypotheses are established utilizing equations (3-34) and (3-35), the probability statement can be established for determining which of the subjects being compared are more probable to be picked. In his publication, Hunter (2004) provided a simplified derivation of this step, demonstrated in equation (3-36).

$$P(i \text{ beats } j) = \frac{\gamma_i}{\gamma_i + \gamma_j} \tag{3-36}$$

Where γ_i = positive-valued parameter related to *i* for each of the comparisons of *i* against *j* (Hunter, 2004). An example of applying equation (3-36) is to assume *i* and *j* are sports teams where γ_i and γ_j represents the skill of each team, respectively. With this probability statement, given the skill levels for each team,

the researcher is able to determine what would the likelihood or probability be that Team *i* will beat Team *j.* (Hunter, 2004)

3. Developing the Goodness of Fit

The goodness of fit metric utilized in the Bradley-Terry model is a statistical test to determine the appropriateness of the model. Equation (3-37) demonstrates this calculation based on the null hypotheses that the model is appropriate:

$$F = 2\left\{\sum_{\substack{i,j\neq 1 \\ i\neq j}}^{t} a(ij)\ln[P(i\ beats\ j)] - \sum_{i=1}^{t} a(i)\ln[\gamma_i] + \sum_{i<j} nln[\gamma_i + \gamma_j]\right\} \quad (3\text{-}37)$$

Where *F* is distributed as a chi squared distribution with (*t*-1)(*t*-2)/2 degrees of freedom. (Cooke, 1991)

Due to the complexity of the Bradley-Terry model and its calculations, computer based regression analysis tools are recommended once the data is ready to be analyzed. It should be noted that an important aspect of utilizing the Bradley-Terry Model is that by following a logarithmic approach, it allows the user to determine the consistency of the expert's preference in their decision between comparisons. By providing a "goodness of fit" metric, identifying circular triads, coefficient of agreements and a coefficient of concordance, the researcher is able to identify the accuracy in which a participant provided their data when compared amongst themselves as well as how consistent the data is to the

"ideal" solution, showing outlying decisions that do not fall within the range of acceptable choices and aids in ensuring that the data being analyzed is accurate.

The Bradley-Terry Method has been applied to many different problems over time, from determining ranking of sports teams (Agresti, 2002, Simons, et al., 1999), to determining the role of statistics journals in communication in related fields (Stigler, 1994), to genetic testing in medicine (Sham, et al., 1995). Utilizing the Bradley-Terry method in each of these examples enabled the authors to compare interrelated items and determine the preferred or ranked solution. These problems followed similar logic to the comparisons made during this research as well, which are further expanded upon in Section 4.3.3.4.1.

3.4 Saaty's Pairwise Comparison

Thomas Saaty developed a method of pairwise comparison, which can be utilized in conjunction or separately of Analytic Hierarchy Process (AHP), to determine weights of factors being evaluated. The process for this pairwise comparison is as follows (Saaty, 2008):

1. Select factors for comparison

2. Utilize evaluators to provide input for the importance of the factors being compared. Saaty's pairwise comparison is based from a 1-9 scale, as shown in Table 3-1, which provides guidance to the evaluator on the "importance" of the factors being compared.

Table 3-1 – Pairwise Comparison Measurement Scale (Saaty, 2008)

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activites contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1-1.9	If the activities are very close	May be difficult to assign the best value, but when compared with other contrasting activities the xize of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities

3. Input the data received by the evaluators into the reciprocal matrix, as seen in equation (3-38). The reciprocal matrix is constructed utilizing the importance ratings in Table 3-1.

$$R = \begin{bmatrix} 1 & A & B \\ 1/A & 1 & C \\ 1/B & 1/C & 1 \end{bmatrix} \quad (3\text{-}38)$$

Where *A* = comparison of Factor 1 to Factor 2

B = comparison of Factor 1 to Factor 3

C = comparison of Factor 2 to Factor 3

4. With the reciprocal matrix completed, compute importance ratings by utilizing the comparison matrix.

4.1. Sum the columns as shown in Table 3-2.

Table 3-2 – Comparison Matrix Summing of Columns

	Factor 1	Factor 2	Factor 3
Factor 1	1	A	B
Factor 2	1/A	1	C
Factor 3	1/B	1/C	1
Column Totals	1+1/A+1/B	A+1+1/C	B+C+1

4.2. Divide each value by the column sum, as shown in Table 3-3, and sum the rows to determine the ranking of the factor.

Table 3-3 – Comparison Matrix Dividing Each Value by Column Sum

	Factor 1	Factor 2	Factor 3	Ranking
Factor 1	1/(1+1/A+1/B)	A/(A+1+1/C)	B/(B+C+1)	(1/(1+1/A+1/B))+ (A/(A+1+1/C))+(B/(B+C+1))
Factor 2	(1/A)/(1+1/A+1/B)	1/(A+1+1/C)	C/(B+C+1)	((1/A)/(1+1/A+1/B))+ (1/(A+1+1/C))+(C/(B+C+1))
Factor 3	(1/B)/((1+1/A+1/B)	(1/C)/(A+1+1/C)	1/(B+C+1)	((1/B)/((1+1/A+1/B))+ ((1/C)/(A+1+1/C))+(1/(B+C+1))
			Sum of Rankings	1

It should be noted that the sum of the rankings column should always equal 1 once completed. If this is not the case, an error has been made.

5. Perform Saaty's Test of consistency by performing the following steps:

5.1. Calculate the Weighted Sum Vector (*WSV*) as shown in equation (3-39). This calculation multiplies the reciprocal matrix by the rankings found in Table 3-3.

$$WSV = \begin{bmatrix} 1 & A & B \\ 1/A & 1 & C \\ 1/B & 1/C & 1 \end{bmatrix} X \begin{bmatrix} \frac{1}{1+1/A+1/B} + \frac{A}{A+1+1/C} + \frac{B}{B+C+1} \\ \frac{1/A}{1+1/A+1/B} + \frac{1}{A+1+1/C} + \frac{C}{B+C+1} \\ \frac{1/B}{1+1/A+1/B} + \frac{1/C}{A+1+1/C} + \frac{1}{B+C+1} \end{bmatrix} \quad (3\text{-}39)$$

5.2. Calculate the Consistency Vector (*CV*) as shown in equation (3-40). This divides the *WSV* calculated in equation (3-39) by the rankings calculated in Table 3-3.

$$CV = WSV / \begin{bmatrix} \frac{1}{1+1/A+1/B} + \frac{A}{A+1+1/C} + \frac{B}{B+C+1} \\ \frac{1/A}{1+1/A+1/B} + \frac{1}{A+1+1/C} + \frac{C}{B+C+1} \\ \frac{1/B}{1+1/A+1/B} + \frac{1/C}{A+1+1/C} + \frac{1}{B+C+1} \end{bmatrix} \quad (3\text{-}40)$$

5.3 Calculate the average of the values in the *CV* matrix found by equation (3-40) to find the largest eigenvalue of the comparison matrix (λ_{MAX}). For the example above, sum the three values in the *CV* matrix and divide by three.

5.4. Determine the Consistency Index (*CI*) as shown in equation (3-41).

$$CI = \frac{\lambda_{MAX} - n}{n - 1} \tag{3-41}$$

Where *n* = size of the matrix. For the example given, *n* = 3.

5.5 Calculate the Consistency Ratio (*CR*) as shown in equation (3-42). The *CR* is calculated utilizing the *CI* calculated in equation (3-41) and the Random Consistency Index (*RI*), as shown in Table 3-4, based upon how many factors are being compared.

$$CR = \frac{CI}{RI} \tag{3-42}$$

Table 3-4 – Random Consistency Index (*RI*) Values (Alonzo, et al., 2006)

	Oak Ridge	Wharton	Golden Wang	Lane, Verdini	Forman	Noble	Tumala, Wan	Aguaron et al	Alonso, Lamata
	100	500	1000	2500		500		100000	100000
3	0.382	0.58	0.5799	0.52	0.5233	0.49	0.500	0.525	0.5245
4	0.946	0.90	0.8921	0.87	0.8860	0.82	0.834	0.882	0.8815
5	1.220	1.12	1.1159	1.10	1.1098	1.03	1.046	1.115	1.1086
6	1.032	1.24	1.2358	1.25	1.2539	1.16	1.178	1.252	1.2479
7	1.468	1.32	1.3322	1.34	1.3451	1.25	1.267	1.341	1.3417
8	1.402	1.41	1.3952	1.40		1.31	1.326	1.404	1.4056
9	1.350	1.45	1.4537	1.45		1.36	1.369	1.452	1.4499
10	1.464	1.49	1.4882	1.49		1.39	1.406	1.484	1.4854
11	1.576	1.51	1.5117			1.42	1.433	1.513	1.5141
12	1.476		1.5356	1.54		1.44	1.456	1.535	1.5365
13	1.564		1.5571			1.46	1.474	1.555	1.5551
14	1.568		1.5714	1.57		1.48	1.491	1.570	1.5713
15	1.586		1.5831			1.49	1.501	1.583	1.5838

Table 3-4 is a compilation of various authors' calculations of *RI*, including Saaty while he was at Wharton. When creating this table, Alonzo, et al. (2006), demonstrated that, while variances occur between the values of *RI*, overall these values were very similar (Alonzo, et al., 2006). This table was utilized in order to

show values of *RI* past the initial 10 referenced by Saaty (1980), since this study utilizes 13 factors to be compared.

Saaty's Pairwise Comparison has been utilized throughout literature through the use of AHP. AHP enables users to compare selections of jobs (Saaty, 2008) to picking suppliers (Nydick, et al., 1992). The biggest benefit to using this type of pairwise comparison is it enables the user to create a ranked or weighted list of factors based on evaluator preferences. It is for these reasons that this type of comparison is important for the problems being undertaken by this study, which will be further expanded upon in Section 4.3.3.4.2.

4 METHODOLOGY

4.1 Research Goals

The goal of this research was to determine if there were variances in importance levels of requirement attributes for materiel and non-materiel solution sets. This research should show that there is a difference in attributes between the two solution sets, demonstrate a potential priority order of these attributes and should be helpful to the DoD to reduce cost and schedule overruns by developing requirements that are feasible and achievable. The specific objectives of this research included: identify attributes for a well-written requirement for materiel and non-materiel solutions; develop and conduct a case study soliciting expert practitioners to rank requirement attributes for both solutions sets; compare the selected attributes with those used in military and scholarly institutions.

This research is not intended to recommend a single list of attributes for a well-written requirement, but provide an example of a well-documented attribute list and how it relates to each solution set based on expert judgment. Additionally, this research did not set a goal to compare various analysis methods of discrete choice models, but KW, Bradley-Terry and Saaty's pairwise comparison were utilized to demonstrate general ranking comparisons.

4.2 Research Method

This research method followed a four-phase process as shown in Figure 4-1. This process includes: the problem phase, the solicitation phase, the analysis phase and the results phase. The problem phase included a review of how DoD writes its requirements and of DAU's curriculum for requirements managers and how attributes for a materiel and non-materiel solution set are defined followed by a review of different requirement writing guidelines to determine a list of requirement attributes. Davis' 13 (Davis, 1993) was selected because it is a well-established list to use as a reference for this research. A reference hierarchy was developed based on these requirement attributes as seen in Figure 4-2. This hierarchy depicts the problem to be solved, starting with the type of solution, the attributes (in no particular order) and the final user requirement. The solicitation phase distributed a survey to requirements and systems engineering subject matter experts to determine their ranking preferences of 13 requirement attributes for each solution set. This data was then translated into a model data sheet that was used to analyze the data. In the analysis phase, the inputs from the subject matter experts were analyzed using KW, Bradley-Terry and Saaty's

pairwise comparison to determine a ranking of attributes for each solution set. The final phase was the results phase, where the rankings of each solution set were compared and findings were presented.

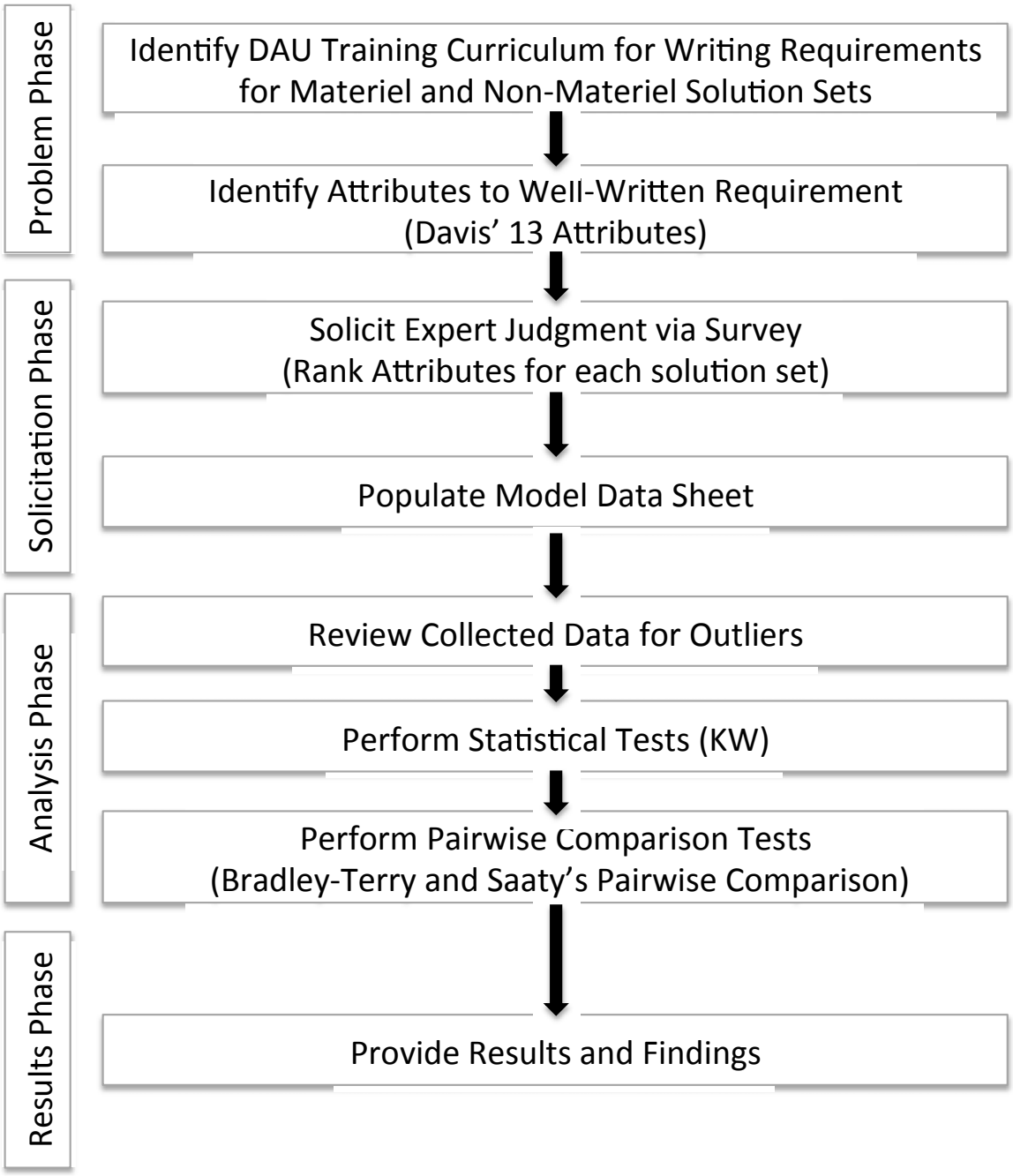

Figure 4-1 – Research Methodology Process Diagram

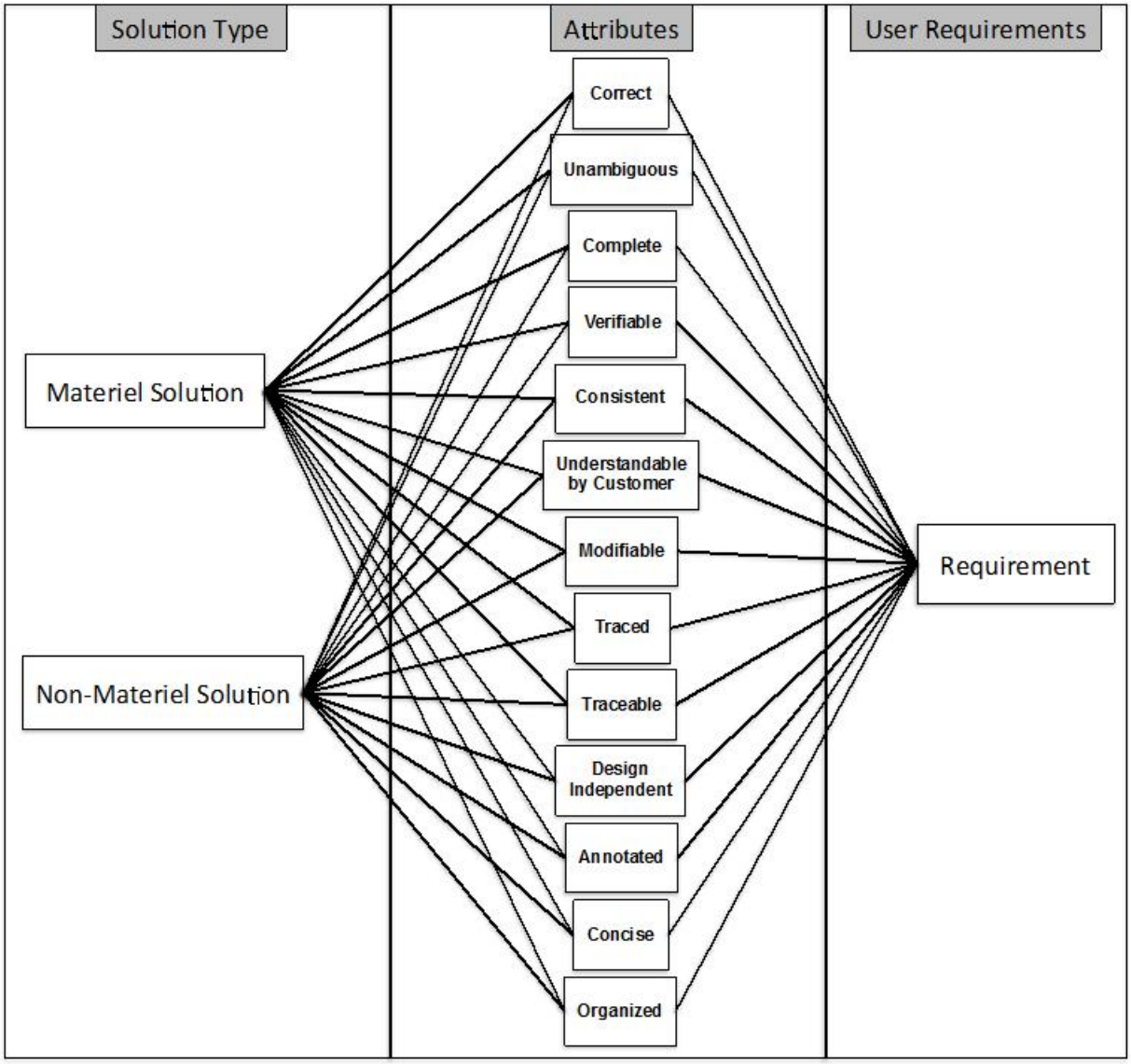

Figure 4-2 – Research Hierarchy of Writing a Requirement for a Materiel and Non-Materiel Solution

4.3 Research Plan

The research plan describes how the phases in the research methodology depicted in Figure 4-1 are undertaken. The literature review presents various different requirement writing guides available for use when developing a requirement. Of these guides, Davis' 13 (Davis, 1993) was chosen as the basis

to perform this study. While Davis' 13 is not necessarily the most utilized requirement writing guide, it has been demonstrated that it encompasses many of the attributes utilized by different requirements guides. This enables this research to be adapted to other guides to compare attribute selection and priority ranking. This research plan also establishes a data collecting procedure for determining a prioritized list of requirement attributes, including participant description and explanation of the survey model. Additionally, the delivery mechanism is explained as well as the methods in which the data collected was analyzed, including analysis of participant demographics, attribute ranking and pairwise comparisons, and the overall model explanation.

4.3.1 Data Collection Procedures

A survey was used to collect the data from requirements and systems engineering subject matter experts. The survey instrument and the associated information and consent sheets followed the guidelines set by the Office of Human Research of the George Washington University and were approved as "Human Subject Research." Participating in this survey was completely voluntary, and was limited to those with experience in requirements development and execution. The purpose of this survey was to develop a ranking of requirement attributes for materiel and non-materiel solution sets to determine if a variance exists.

The survey instrument was broken up into two parts, with 182 fields the participants were required to complete and 18 optional fields. Part one consisted of 26 required fields and 13 optional fields to provide rationale for why they might

have ranked the attributes differently where required. Part two consisted of 156 required fields where the participants were requested to complete a pairwise comparison of each attribute. The remainder of the optional fields consisted of a demographics section, where the participants could input information such as: years of requirements analysis/systems engineering experience; education level achieved; position title; organization size, as well as general comment section where they could provide input on survey instrument, suggestions for attribute list, etc. An example survey is shown in APPENDIX A. All survey data was inputted into a master Model Data Sheet (see APPENDIX B) so that it can be analyzed.

4.3.1.1 Participants

A total of 43 requirements writing and systems engineering experts were selected as participants in this study. Individuals were selected from government acquisition offices, resource sponsors, as well as private industry. The sole restriction on this survey was that participants must have been involved with requirements writing or systems engineering for a minimum of three years.

4.3.1.2 Attribute Ranking and Pairwise Comparisons

The survey instrument was two parts. Part one required the participants to rank Davis' 13 attributes (Davis, 1993) while the second part required the participants to perform a pairwise comparison of Davis' attributes.

In part one, the participants were requested to rank attributes from 1-13 for a materiel and a non-materiel solution, respectively, where 1 was most important

and 13 was least important. Additionally, participants were given space to provide rationale for why they ranked them differently where applicable. These rankings were used to establish the participants subjective ranking of requirement attributes for each solution.

In part two, the participants were requested, based on their rankings in part one, to perform a pairwise comparison of the attributes for a materiel and non-materiel solution, respectively. Weighting for the pairwise comparison was based on an altered version of the Pairwise Comparison Measurement Scale (Saaty, 2008). Table 4-1 is the measurement scale that participants were provided with the survey.

Table 4-1 – Survey Pairwise Comparison Measurement Scale

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or Slight Importance	
3	Moderate Importance	Experience and judgement slightly favor one activity over the other
4	Moderate Plus Importance	
5	Strong Importance	Experience and judgement strongly favor one activity over another
6	Strong Plus Importance	
7	Very Strong or Demonstrated Importance	An Activity is favored very strongly over another; its dominance demonstrated in practice
8	Very Very Strong Importance	
9	Extreme Importance	Evidence favoring one activity over another is of the highest possible order of affirmation
1/2	Weak or Slightly Less Important	
1/3	Moderately Less Important	Experience and judgement slightly DON'T favor one activity over the other
1/4	Moderate Plus Less Important	
1/5	Strongly Less Important	Experience and judgement strongly DON'T favor one activity over another
1/6	Strong Plus Less Important	
1/7	Very Strong or Demonstrated Less Importance	An Activity is NOT favored very strongly over another; its dominance is NOT demonstrated in practice
1/8	Very Very Strongly Less Importance	
1/9	Extreme Less Importance	Evidence DOES NOT exist favoring one activity over another

The pairwise comparison was used to establish the participants' subjective comparison of attributes against each other and determine the level of importance each attribute had against each other.

4.3.2 Delivery Mechanism

The participation of this survey was anonymous. Solicitations for participation in the survey were distributed through electronic mail. Provided with the survey were information/consent forms as well as an example survey. Once the survey was completed by the participant and returned, all identifiable information was

removed from the survey and password protected. No personally identifiable information was collected or used in this study.

4.3.3 Analysis Procedures

The analysis for this case study was performed in four sections: participant summary, data verification, ranking model implementation and pairwise comparison model implementation. Of the 43 invitations distributed, 20 were completed and returned.

4.3.3.1 Participant Demographic Analysis

A total of 20 survey instruments were completed and returned (approximately a 47% participation rate), meeting the required participation of 20 surveys. The experience level in requirements writing and systems engineering ranged from three years (minimum requirement) to 37 years. The education level of participants was: 5% Associates Degree, 30% BS, 40% MS, and 25% PhD. The participants surveyed worked for the DoD and private industry. Of the participants, approximately 48% worked for organizations with fewer than 300 employees. Participation came from organizations ranging in sizes fewer than 5 employees to over 10,000 employees. This wide spread demographic provided a diverse set of inputs.

4.3.3.2 Data Verification

The first part of the survey required the participant to rank 13 attributes in order of importance, while not ranking any attribute the same. These rankings

were required to sum to 91. All survey rankings summed to 91 as required, verifying that no two attributes were ranked the same.

The second part of the survey required the participant to perform a pairwise comparison of the 13 attributes. This data was verified by comparing the participants attribute rank to the weighting assigned in the pairwise comparison to ensure consistency. All survey pairwise comparisons proved to be consistent with their rankings.

4.3.3.3 Ranking Model Implementation

Two models were identified for enabling the ranking of requirement attributes, KW and ANOVA. Since the participants were requested to use a fixed range of choices (1-13) to rank the attributes for importance, a ranked-order formatted data was collected; therefore, using ANOVA was not possible because these values were not normally distributed. With this known, KW was the model of choice for analyzing the data. Additionally, by utilizing KW, as stated by Sheeskin, "…by the virtue of ranking interval/ratio data a researcher can reduce or eliminate the impact of outliers (Sheeskin, 2000)," which provides further proof that KW is a better suited tool for this analysis over ANOVA.

4.3.3.3.1 Kruskal-Wallis one-way Analysis of Variance by Ranks

Prior to starting the KW process, all data collected was analyzed to ensure it met the four assumptions stated by Sheskin (2000). It was determined that all assumptions were met, with exception to assumption 3. Since the rankings were limited to a specific range, one is unable to successfully allow the dependent variable to be a continuous random variable. Fortunately, the rankings used in this study satisfy the exception to this assumption in that the dependent variable represents a discrete random variable, allowing the KW process to begin without concern for compromised analysis.

The hypotheses for this study were developed from equations (3-1) and (3-2):

$$\mathrm{H}_0: A_1 = A_2 = \ldots = A_{13} \tag{4-1}$$

$$\mathrm{H}_1: \mathrm{Not}\ H_0 \tag{4-2}$$

Using equations (3-3) - (3-8) resulted in Table 4-2:

Table 4-2 – KW Calculations

	H	*df*	p-value	Confidence Level	χ^2
Materiel Solution	178.9	12	< 0.0001	0.05	21.03
Non-Materiel Solution	156.4				

Since *H* is greater than χ^2, the Null Hypothesis can be rejected, demonstrating that one or more of the attributes assessed are not equal to each other for the two cases, materiel and non-materiel solution requirements. The

ranking means from the 20 survey results were evaluated using KW in XLSTAT. See Table 4-3

Table 4-3 – Survey Ranking Means of Materiel and Non-Materiel Solutions

	Attribute	Materiel Solution KW Ranking	Non-Materiel Solution KW Ranking
A1	Correct	1	1
A2	Unambiguous	3	4
A3	Complete	2	2
A4	Verifiable	4	3
A5	Consistent	5	5
A6	Understandable by Customer	8	7
A7	Modifiable	9	9
A8	Traced	6	6
A9	Traceable	7	8
A10	Design Independent	10	12
A11	Annotated	11	10
A12	Concise	13	13
A13	Organized	12	11

Figure 4-3 and Figure 4-4 depict the distribution of requirement attribute rankings for materiel and non-materiel solution sets respectively.

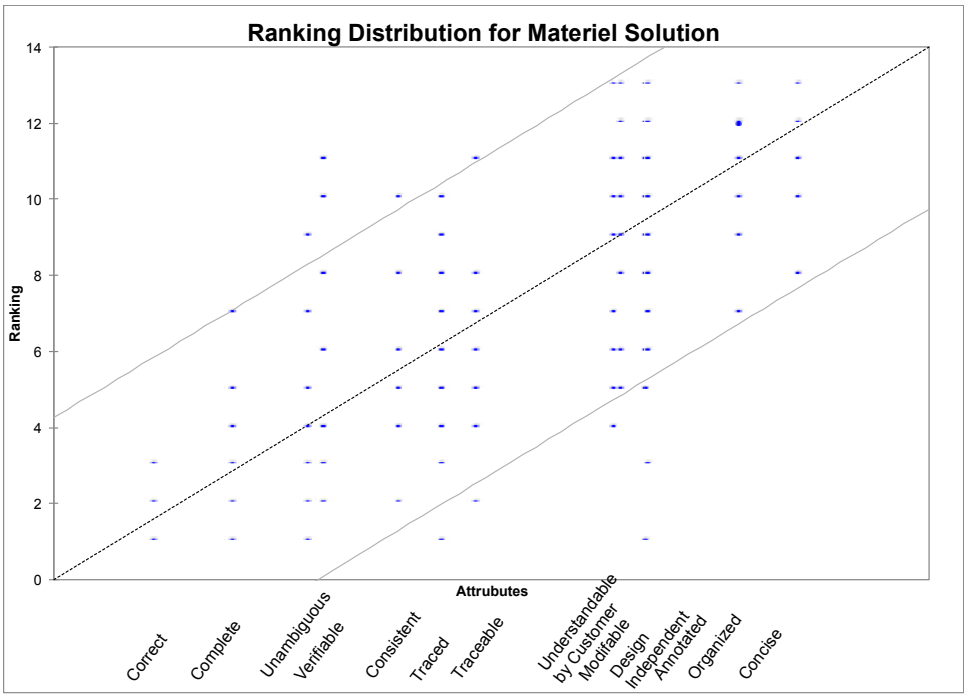

Figure 4-3 – Materiel Solution Ranking Distribution

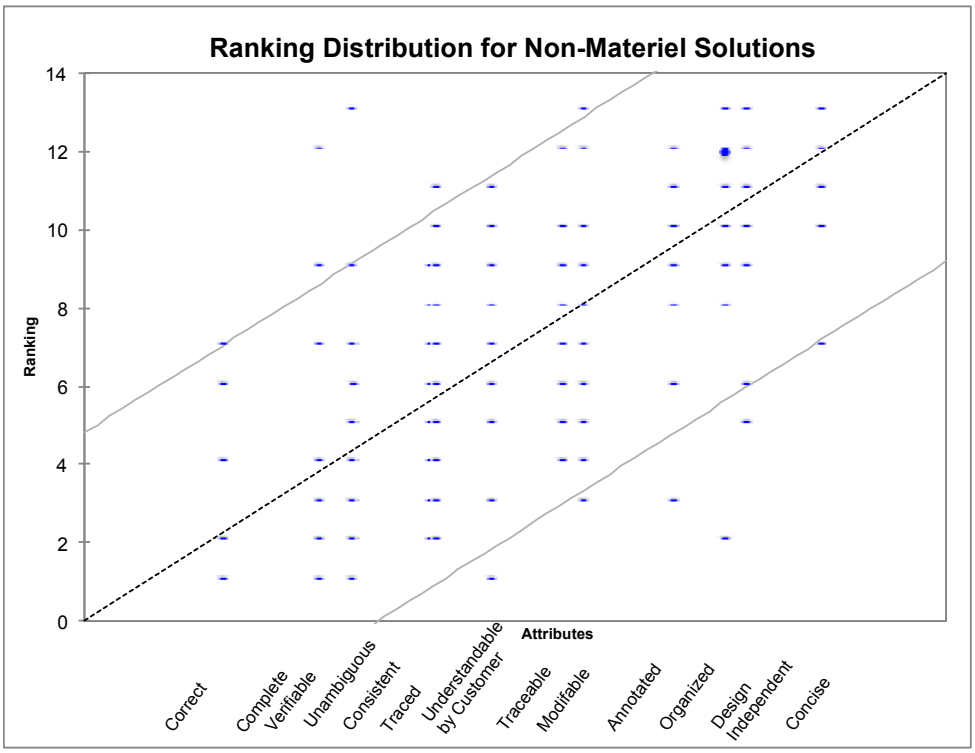

Figure 4-4 – Non-Materiel Solution Ranking Distribution

4.3.3.4 Pairwise Comparison Model Implementation

By utilizing Table 4-1, the participants in this survey were able to populate a pairwise comparison chart for both materiel and non-materiel solution requirement attributes. An example of this table can be seen in APPENDIX A. It should be noted that the Bradley-Terry model does not utilize the exact values found in Table 4-1, but fortunately these values can be translated into the appropriate values required to execute the Bradley-Terry model.

4.3.3.4.1 Bradley-Terry

The Bradley-Terry method is a very complex calculation, and software is recommended to perform these calculations. For this research, Unibalance was utilized (Macutkiewicz, 2006) to calculate the ranking of each attribute. There are various other programs that enable the calculation of the BT method, such as SAS, SPSS, Sata, S-Plus, R, or GLIM (Agresti, 2002). Additionally, MATLAB can also be programed to calculate BT problems.

In order to utilize the data collected from the participants in Unibalance, the weighting scale utilized in this survey was converted to binary. For example, if attribute 1 were ranked any degree more important than attribute 2, then it would be a "1." If attribute 1 were ranked any degree less important than attribute 2, then it would be a "0." An example of a converted survey input can be seen in Table 4-4.

Table 4-4 – Example Bradley-Terry Pairwise Comparison Chart

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct		0	1	0	1	1	1	1	1	1	1	1	1
Unambiguous	1		1	1	1	1	1	1	1	1	1	1	1
Complete	0	0		0	1	1	1	1	1	1	1	1	1
Verifiable	1	0	1		1	1	1	1	1	1	1	1	1
Consistent	0	0	0	0		0	1	1	0	1	0	1	1
Understandable by Customer	0	0	0	0	1		1	1	1	1	1	1	1
Modifiable	0	0	0	0	0	0		0	0	1	0	1	1
Traced	0	0	0	0	0	0	1		0	1	0	1	1
Traceable	0	0	0	0	1	0	1	1		1	0	1	1
Design Independent	0	0	0	0	0	0	0	0	0		0	1	0
Annotated	0	0	0	0	1	0	1	1	1	1		1	1
Concise	0	0	0	0	0	0	0	0	0	0	0		0
Organized	0	0	0	0	0	0	0	0	0	1	0	1	

Each survey input was entered into the Unibalance software for a materiel and non-materiel solution. Unibalance performed the three steps outlined in Section 3.3 for each solution. When analyzing the experts and their submitted preferences, it was found that one expert had to be rejected for the materiel solution pairwise comparison because they failed to pass the 5% level of significance required. For the non-materiel solution pairwise comparison, it was found that all experts passed the required 5% level of significance. As part of the calculations, Unibalance outputted scores for each solution set as shown in Figure 4-5 and Figure 4-6, with an overall goodness of fit of 53 for materiel solutions and 56 for non-materiel solutions.

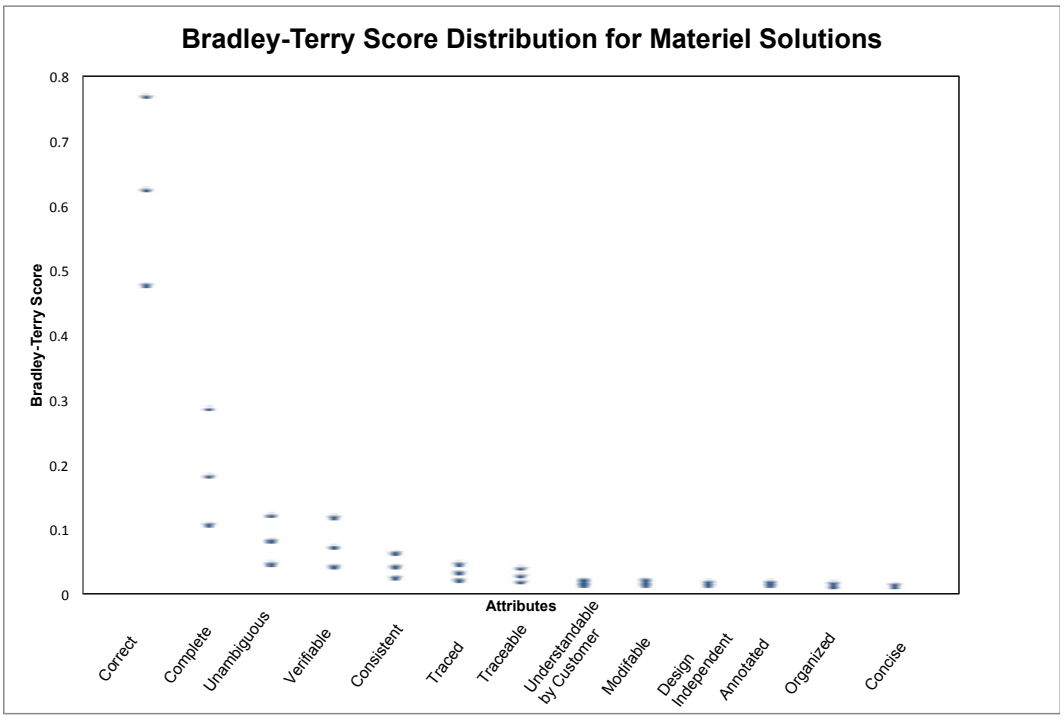

Figure 4-5 – Bradley-Terry Score Distribution for Materiel Solutions

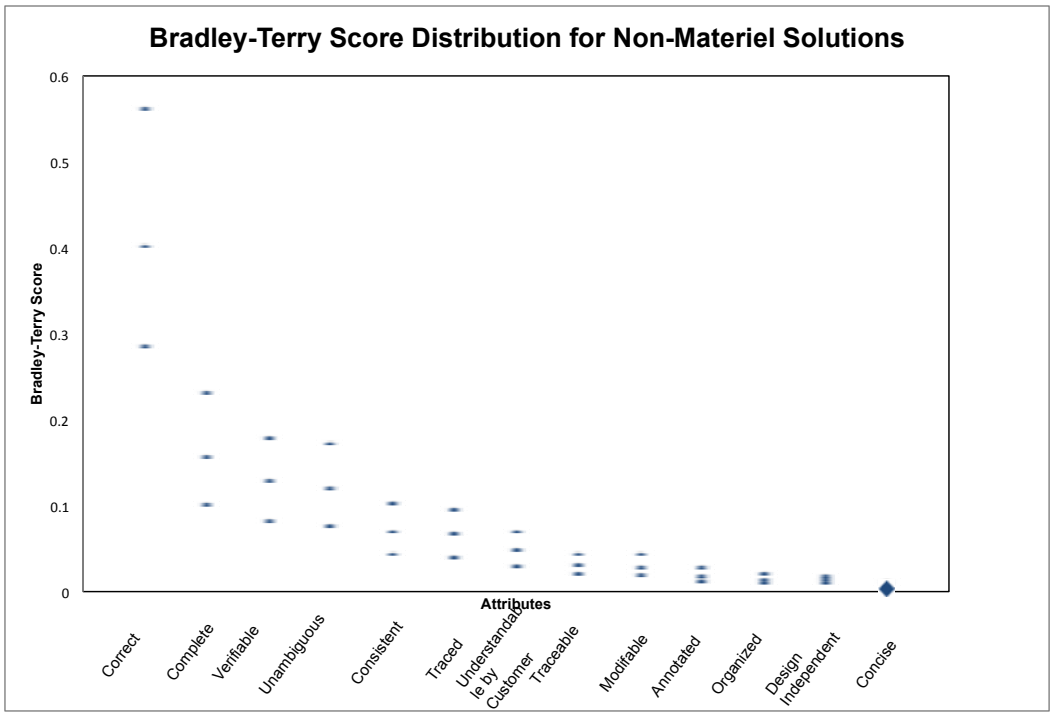

Figure 4-6– Bradley-Terry Score Distribution for Non-Materiel Solutions

The overall ranking for each attribute is demonstrated in Table 4-5.

Table 4-5 – Bradley-Terry Rankings for Materiel and Non-Materiel Solutions

	Attribute	Materiel Solution BT Ranking	Non-Materiel Solution BT Ranking
A1	Correct	1	1
A2	Unambiguous	3	4
A3	Complete	2	2
A4	Verifiable	4	3
A5	Consistent	5	5
A6	Understandable by Customer	8	7
A7	Modifiable	9	9
A8	Traced	6	6
A9	Traceable	7	8
A10	Design Independent	10	12
A11	Annotated	11	10
A12	Concise	13	13
A13	Organized	12	11

It should be noted that the low goodness of fit is not saying the data is poor; instead, because of the lower participation rate, the consistency of data inputs results in a large overall distribution of scores. It is believed that the goodness of fit numbers would improve with more participation. Despite the low goodness of fit values, the rankings in Table 4-5 follow similar order to those found when analyzing the rankings in KW.

4.3.3.4.2 Saaty's Pairwise Comparison

By utilizing the arithmetic sample means from the inputs given by the participants in the survey, using equation (3-38), a reciprocal matrix was

developed for a materiel and non-materiel solution set, as shown in Table 4-6 and Table 4-7, respectively.

Table 4-6 – Materiel Solution Reciprocal Matrix

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	3 11/30	2 19/60	3 9/40	3 17/20	5 7/10	6 1/10	4 1/8	4 1/2	6 11/40	6 3/20	7 11/20	7 2/5
Unambiguous	20/43	1	1 1/19	1 62/75	2 9/26	4 13/60	4 33/40	3 11/67	3 13/20	5 1/40	5 1/8	6 11/40	6 1/15
Complete	1	2 56/89	1	2 60/89	2 23/30	4 31/60	4 19/20	3 5/12	3 13/15	5 5/13	5 33/80	6 17/20	6 13/20
Verifiable	9/20	1 34/49	1 15/73	1	2 74/99	4 1/16	4 10/49	3 15/97	3 1/2	5 17/40	4 23/30	6 9/20	6 3/20
Consistent	7/24	59/60	20/31	1 13/69	1	3 59/96	3 29/60	2 39/80	2 3/5	4 41/80	4 7/29	5 23/30	5 23/40
Understandable by Customer	3/14	11/27	15/38	7/15	1	1	2 10/93	1 3/82	1 11/50	2 11/90	1 59/62	3 3/20	3 5/33
Modifiable	8/45	29/93	7/29	37/55	57/83	1 32/39	1	35/59	1 1/62	2 1/11	1 58/61	3 5/33	2 19/25
Traced	6/17	52/55	29/50	1 9/62	1 1/75	2 67/80	2 34/53	1	1 3/4	3 11/48	3 2/5	4 17/20	4 9/20
Traceable	1/4	15/19	4/7	26/29	1 23/84	2 44/59	2 43/80	1 11/80	1	3 1/7	2 65/67	4 13/20	4 3/10
Design Independent	15/58	18/55	41/77	42/67	37/81	1 13/16	1 1/2	27/34	42/43	1	2 1/5	2 71/80	2 17/48
Annotated	1/5	29/92	2/5	13/34	15/31	1 27/38	1 60/89	79/99	21/22	1 95/96	1	2 5/6	2 3/5
Concise	5/34	17/64	5/31	8/43	1/3	61/96	41/54	5/21	1/4	23/36	34/43	1	1 11/80
Organized	1/7	29/93	4/23	5/14	19/63	34/37	35/39	19/73	5/19	1 9/17	73/76	1 50/71	1

Table 4-7 – Non-Materiel Solution Reciprocal Matrix

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	2 74/83	2 4/13	2 23/31	3 23/43	4 7/23	4 47/60	3 16/17	5 1/60	6 17/30	6 1/20	7 3/10	6 11/27
Unambiguous	22/31	1	1 28/57	1 3/11	2 9/23	3 1/60	3 67/80	2 40/57	3 16/17	5 9/20	4 7/8	6 11/20	5 23/40
Complete	28/31	2 52/85	1	2 37/98	2 73/94	3 21/40	4 11/80	2 81/85	4 5/24	5 23/43	4 61/80	6 1/5	5 13/24
Verifiable	7/8	2 14/75	2 5/46	1	2 80/91	3 19/47	3 47/60	2 77/87	3 5/6	5 41/60	4 7/8	6 11/29	5 47/80
Consistent	37/59	3/4	1 19/65	1 1/13	1	2 17/53	3	2 2/51	3 11/91	4 2/3	3 9/13	5 1/2	4 53/80
Understandable by Customer	19/29	11/17	1 13/69	54/55	1 15/92	1	2 43/54	1 59/96	2 11/24	3 11/12	2 39/40	4 4/5	3 4/5
Modifiable	17/28	22/31	4/5	2/3	1 7/44	1 24/65	1	1 1/39	1 13/18	3 7/73	2 33/38	3 12/13	3 1/24
Traced	33/43	1 1/3	1 3/29	5/6	1 35/58	2 32/81	2 73/86	1	2 11/30	4 43/67	3 63/79	5 13/80	4 11/60
Traceable	4/11	11/17	43/76	39/56	53/63	1 9/22	1 37/57	50/71	1	3 21/40	3 3/17	4 13/16	3 5/8
Design Independent	3/10	5/23	49/96	26/45	25/67	18/43	40/43	39/85	13/18	1	1 4/7	2 5/33	1 27/89
Annotated	17/94	27/85	10/17	49/71	1/2	56/69	1 22/67	61/79	1 13/77	2 15/41	1	2 11/12	2 7/40
Concise	5/33	1/6	10/53	20/41	5/24	18/71	58/69	17/42	5/12	1 2/15	20/39	1	70/81
Organized	12/23	11/38	5/12	35/76	37/86	6/13	87/89	23/44	2/3	2	1 4/31	2 1/15	1

Utilizing step 4.1 and 4.2 (see Table 3-2 and Table 3-3), a comparison matrix is formed and a weighting of importance of each attribute is provided. Table 4-8 and Table 4-9 show the comparison matrices for both a materiel and non-materiel solution set, respectively. As required, the sum of the weights equals one.

Table 4-8 – Materiel Solution Comparison Matrix

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized	Weights
Correct	19/94	1/4	1/4	11/50	4/19	4/25	1/6	13/70	3/17	4/27	3/20	7/53	4/29	**0.184**
Unambiguous	3/32	3/40	5/44	1/8	9/70	9/76	5/38	1/7	1/7	7/59	1/8	10/91	6/53	**0.118**
Complete	1/5	13/66	7/65	2/11	5/33	8/63	5/37	2/13	5/33	8/63	9/68	3/25	1/8	**0.147**
Verifiable	1/11	8/63	10/77	3/44	14/93	4/35	11/96	1/7	10/73	5/39	5/43	7/62	7/61	**0.119**
Consistent	1/17	7/95	5/72	3/37	4/73	7/69	2/21	1/9	6/59	5/47	3/29	10/99	5/48	**0.089**
Understandable by Customer	1/23	1/33	2/47	3/94	4/73	2/71	5/87	2/43	1/21	1/20	1/21	1/18	1/17	**0.046**
Modifiable	1/28	1/43	2/77	4/87	2/53	2/39	1/37	2/75	1/25	4/81	1/21	1/18	5/97	**0.040**
Traced	1/14	1/14	1/16	5/64	1/18	2/25	1/14	4/89	5/73	1/13	1/12	4/47	1/12	**0.072**
Traceable	5/98	1/17	4/65	3/49	3/43	1/13	2/29	2/39	2/51	2/27	4/55	7/86	2/25	**0.065**
Design Independent	1/19	1/41	5/87	3/70	1/40	3/59	2/49	1/28	1/26	2/85	5/93	5/99	4/91	**0.042**
Annotated	3/74	2/85	4/93	1/38	1/38	1/21	1/22	1/28	1/27	3/64	1/41	1/20	3/62	**0.038**
Concise	2/67	1/50	1/57	1/79	1/54	1/56	1/48	1/93	0	1/66	1/52	1/57	1/47	**0.018**
Organized	1/35	1/43	1/53	1/41	1/61	1/39	1/41	1/85	1/97	3/83	2/85	2/67	1/54	**0.022**
													Sum of Weights	**1**

Table 4-9 – Non-Materiel Solution Comparison Matrix

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized	Weights
Correct	3/23	4/19	8/47	18/91	3/16	15/86	3/20	3/16	9/55	11/83	6/41	1/8	11/82	**0.162**
Unambiguous	5/54	4/55	10/91	9/98	9/71	11/90	3/25	9/70	9/70	10/91	2/17	1/9	7/60	**0.112**
Complete	2/17	11/58	7/95	6/35	5/34	1/7	7/54	8/57	7/51	1/9	3/26	2/19	8/69	**0.131**
Verifiable	4/35	10/63	7/45	7/97	9/59	4/29	7/59	7/51	1/8	7/61	2/17	5/46	11/94	**0.125**
Consistent	5/61	3/55	2/21	7/90	1/19	3/32	5/53	3/31	6/59	8/85	5/56	3/32	4/41	**0.086**
Understandable by Customer	3/35	4/85	5/57	1/14	5/81	3/74	5/57	1/13	2/25	3/38	1/14	4/49	7/88	**0.073**
Modifiable	5/63	5/97	1/17	1/21	4/65	1/18	1/32	2/41	5/89	1/16	5/72	1/15	3/47	**0.058**
Traced	1/10	3/31	7/86	3/50	4/47	3/31	5/56	1/21	1/13	3/32	8/87	8/91	7/80	**0.084**
Traceable	1/21	4/85	1/24	1/20	2/45	2/35	3/58	1/30	3/92	1/14	1/13	5/61	6/79	**0.055**
Design Independent	2/51	1/63	2/53	1/24	1/51	1/59	1/34	1/46	2/85	2/99	3/79	3/82	2/73	**0.028**
Annotated	2/85	2/87	1/23	1/20	1/38	2/61	1/24	1/27	1/26	1/21	1/41	1/20	1/22	**0.037**
Concise	1/50	1/82	1/72	2/57	1/90	1/97	1/38	1/52	1/73	1/44	1/80	1/59	1/55	**0.018**
Organized	3/44	2/95	2/65	1/30	1/44	1/53	3/98	1/40	1/46	1/25	2/73	2/57	1/48	**0.030**
													Sum of Weights	1

After completing the comparison matrices for each solution set, Saaty's Test for consistency must be calculated to determine if the solutions found were consistent and accurate. In order to calculate the CR, the WSV, CV, λ_{max} and CI must be calculated (equations (3-39) through (3-42)). The results of these calculations are shown in Table 4-10 and Table 4-11 for each respective solution.

Table 4-10 – Materiel Solution Consistency Ratio

	Attribute	WSV	CV	λ_{MAX}	CI	CR
A1	**Correct**	3.538802	19.23124638	18.98622	0.498851	0.3197765
A2	**Complete**	2.287259	19.33449413			
A3	**Verifiable**	2.808371	19.10995834			
A4	**Unambiguous**	2.292249	19.26764757			
A5	**Consistent**	1.724042	19.26389117			
A6	**Traced**	0.863474	18.87083362			
A7	**Traceable**	0.757575	19.03195243			
A8	**Understandable by Customer**	1.359392	18.98544455			
A9	**Design Independent**	1.240605	19.02360198			
A10	**Modifiable**	0.772855	18.61558062			
A11	**Annotated**	0.715415	18.73613951			
A12	**Organized**	0.327035	18.45879553			
A13	**Concise**	0.424459	18.89122336			

Table 4-11 – Non-Materiel Solution Consistency Ratio

	Attribute	WSV	CV	λ_{MAX}	CI	CR
A1	**Correct**	3.369907	20.7751058	20.35599	0.612999	0.392948
A2	**Complete**	2.295896	20.58941608			
A3	**Verifiable**	2.69586	20.63061715			
A4	**Unambiguous**	2.582175	20.59148491			
A5	**Consistent**	1.771623	20.4848764			
A6	**Traced**	1.485637	20.32919841			
A7	**Traceable**	1.16125	20.03676904			
A8	**Understandable by Customer**	1.705877	20.24464708			
A9	**Design Independent**	1.091723	19.9377268			
A10	**Modifiable**	0.571555	20.21517081			
A11	**Annotated**	0.758937	20.4358985			
A12	**Organized**	0.366671	20.54062489			
A13	**Concise**	0.602584	19.8162872			

According to Saaty, if the CR ≤ .10, it is deemed acceptable. If the CR ≥ .10, the comparison matrix is inconsistent and should be improved, though not all agree with this 10% threshold (Koczkodaj, 1993). Table 4-12 demonstrates the

rankings determined by using Saaty's pairwise comparisons of the attributes for both materiel and non-materiel solutions.

Table 4-12 – Saaty's Rankings for Materiel and Non-Materiel Solution Attributes

	Attribute	Materiel Solution Saaty's Ranking	Non-Materiel Solution Saaty's Ranking
A1	Correct	1	1
A2	Unambiguous	4	4
A3	Complete	2	2
A4	Verifiable	3	3
A5	Consistent	5	5
A6	Understandable by Customer	8	7
A7	Modifiable	10	8
A8	Traced	6	6
A9	Traceable	7	9
A10	Design Independent	9	12
A11	Annotated	11	10
A12	Concise	13	13
A13	Organized	12	11

When analyzing this data, it can be seen that the CR for these matrices are above Saaty's 10% threshold, but when analyzing the rankings seen in Table 4-12, they follow a similar order to those found when analyzing the rankings with KW and BT. A suggestion for future studies is to include more participants to help produce a more consistent set of inputs in order to improve upon the CR found during this pairwise comparison.

4.3.3.5 Survey Comments

A comment box was provided in the survey to gain feedback from the participants in regards to the survey or information covered in the survey. Some comments stated the list of attributes was too broad. Recommendations were also made to include additional attributes such as “necessary” and “testable” in future studies. Additionally, one comment recommended ignoring Davis’ attributes and constructing a list that was specifically designed for requirements in general that might help in deciding whether or not a non-materiel solution is possible vs. going straight to a materiel solution. Each of the comments received provide for future research ideas.

5 RESULTS

5.1 Ranking Model Interpretation

Of the 13 attributes analyzed and ranked, it can be seen within Table 4-3 that for both materiel and non-materiel solutions a ‘correct’ and ‘complete’ requirement were identified as the two most important attributes when writing a requirement. Furthermore, it can be seen that the top five attributes are the same for both solutions, though they are not ranked the same. Through the use of expert judgments and KW, the ranking of attributes of a well-written requirement are shown to be different between a materiel and non-materiel solution. It can also be noted, as illustrated within Figure 4-3 and Figure 4-4, the experts had varying opinions on how each attribute should be ranked. Additionally, of the 20 participants, 85% felt there was a decidable difference in attribute rankings between the two solution sets.

5.2 Pairwise Comparison Model Interpretation

After performing the two separate pairwise comparison methods, it can be seen in Table 5-1 that for materiel and non-materiel solutions, a ‘correct’ and ‘complete’ requirement were identified as the two most important attributes when writing a requirement. Additionally, for non-materiel solutions, both methods demonstrated that the top five attributes are identical to each other, while there were slight variations identified between attribute importance for materiel solutions. Regardless of method, the overall top five attributes were the same for each solution set. Through the use of the BT method and Saaty’s pairwise

comparison, the ranking of attributes of a well-written requirement are shown to be different between a materiel and non-materiel solution.

Table 5-1 – Pairwise Comparison Attribute Ranking

	Attribute	Materiel Solution Saaty's Ranking	Non-Materiel Solution Saaty's Ranking	Materiel Solution BT Ranking	Non-Materiel Solution BT Ranking
A1	Correct	1	1	1	1
A2	Unambiguous	4	4	3	4
A3	Complete	2	2	2	2
A4	Verifiable	3	3	4	3
A5	Consistent	5	5	5	5
A6	Understandable by Customer	8	7	8	7
A7	Modifiable	10	8	9	9
A8	Traced	6	6	6	6
A9	Traceable	7	9	7	8
A10	Design Independent	9	12	10	12
A11	Annotated	11	10	11	10
A12	Concise	13	13	13	13
A13	Organized	12	11	12	11

As can be seen when comparing the rankings determined by Saaty's and BT, variances between the two methods exist. This can be attributed to a few aspects where the two methods vary. While capable of producing similar results, the main downfall of Saaty's pairwise comparison is it has no statistical checks to determine if the data inputted to the model is accurate, unlike the expert practitioner analysis that is performed during the BT calculations. By performing this type of statistical test, the BT method is able to produce a more statistically significant and accurate result than the Saaty's method. As demonstrated by the BT calculations, there was one expert that had to be removed from the study due to failing the expert analysis checks. Since Saaty's method does not include these types of checks to remove significantly insignificant participants, this expert was included in the analysis. While not necessarily making a serious impact on

the overall rankings, for larger scale research, the effects can be substantially greater. It is for these reasons that the BT method is recommended over the Saaty's method for future research. Other smaller rationale for differences in results between the two methods is how the data was calculated. This difference can be attributed to the BT method being a binary-based method vs. the Saaty's method, which has degrees of importance/unimportance.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Findings

Identifying attributes to a well-written requirement is far from a new topic in the requirements developing world. The issue that was found during this research was that there was no differentiation between attribute importance for a materiel or non-materiel solution when analyzing DoD requirements training. This research paper identified that, through the use of expert judgment, there are differences in attribute importance between each solution set and this is something that should be addressed when developing requirements for a program.

6.1.1 Discussion

The goal of this research was to determine if there was a variance between requirement attributes for materiel and non-materiel solutions, utilizing a fixed list of requirement attributes. Three separate methods were identified for determining the ranking of these attributes for each solution set.

With a ranked list of attributes, requirements writers would potentially be able to concentrate on the more important aspects of the requirement to ensure that it is well written. While only a small portion of the life cycle of a program, requirements are the basis for development of all programs. If they are not well written, a poor requirement can and will cause cost overages, schedule slips, or create severe logistical and maintenance issues for programs, which can be seen in many DoD programs, such as the Abrams tank or Apache helicopter (US

GAO, 2003), to name just a few. As stated by Blanchard (2003), having requirements that are constantly changing create many issues for logistics and maintenance support capabilities, requiring them to be more flexible than ever to support the programs.

Additionally, identifying differences between the attributes for each solution set will enhance the ability of requirement writers to determine whether or not a capability can be answered more suitably by a new solution (materiel) or adaptation of an existing solution (non-materiel). By knowing which attributes are more important for each solution, requirements writers could potentially create better suited requirements for each solution, potentially creating a solution that is more cost effective, logistically easier to maintain and quicker to provide to area of need.

6.1.2 Boundaries of Study

This research focused purely on a fixed list of attributes for writing requirements. This research did not address any of the other aspects that are required for a full development of a requirement, nor was the intent of this research to analyze the process for developing a requirement.

The survey used in this study utilized the researcher's professional circle of systems engineers and requirements writing experts. By leveraging against this professional circle of experts, a diverse set of responses from across private and government industry was collected. There was no further solicitation for additional survey participants outside of this circle. Additionally, the participants

were not asked to list their on-the-job training such as Defense Acquisition certifications, etc. that might potentially sway their opinions or decisions in a certain direction over the other (such as ranking materiel and non-materiel solutions the same as taught by the DAU). While the author believes that the job experience of the participants outweighs the initial training, this is an aspect that was not identified in this study.

The survey presented a fixed list of attributes that the participants were requested to rank and perform a weighted pairwise comparison on. According to some feedback from participants, this fixed list was too specific in certain aspects, and lacked certain attributes that were considered more important in others. If different attributes were used, it's possible that a different ranking order might have been obtained from the experts.

6.1.3 Conclusions

This study demonstrates that attributes for materiel and non-materiel solution sets were not alike, according to a fixed panel of reviewers. When reviewing the findings of this study, it can be seen that the variances between the two solution sets is very minimal, but still different. There is potential that through a bigger participant pool, a more definitive decision can be made on the degree to which these solution sets differ from one another. Due to the findings of this research demonstrating that these attributes are not identical, it is recommended that the DoD re-evaluate how it trains and performs requirements generation for both solution sets, and add an emphasis of utilizing a ranked list of attributes for generating requirements. The author hypothesizes that if the DoD undertakes a

concentrated effort in establishing a prioritized requirement attribute list for both materiel and non-materiel solutions, it may alleviate wasteful spending caused by poorly written requirements.

Davis' 13 Attributes of a Well Written Requirement (Davis, 1993) was utilized in order to develop a basis in which to compare various requirements writing guides. Through the use of expert judgment in this case study, a recommended prioritized order of attributes is provided for writing requirements for materiel and non-materiel solutions. It was found that requirement attributes for both solutions are different, and requirement writing guides should address this difference to add benefit in future requirements development.

6.2 Recommendations for Future Research

As a result of this research, there are a few recommendations for future research. First, it is recommended to recreate this study, but include more participants. As was noted in the pairwise comparison section, the 'goodness of fit' factor used in the BT method was lower than preferred in this type of research, and the CR factor used in the Saaty's pairwise comparison method was high. The researcher attributes this to the fact that there was a limited amount of surveys collected for this research, and it is believed that with a higher participation in future studies, these numbers will improve. By improving these numbers, one would be able to raise the level of consistency in the rankings that were determined during the analysis.

Secondly, it is recommended to expand on the existing survey to collect additional information from the participants in regards to their training background and experience levels (DAU trained and certified, etc.). With this demographic information collected, the researcher should perform additional comparisons between government professionals and private industry professionals to determine if the training potentially altered the expert preferences.

Thirdly, available literature does not address the ranking of requirement attributes or how to write a requirement for a non-materiel solution. It is recommended to create a more thorough list of requirement attributes for a non-materiel solution so that requirement writers have a more focused guideline for use within a CBA.

Finally, it is recommended that a hybrid list of attributes be generated and studied by excluding those lower ranked attributes identified within this study and possibly incorporating others that are not included within Davis' 13 attributes that were used during this study, but identified by other requirements writing guides. By creating this hybrid list, one could include attributes that came highly recommended from the participants, such as 'necessary' and 'feasible.'

REFERENCES

Agresti, A. (2002). Categorical data analysis (Vol. 359). Wiley-interscience.

Alonso, J. A., (2006). Consistency In The Analytic Hierarchy Process: A New Approach, *International Journal of Uncertainty*, Vol. 14, No. 4, 445−459

Bahill, A. T., & Dean, F. F. (2009). 4 Discovering System Requirements. Handbook of systems engineering and management, 205-267. Retrieved June 19, 2013 from http://www.sie.arizona.edu/sysengr/publishedPapers/ReqPageProofs2009.pdf

Basili, V. R., & Weiss, D. M. (1981, March). Evaluation of a software requirements document by analysis of change data. In *Proceedings of the 5th international conference on Software engineering* (pp. 314-323). IEEE Press.

Berkun, S. (2009). Why Requirements Stink. In http://scottberkun.com/. Retrieved March 5, 2013, from http://scottberkun.com/2009/why-requirements-stink/.

Berry, S. T. (1994). Estimating discrete-choice models of product differentiation. The RAND Journal of Economics, 242-262.

Bierlaire, M. (1998). Discrete choice models. NATO ASI SERIES F COMPUTER AND SYSTEMS SCIENCES, 166, 203-227.

Blanchard, B.S., (2003). *Logistics Engineering and Management*. Upper Saddle River, New Jersey: Pearson Prentice Hall, Inc.

Bradley, R. A., & Terry, M. E. (1952). Rank analysis of incomplete block designs: I. The method of paired comparisons. *Biometrika*, *39*(3/4), 324-345.

Braun, M., & McAuliffe, J. (2010). Variational inference for large-scale models of discrete choice. Journal of the American Statistical Association, 105(489), 324-335.

Breslow, N. (1970). A generalized Kruskal-Wallis test for comparing K samples subject to unequal patterns of censorship. Biometrika, 57(3), 579-594.

Carson, R. (1995). A set theory model for anomaly handling in system requirements analysis. In *Proceedings of INCOSE*.

Carson, R. S. (1998). Requirements completeness: A deterministic approach. In *Proc 8th annual international symposium of the INCOSE*.

Celko, J., Davis, J. S., & Mitchell, J. (1983). A demonstration of three requirements language systems. *ACM SIGPLAN Notices*, *18*(1), 9-14.

Chrisman, J. J., Chua, J. H., & Sharma, P. (1998). Important attributes of successors in family businesses: An exploratory study. *Family business review*, *11*(1), 19-34.

CJCSI 3170.01H, (2012). CHAIRMAN OF THE JOINT CHIEFS OF STAFF INSTRUCTION, Retrieved Jan 20, 2013, from https://acc.dau.mil/CommunityBrowser.aspx?id=275931

Conover, W., & Iman, R. L. (1976). On some alternative procedures using ranks for the analysis of experimental designs. Communications in Statistics-Theory and Methods, 5(14), 1349-1368.

Conover, W. J., & Iman, R. L. (1981). Rank transformations as a bridge between parametric and nonparametric statistics. The American Statistician, 35(3), 124-129.

Cooke, R. M. (1991). Experts in uncertainty: opinion and subjective probability in science. Oxford University Press, USA.

Daniels, J., Botta, R., & Bahill, T. (2005). A hybrid requirements capture process. In Proceedings of the 15'th International INCOSE Symposium.

David, H. A. (1963), The method of paired comparison, London: Charles Griffin & Co. Ltd

Davidson, R. R. (1970). On extending the Bradley-Terry model to accommodate ties in paired comparison experiments. *Journal of the American Statistical Association*, *65*(329), 317-328.

Davis, A. M. (2005). Just enough requirements management. New York: Dorset House, retrieved from http://www.sigs.de/download/oop_09/Davis%20Mo4%20brb%20WR%20A4.pdf June 14, 2013

Davis, A.M., (1993). Software Requirements Objectives, Functions and States, Prentice Hall PTR

Davis, A., Overmyer, S., Jordan, K., Caruso, J., Dandashi, F., Dinh, A., & Theofanos, M. (1993). Identifying and measuring quality in a software

requirements specification. In Software Metrics Symposium, 1993. Proceedings., First International (pp. 141-152). IEEE.

Davis, A. M., & Rauscher, T. G. (1979, April). Formal techniques and automatic processing to ensure correctness in requirements specifications. In*Proceedings of the 1979 Conference on Specifications of Reliable Software* (p. 15).

Defense Acquisition University, (2012). Core Concepts for Requirements Management (CCRM) (RQM110), retrieved from http://www.dau.mil/Training/default.aspx January 18, 2013

Defense Acquisition University, (2012). Defining Requirements (CLR252), retrieved from http://www.dau.mil/Training/default.aspx January 18, 2013

Defense Acquisition University, (2012). Introduction to JCIDS (CLR101), retrieved from http://www.dau.mil/Training/default.aspx January 19, 2013

Defense Acquisition University (2001), Systems engineering fundamentals guide, Defense Acquisition University Press, Fort Belvoir, VA, retrieved from https://acc.dau.mil/CommunityBrowser.aspx?id=25830 June 18, 2013

Department of Defense (DoD) Standard Practice; Defense and Program Unique Specifications Format and Content, (2008). MIL-STD-961E, retrieved November 18, 2012, from https://acc.dau.mil/CommunityBrowser.aspx?id=378460

Dick, J., Ryan, M., Wheatcraft, L., Zinni, R., Baksa, K., Fernandez, J.L., Smith, G.R., Unger, C. (INCOSE Requirements Writing Group), (2012), Guide to Writing Requirements, International Council on Systems Engineering (INCOSE) Document No.: INCOSE-TP-2010-006-01, retrieved from http://www.incose.org/ProductsPubs/products/guideforwritingrequirements.aspx on 12 Feb 2013

Doctrine Study Group, (2008). USCG policy, Doctrine & TTP Requirements & Functions Analysis, retrieved March 5, 2013, from http://www.uscg.mil/doctrine/Doctrine_Report/TAB17.pdf

DoDI 5000.02, (2008). Department of Defense Instruction, Operation of the Defense Acquisition System, SUD (AT&L), Retrieved January 19, 2013, from https://acc.dau.mil/CommunityBrowser.aspx?id=250027

European Space Agency (ESA) Board for Software Standardization and Control (BSSC), (1995), Guide to the User Requirements Definition Phase, ESA PSS-05-02 Issue 1, retrieved June 29, 2013 from ftp://ftp.estec.esa.nl/pub/wm/anonymous/wme/bssc/PSS0502.pdf

Foster, G. D. (1995). Integrating the US Industrial Base: Strategic Necessity for America's Future. *Fletcher F. World Aff.*, *19*, 133.

Fuller, W. C., Manski, C. F., & Wise, D. A. (1982). New evidence on the economic determinants of postsecondary schooling choices. Journal of Human Resources, 477-498.

Furr, W.F., (1991), Joint Doctrine Progress, Prospects, and Problems, Airpower Journal, Vol V, No.3, retrieved March 5, 2013, from http://www.airpower.au.af.mil/airchronicles/apj/apj91/fal91/furr.htm

Gelman, A. (2005). Analysis of variance—why it is more important than ever. The Annals of Statistics, 33(1), 1-53.

Georgiadis, D. R., Mazzuchi, T. A., & Sarkani, S. (2012). Using multi criteria decision making in analysis of alternatives for selection of enabling technology. *Systems Engineering*.

Giorgini, P., Rizzi, S., & Garzetti, M. (2005, November). Goal-oriented requirement analysis for data warehouse design. In *Proceedings of the 8th ACM international workshop on Data warehousing and OLAP* (pp. 47-56). ACM.

Guidebook, D.A, (2012). Defense Acquisition University. November, 1, 2012.

Hall, J., Kenny, P., King, M., Louviere, J., Viney, R., and Yeoh, A. (2002), "Using Stated Preference Discrete Choice Modelling to Evaluate the Introduction of Varicella Vaccination," Health Economics, 11, 457–465.

Hanks, C.H., Axelband, E.I., & Linsay, S., (2005). Reexamining Military Acquisition Reform: Are We There Yet?, Santa Monica, California, RAND Corporation.

Hari, A., Kasser, J. E., & Weiss, M. P. (2007). How lessons learned from using QFD led to the evolution of a process for creating quality requirements for complex systems. Systems engineering, 10(1), 45-63.

Hoaglin, D. C., & Welsch, R. E. (1978). The hat matrix in regression and ANOVA. The American Statistician, 32(1), 17-22.

Hood, C., Wiedemann, S., & Fichtinger, S. (2008). Requirements Management: The interface between requirements development and all other systems engineering processes. Springer.

Hooks, I. (1993). Writing Good Requirements (A Requirements Working Group Information Report). In Proc. Third International Symposium of the INCOSE (Vol. 2).

Hooks, I., & Farry, K. (2001). Customer-centered products: Creating successful products through smart requirements management (New York: AMACOM).

Hooks, I., Gallagher, B. P., Shrum, S., Schneidewind, N. F., Charette, R., Dwinnell, L. M., & Wunder, J. (2004). Systems Approach. crosstalk, 801, 586-0095.

Huck, S. W., & McLean, R. A. (1975). Using a repeated measures ANOVA to analyze the data from a pretest-posttest design: A potentially confusing task. Psychological Bulletin; Psychological Bulletin, 82(4), 511.

Hui, J., McLean-Meyinsse, P. E., & Jones, D. (1995). An empirical investigation of importance ratings of meat attributes by Louisiana and Texas consumers. *Journal of Agricultural and Applied Economics*, *27*, 636-643.

Hull, E., Jackson, K., & Dick, J. (2011). Requirements engineering. Springer.

Hunter, D. R. (2004). MM algorithms for generalized Bradley-Terry models.*Annals of Statistics*, 384-406.

IEEE Guide for Developing System Requirements Specifications, (1998). IEEE Standard 1233, 1998 Edition, retrieved November 18, 2012, from http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=5982

IEEE Recommended Practice for Software Requirements, (1998). IEEE Standard 830 – 1998, retrieved June 17, 2013, from http://www.math.uaa.alaska.edu/~afkjm/cs401/IEEE830.pdf

Inspector General United States Department of Defense, (2012). Report No. DoDIG-2012-101, retrieved March 5, 2013, from http://www.dodig.mil/audit/reports/fy12/dodig-2012-101.pdf

Jain, R., VanLeer, M., & Chandrasekaran, A. (2011). A framework for requirements engineering method selection. International Journal of Industrial and Systems Engineering, 8(2), 198-214.

Japenga, R. (2003). How to write a software requirements specification. Micro Tools, Inc., retrieved June 24, 2013 from http://bwilson.cs.georgefox.edu/CSIS_321/readings/SE_WritingSRS.pdf

JCS J-8 (Force Structure, Resources, and Assessments Dictorate), (2009). Capabilities-Based Assessment (CBA) User's Guide Version 3, retrieved January 20, 2013, from https://acc.dau.mil/CommunityBrowser.aspx?id=224772

Kasser, J., Scott, W., Tran, X. L., & Nesterov, S. (2006). A proposed research programme for determining a metric for a good requirement. In The Conference on Systems Engineering Research (p. 1).

Kendall, M., (1962). Rank correlation methods. London: Charles Griffen & Co. Ltd

Koczkodaj, W.W., (1993). A New Definition of Consistency of Pair Wise Comparisons, *Mathematical and Computer Modelling,* Vol. 18, No. 7, 79-84

Lamsweerde, A. V. (2009). *Requirements Engineering From System Goals to UML Models to Software Specifications*. John Wiley & Sons

Lattin, J.M, Carrol, J.D., Green, P.E., (2003). Analyzing Multivariate Data, Brooks/Cole CENGAGE Learning

Macutkiewicz, Marcin, (2006). Unibalance (discrete choice stakeholder preference) software, http://risk2.ewi.tudelft.nl/oursoftware/11-unibalance, retrieved July 25, 2013.

Manual, JCIDS, (2012). Joint Capabilities Integration and Development System Manual, Retrieved January 19, 2013, from https://acc.dau.mil/CommunityBrowser.aspx?id=267116

Mazzuchi, T. A., Linzey, W. G., & Bruning, A. (2008). A paired comparison experiment for gathering expert judgment for an aircraft wiring risk assessment.*Reliability Engineering & System Safety*, *93*(5), 722-731.

Mead, N. R., & Stehney, T. (2005). *Security quality requirements engineering (SQUARE) methodology* (Vol. 30, No. 4, pp. 1-7). ACM

Moore, W. L., Louviere, J., and Verma, R. (1999), "Using Conjoint Analysis to Help Design Product Platforms," Journal of Product Innovation Management, 16, 27–39.

Morikawa, T., Ben-Akiva, M., & McFadden, D. (2002). Discrete choice models incorporating revealed preferences and psychometric data. *Advances in Econometrics*, *16*, 29-55.

Nix, R. E., Hopkins, C., Pang, G., Onofrio, K., & Konoske, P. (2008). The Air Force Global Reach Laydown (GR1): An Allowance Standard Review Using the Estimating Supplies Program to Develop a Requirements-Based Materiel Solution (No. NHRC-08-10J). NAVAL HEALTH RESEARCH CENTER SAN DIEGO CA.

Nydick, R.L. & Hill, R.P., (1992). Using the Analytic Hierarchy Process to Structure the Supplier Selection Procedure, *International Journal of Purchasing and Materials Management*, Vol. 28, No. 2, 31-36

Rajnish, R., & VYAS, R. (2010). Writing Quality Requirements (SRS): An Approach To Manage Requirements Volatility. WRITING, 1(1), 28-37.

Rettaliata, J. M., Mazzuchi, T. A., & Sarkani, S. (2013). Identifying Requirement Attributes for Materiel and Non-Materiel Solution Sets Utilizing Discrete Choice Models, *Information Knowledge Systems Management*

Robertson, S., & Robertson, J. (1999). Reliable requirements through the quality gateway. In Database and Expert Systems Applications, 1999. Proceedings. Tenth International Workshop on (pp. 357-363). IEEE.

Rombach, H. D. (1989). *Software Specifications: A Framework* (No. SEI-CM-11-2.1). CARNEGIE-MELLON UNIV PITTSBURGH PA SOFTWARE ENGINEERING INST.

Saaty, T.L., (2008). Decision Making With the Analytic Hierarchy Process, *International Journal of Services Sciences*, Vol. 1, No. 1, 83–98.

Saaty, T.L. (1980). The analytic hierarchy process. McGraw-Hill, New York

Sage, A. P. (1977). Methodology for large-scale systems (pp. 165-203). New York: McGraw-Hill.

Sanders, N., (2012). Navy's OASIS Program All Wet Because of Mismanagement, According to DOD IG, retrieved March 5, 2013, from http://www.apogeeconsulting.biz/index.php?view=article&catid=1%3Alatest-news&id=683%3Anavys-oasis-program-all-wet-because-of-mismanagement-according-to-dod-ig&format=pdf&option=com_content&Itemid=55

Sham, P. C., & Curtis, D. (1995). An extended transmission/disequilibrium test (TDT) for multi-allele marker loci. *Annals of human genetics*, *59*(3), 323-336.

Shaw, R. G., & Mitchell-Olds, T. (1993). ANOVA for unbalanced data: an overview. Ecology, 1638-1645.

Sheskin, D. (2000). Handbook of parametric and nonparametric statistical procedures. CRC Press LLC.

Siegel, S. (1956). Nonparametric statistics. New York, NY: McGraw-Hill

Siegel, S. (1957). Nonparametric statistics. The American Statistician, 11(3), 13-19.

Simons, G., & Yao, Y. C. (1999). Asymptotics when the number of parameters tends to infinity in the Bradley-Terry model for paired comparisons. *The Annals of Statistics*, *27*(3), 1041-1060.

Stigler, S. M. (1994). Citation patterns in the journals of statistics and probability. *Statistical Science*, 94-108.

Stockholm International Peace Research Institute (SIPRI) Military Expense Database, retrieved from http://www.sipri.org/research/armaments/milex/milex_database on 19 Jan 2013

Sueyoshi, T., & Aoki, S. (2001). A use of a nonparametric statistic for DEA frontier shift: the Kruskal and Wallis rank test. *Omega*, *29*(1), 1-18.

Theodorsson-Norheim, E. (1986). Kruskal-Wallis test: BASIC computer program to perform nonparametric one-way analysis of variance and multiple comparisons on ranks of several independent samples. Computer methods and programs in biomedicine, 23(1), 57-62.

Titcomb, J., (2012). New £500million Joint Strike Fighters set to cost taxpayers even more... because jump jets may MELT ships' decks. In Mail Online.

Retrieved March 5, 2013, from http://www.dailymail.co.uk/news/article-2149237/New-500m-jets-set-cost-taxpayers-MELT-ships-decks.html.

Train, K. (1986). Qualitative choice analysis: Theory, econometrics, and an application to automobile demand (Vol. 10). MIT press.

U.S. Government Accountability Office, (2008). Best Practices: Increased Focus on Requirements and Oversight Needed to Improve DOD's Acquisition Environment and Weapon System Quality (Publication No. GAO-08-294). Retrieved June 10, 2012, from http://www.gao.gov/products/GAO-08-294

U.S. Government Accountability Office, (2003). Best Practices: Setting Requirements Differently Could Reduce Weapon Systems' Total Ownership Costs (Publication No.GAO-03-57). Retrieved June 18, 2012, from http://www.gao.gov/products/GAO-03-57

Westfall, L. (2005). Software requirements engineering: what, why, who, when, and how. Software Quality Professional, 7(4), 17.

Wiegers, K. E. (1999). Writing quality requirements. *Software Development*,*7*(5), 44-48.

Young, R. (2004). Criteria of a good requirement. The Requirements Engineering Handbook (Artech House, 2004), www.ralphyoung.net.

Young, R. R. (2001). Effective requirements practices. Addison-Wesley Longman Publishing Co., Inc..

APPENDIX A
Example Survey

SURVEY PURPOSE:

The purpose of this survey is to question subject matter experts to determine if there is a varience in importance of requirement attributes between a Materiel Solution and a Non-Materiel Solution. Attributes chosen for this study are Davis' 13 Attributes of a Well Written Requirement.

Your participation in this survey is greatly appreciated, and will critical in the expanding of knowledge in how to properly write requirements for Materiel and Non-Materiel Solutions.

This survey will take approximately 1 hour to complete both parts.

Directions:

1) Fill out demographics information

2) Read definitions for Materiel and Non-Materiel Solutions and examples of each - these definitions are the bases for both parts of survey

3) **Fill in PART 1** - starting at cell G31 (for Materiel) and J31 (for Non-Materiel), rank the attributes found in column A31-A39 from 1-13 (1 being most important, 13 being least important) - *NOTE: example rankings have been provided for demonstration purposes only - your answers may vary from example.* **Each attribute must be ranked differently (i.e. you can not have two attributes with the same ranking), and a ranking number can NOT be repeated. Values in Cell G44 and J44 must equal 91 when ranking is complete. If this is not the case, please ensure that rankings were done correctly, otherwise your survey will be rejected.**

4) **Fill in PART 2** - starting at cell C72 (for Materiel) and Q72 (for Non-Materiel), assign comparative weights to the attributes, comparing Attribute '*a*' to Attribute '*b*' (NOTE: form will automatically fill out comparison of Attribute '*b*' to Attribute '*a*'). Definitions for weights can be found starting in Cell A51. **When completing this section, you will base your answers off the rankings you produced in PART 1. You will also notice that you are unable to select "1 (Equal Importance)," because each attribute can not be ranked the same (same as PART 1); therefore, attributes are unable to be equal to eachother.** *NOTE: example weights have been provided for demonstration purposes only - your answers may vary from the example.*

5) Optional: Please provide comments as required. Attributes chosen for this survey are Davis' 13 Attributes of a Well Written Requirement. If surveyer has other recommendations for additional requirement attributes, please provide attributes in comment/additional attribute box. Rationale for additional attribute recommendations will support fulure research into determining optimal attributes for requirements.

Demographic	
Years of Requirements Analysis/Systems Engineering	3
Education (BS, MS, PhD)	MS
Title	Program Manager for Shipyard Military Construction
Organization Size (# of employees)	1000+

Comment Box/Recommended Additional Attributes

DEFINITIONS	
Materiel Solution	Correction of a deficiency, satisfaction of a capability gap, or incorporation of new technology ***that results in the development, acquisition, procurement, or fielding of a new item***, including ships, tanks, self-propelled weapons, aircraft, etc., and related software, spares, repair parts, and support equipment, but excluding real property, installations, and utilities, necessary to equip, operate, maintain, and support military activities without disruption as to their application for administrative or combat purposes. **EXAMPLE: Designing new Helicopter Platform to meet capability gap**
Non-Materiel Solution	***Changes doctrine, organization, training, materiel, leadership and education, personnel, facilities, or policy*** (including all human systems integration domains) to satisfy identified functional capabilities. The materiel portion is restricted to commercial or non-developmental items, which may be purchased commercially, or by purchasing more systems from an existing materiel program. **EXAMPLE: Alter tactics of flight operations for current Helicopter platform to meet capability gap**

PART 1 - Ranking Attributes 1 thru 13 (1 being MOST important, 13 being LEAST important)

Attributes	Definition	Rank Materiel Solutions	*Example*	Rank Non-Materiel Solutions	*Example*	Ranking Difference Rationale *(Explain why each attribute is ranked the same/different)*
Correct	Represents something required of the system	2	2	2	2	When looking at a M and NM solution, I believe that these attributes are still equal to eachother when comparing goals of each solution
Unambiguous	Can only have one interpretation	5	5	7	7	While still important, because you're altering an existing program (Non-Materiel) vs. starting from scratch (Materiel), there is more structure, so the requirement won't necessarily be as difficult to comprehend
Complete	All aspects are accounted for, and no gaps are left	1	1	1	1	This is still as important an attribute, regardless of whether it's a M or NM solution
Verifiable	Finite way of determining if requirement meets intended purposes	3	3	4	4	These are almost equal, but the fact that a Non Materiel Solution should be more modifiable than a Materiel Solution, the fact that it's verifiable drops down a notch
Consistent	Does not conflict or present inconsistency with other requirements	4	4	8	8	Consistency is an important attribute, but when starting a new program it is much more important to require consistency.
Understandable by Customer	Explainable by non-subject matter experts	11	11	9	9	Because you'll be altering an existing program, you must be sure that the end user (pilots for examples above) fully comprehend the changes that are being made to the craft, esp if they're used to using the craft in a certain way.
Modifiable	Structure allows alterations to be made without compromising intent	9	9	3	3	Due to the fact that you're changing the tactics on an existing vessel, it is extremely important that the requirement can be modified to work with the platform at hand, vs. in a Materiel Solution where there is more leeway in design, etc to adapt to the requirement.
Traced	Origin is clear	6	6	5	5	In order to change a requirement, one must understand where the requirement originated from. This is more important in a Non-Materiel Solution due to the fact that it is altering how you use an existing system
Traceable	Process can be followed back to origin	7	7	6	6	In order to change a requirement, one must understand where the requirement originated from, and how it came to be at its current form. This is more important in a Non-Materiel Solution due to the fact that it is altering how you use an existing system
Design Independent	Does not rely on a single architecture	12	12	12	12	These are considered equally important
Annotated	Rank in order to determine importance to the end user	8	8	10	10	Because you're starting with a new system in a Materiel Solution, it is more important to determine the ranking of the requirements (KPP, etc) as this will affect the design a lot more than merely altering tactics (i.e. won't affect performance parameters of the craft).
Concise	Short and to the point	13	13	13	13	Equally important, as length doesn't necessarily determine a good requirement
Organized	Structured to be easily found	10	10	11	11	Requirements must be more organized in a Materiel Solution as you are starting a system from scratch, and you must paint a clear picture in order to successfully achieve the end product.
	Ranking Sum (must equal 91)	91	91	91	91	

PART 2 - Assigning Weights of Importants to Attributes

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or Slight Importance	
3	Moderate Importance	Experience and judgement slightly favor one activity over the other
4	Moderate Plus Importance	
5	Strong Importance	Experience and judgement strongly favor one activity over another
6	Strong Plus Importance	
7	Very Strong or Demonstrated Importance	An Activity is favored very strongly over another; its dominance demonstrated in practice
8	Very Very Strong Importance	
9	Extreme Importance	Evidence favoring one activity over another is of the highest possible order of affirmation
1/2	Weak or Slightly Less Important	
1/3	Moderately Less Important	Experience and judgement slightly DON'T favor one activity over the other
1/4	Moderate Plus Less Important	
1/5	Strongly Less Important	Experience and judgement strongly DON'T favor one activity over another
1/6	Strong Plus Less Important	
1/7	Very Strong or Demonstrated Less Importance	An Activity is NOT favored very strongly over another; its dominance is NOT demonstrated in practice
1/8	Very Very Strongly Less Importance	
1/9	Extreme Less Importance	Evidence DOES NOT exist favoring one activity over another

MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	4	1/2	2	3	5	4	3	4	8	7	9	7
Unambiguous	1/4	1	1/4	1/3	1/2	5	3	2	2	7	5	8	7
Complete	2	4	1	3	4	6	5	4	4	7	5	9	7
Verifiable	1/2	3	1/3	1	2	4	5	3	4	6	4	8	6
Consistent	1/3	2	1/4	1/2	1	5	4	3	4	6	3	8	6
Understandable by Customer	1/5	1/5	1/6	1/4	1/5	1	1/3	1/4	1/3	2	1/3	3	2
Modifiable	1/4	1/3	1/5	1/5	1/4	3	1	1/3	1/2	4	1/2	4	3
Traced	1/3	1/2	1/4	1/3	1/3	4	3	1	2	5	3	5	4
Traceable	1/4	1/2	1/4	1/4	1/4	3	2	1/2	1	4	2	5	4
Design Independent	1/8	1/7	1/7	1/6	1/6	1/2	1/4	1/5	1/4	1	1/4	2	1/3
Annotated	0.142857	1/5	1/5	1/4	1/3	3	2	1/3	1/2	4	1	6	5
Concise	1/9	1/8	1/9	1/8	1/8	1/3	0.25	0.2	0.2	1/2	1/6	1	1/4
Organized	1/7	1/7	1/7	1/6	1/6	1/2	1/3	1/4	1/4	3	1/5	4	1

NON-MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	5	1/2	3	4	6	2	3	3	8	7	9	7
Unambiguous	1/5	1	1/5	1/3	2	3	1/4	1/3	1/3	4	4	8	7
Complete	2	5	1	4	6	6	3	4	4	8	7	9	7
Verifiable	1/3	3	1/4	1	3	4	1/2	2	2	7	6	8	6
Consistent	1/4	1/2	1/6	1/3	1	2	1/4	1/3	1/3	5	4	6	4
Understandable by Customer	1/6	1/3	1/6	1/4	1/2	1	1/4	1/3	1/3	4	3	4	3
Modifiable	1/2	4	1/3	2	4	4	1	4	4	7	6	8	6
Traced	1/3	3	1/4	1/2	3	3	1/4	1	2	6	5	7	5
Traceable	1/3	3	1/4	1/2	3	3	1/4	1/2	1	5	4	6	4
Design Independent	1/8	1/4	1/8	1/7	1/5	1/4	1/7	1/6	1/5	1	1/3	2	1/2
Annotated	1/7	1/4	1/7	1/6	1/4	1/3	1/6	1/5	1/4	3	1	3	2
Concise	1/9	1/8	1/9	1/8	1/6	1/4	1/8	1/7	1/6	1/2	1/3	1	1/3
Organized	1/7	1/7	1/7	1/6	1/4	1/3	1/6	1/5	1/4	2	1/2	3	1

MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	4	1/2	2	3	5	4	3	4	8	7	9	7
Unambiguous	1/4	1	1/4	1/3	1/2	5	3	2	2	7	5	8	7
Complete	2	4	1	3	4	6	5	4	4	7	5	9	7
Verifiable	1/2	3	1/3	1	2	4	5	3	4	6	4	8	6
Consistent	1/3	2	1/4	1/2	1	5	4	3	4	6	3	8	6
Understandable by Customer	1/5	1/5	1/6	1/4	1/5	1	1/3	1/4	1/3	2	1/3	3	2
Modifiable	1/4	1/3	1/5	1/5	1/4	3	1	1/3	1/2	4	1/2	4	3
Traced	1/3	1/2	1/4	1/3	1/3	4	3	1	2	5	3	5	4
Traceable	1/4	1/2	1/4	1/4	1/4	3	2	1/2	1	4	2	5	4
Design Independent	1/8	1/7	1/7	1/6	1/6	1/2	1/4	1/5	1/4	1	1/4	2	1/3
Annotated	1/7	1/5	1/5	1/4	1/3	3	2	1/3	1/2	4	1	6	5
Concise	1/9	1/8	1/9	1/8	1/8	1/3	1/4	1/5	1/5	1/2	1/6	1	1/4
Organized	1/7	1/7	1/7	1/6	1/6	1/2	1/3	1/4	1/4	3	1/5	4	1

NON-MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	5	1/2	3	4	6	2	3	3	8	7	9	7
Unambiguous	1/5	1	1/5	1/3	2	3	1/4	1/3	1/3	4	4	8	7
Complete	2	5	1	4	6	6	3	4	4	8	7	9	7
Verifiable	1/3	3	1/4	1	3	4	1/2	2	2	7	6	8	6
Consistent	1/4	1/2	1/6	1/3	1	2	1/4	1/3	1/3	5	4	6	4
Understandable by Customer	1/6	1/3	1/6	1/4	1/2	1	1/4	1/3	1/3	4	3	4	3
Modifiable	1/2	4	1/3	2	4	4	1	4	4	7	6	8	6
Traced	1/3	3	1/4	1/2	3	3	1/4	1	2	6	5	7	5
Traceable	1/3	3	1/4	1/2	3	3	1/4	1/2	1	5	4	6	4
Design Independent	1/8	1/4	1/8	1/7	1/5	1/4	1/7	1/6	1/5	1	1/3	2	1/2
Annotated	1/7	1/4	1/7	1/6	1/4	1/3	1/6	1/5	1/4	3	1	3	2
Concise	1/9	1/8	1/9	1/8	1/6	1/4	1/8	1/7	1/6	1/2	1/3	1	1/3
Organized	1/7	1/7	1/7	1/6	1/4	1/3	1/6	1/5	1/4	2	1/2	3	1

APPENDIX B
Survey Data – Ranking

Survey Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SE Experience	13	5	32	25	30	8 yrs Requirements Analysis / 10 yrs Systems Engineering	7	30	4	33	15	15	10	3	12	13	16	7	37	10
Education	PhD	MS	MS	MS	BS	MS Johns Hopkins	MS	PhD	MS	PhD	AA+ experience	MS	MS	BS	BS	BS	B.S.	PhD	PhD	BS
Position	Asst Program Manager	Program Manager	Group Supervsor	Senior Systems Engineer	MIW TWH	Foreign Military Sales APM	Project Manager	Technical Fellow	Assistant Program Manager	Deputy Chief Enginer	DAPM	Technical Program Manager	System Engineer/Deputy Project Engineer	Consultant	Project Manager	System Test & Evaluation Engineer	Senior Manager	Assistant Program Manager Post Mission Analysis	Mission System Engineer	APM, In-service weapon systems
Org size #employee	200	36	16	1300	100+	Approx 60	5000	5000	20	10000	2000	~1300	1000+	self only	1200	1200	~140	23	2	1200
MATERIEL SOLUTION ATTRIBUTES	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**
Correct	3	1	1	2	2	2	2	1	1	1	2	1	2	2	1	2	1	1	1	2
Unambiguous	1	4	3	5	3	5	3	3	3	4	4	7	5	7	9	3	3	4	2	3
Complete	4	7	2	1	1	1	7	2	5	3	1	5	1	1	3	4	2	2	4	1
Verifiable	2	2	8	3	11	3	10	4	2	6	3	2	3	3	4	6	4	3	3	4
Consistent	8	5	4	4	4	4	6	5	6	2	5	8	4	4	10	8	5	8	5	5
Understandable by Customer	5	9	13	6	7	9	13	7	4	10	9	13	9	10	5	13	10	7	11	9
Modifiable	10	11	9	11	9	8	8	13	13	9	11	6	8	9	12	5	6	9	8	6
Traced	9	10	7	7	5	6	4	6	8	7	7	3	7	5	6	1	7	5	6	8
Traceable	7	8	6	8	6	7	5	8	7	5	6	4	11	6	2	7	8	6	7	11
Design Independent	12	6	5	9	12	10	1	9	9	8	12	11	6	12	13	10	9	12	13	10
Annotated	6	3	10	12	8	11	12	10	11	13	8	9	10	8	11	11	11	10	9	7
Concise	13	12	11	13	13	12	11	11	10	11	13	12	13	13	8	12	12	13	12	13
Organized	11	13	12	10	10	13	9	12	12	12	10	10	12	11	7	9	13	11	10	12
NON MATERIEL SOLUTION ATTRIBUTES	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**	**RANK**
Correct	4	1	1	2	2	1	7	1	1	1	2	1	1	2	6	7	1	1	1	2
Unambiguous	2	4	3	5	3	5	3	3	3	5	5	7	6	7	5	4	4	6	2	5
Complete	7	7	2	1	1	2	12	2	7	3	1	3	2	1	7	9	2	2	4	1
Verifiable	1	2	9	3	9	4	1	4	2	7	3	2	4	3	1	13	5	5	3	3
Consistent	5	6	4	4	4	3	6	5	5	2	6	8	7	9	4	8	6	8	5	7
Understandable by Customer	6	5	5	6	5	7	5	7	8	9	7	9	10	10	3	1	3	7	11	8
Modifiable	3	8	8	9	13	8	8	13	12	10	8	6	5	4	13	6	7	9	8	4
Traced	10	9	7	7	11	6	2	6	4	8	4	4	3	5	2	3	8	3	6	6
Traceable	8	10	6	8	12	9	4	8	9	4	10	5	8	6	8	10	9	4	7	10
Design Independent	13	13	10	11	10	10	11	9	13	6	12	13	11	12	12	5	10	10	13	11
Annotated	9	3	11	12	6	11	10	10	6	11	9	10	12	8	10	12	11	12	9	9
Concise	12	12	12	13	7	13	13	11	10	13	13	12	13	13	11	11	12	13	12	13
Organized	11	11	13	10	8	12	9	12	11	12	11	11	9	11	9	2	13	11	10	12

Survey Data – Pairwise Comparison

Survey Number

1 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	1/3	2	1/2	6	3	8	6	4	9	3	9	8
Unambiguous	3	1	4	2	6	3	9	8	6	9	5	9	9
Complete	1/2	1/4	1	1/2	4	2	6	5	4	9	2	9	8
Verifiable	2	1/2	2	1	6	3	8	7	5	9	4	9	9
Consistent	1/6	1/6	1/4	1/6	1	1/3	2	2	1/2	4	1/2	5	3
Understandable by Customer	1/3	1/3	1/2	1/3	3	1	5	4	2	7	2	8	6
Modifiable	1/8	1/9	1/6	1/8	1/2	1/5	1	1/2	1/3	2	1/4	3	2
Traced	1/6	1/8	1/5	1/7	1/2	1/4	2	1	1/2	3	1/3	4	2
Traceable	1/4	1/6	1/4	1/5	2	1/2	3	2	1	5	1/2	6	4
Design Independent	1/9	1/9	1/9	1/9	1/4	1/7	1/2	1/3	1/5	1	1/6	2	1/2
Annotated	1/3	1/5	1/2	1/4	2	1/2	4	3	2	6	1	7	5
Concise	1/9	1/9	1/9	1/9	1/5	1/8	1/3	1/4	1/6	1/2	1/7	1	1/2
Organized	1/8	1/9	1/8	1/9	1/3	1/6	1/2	1/2	1/4	2	1/5	2	1

2 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	4	7	2	5	8	9	8	3	5	3	8	9
Unambiguous	1/4	1	3	1/3	2	3	7	6	5	4	1/2	8	9
Complete	1/7	1/3	1	1/5	1/3	3	5	3	2	1/2	1/4	6	7
Verifiable	1/2	3	5	1	4	5	7	6	5	6	2	8	9
Consistent	1/5	1/2	3	1/4	1	5	6	5	2	2	1/3	8	9
Understandable by Customer	1/8	1/3	1/3	1/5	1/5	1	3	2	1/2	1/3	1/5	4	5
Modifiable	1/9	1/7	1/5	1/7	1/6	1/3	1	1/2	1/4	1/5	1/7	2	3
Traced	1/8	1/6	1/3	1/6	1/5	1/2	2	1	1/3	1/4	1/6	3	4
Traceable	1/3	1/5	1/2	1/5	1/2	2	4	3	1	1/3	1/5	4	5
Design Independent	1/5	1/4	2	1/6	1/2	3	5	4	3	1	1/4	5	6
Annotated	1/3	2	4	1/2	3	5	7	6	5	4	1	6	7
Concise	1/8	1/8	1/6	1/8	1/8	1/4	1/2	1/3	1/4	1/5	1/6	1	2
Organized	1/9	1/9	1/7	1/9	1/9	1/5	1/3	1/4	1/5	1/6	1/7	1/2	1

3 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	2	2	5	3	7	6	5	4	4	6	6	7
Unambiguous	1/2	1	1/2	4	2	6	5	4	3	2	5	6	6
Complete	1/2	2	1	5	2	7	5	4	4	3	6	6	6
Verifiable	1/5	1/4	1/5	1	1/4	4	2	1/2	1/2	1/3	2	3	4
Consistent	1/3	1/2	1/2	4	1	6	4	3	2	2	5	5	6
Understandable by Customer	1/7	1/6	1/7	1/4	1/6	1	1/4	1/5	1/5	1/6	1/3	1/2	1/2
Modifiable	1/6	1/5	1/5	1/2	1/4	4	1	1/2	1/3	1/4	2	2	3
Traced	1/5	1/4	1/4	2	1/3	5	2	1	1/2	1/2	3	4	4
Traceable	1/4	1/3	1/4	2	1/2	5	3	2	1	1/2	4	4	5
Design Independent	1/4	1/2	1/3	3	1/2	6	4	2	2	1	4	5	5
Annotated	1/6	1/5	1/6	1/2	1/5	3	1/2	1/3	1/4	1/4	1	2	2
Concise	1/6	1/6	1/6	1/3	1/5	2	1/2	1/4	1/4	1/5	1/2	1	2
Organized	1/7	1/6	1/6	1/4	1/6	2	1/3	1/4	1/5	1/5	1/2	1/2	1

4 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	2	1/3	2	2	2	5	4	4	5	6	6	5
Unambiguous	1/2	1	1/3	1/3	1/2	2	5	4	4	5	6	6	5
Complete	3	3	1	3	3	3	5	4	4	5	6	6	5
Verifiable	1/2	3	1/3	1	2	3	5	4	4	5	6	6	5
Consistent	1/2	2	1/3	1/2	1	3	5	4	4	5	6	6	5
Understandable by Customer	1/2	1/2	1/3	1/3	1/3	1	5	4	4	5	6	6	5
Modifiable	1/5	1/5	1/5	1/5	1/5	1/5	1	1/3	1/3	1/2	4	4	1/2
Traced	1/4	1/4	1/4	1/4	1/4	1/4	3	1	2	3	5	5	4
Traceable	1/4	1/4	1/4	1/4	1/4	1/4	3	1/2	1	3	5	5	4
Design Independent	1/5	1/5	1/5	1/5	1/5	1/5	2	1/3	1/3	1	4	4	1/2
Annotated	1/6	1/6	1/6	1/6	1/6	1/6	1/4	1/5	1/5	1/4	1	2	1/2
Concise	1/6	1/6	1/6	1/6	1/6	1/6	1/4	1/5	1/5	1/4	1/2	1	1/2
Organized	1/5	1/5	1/5	1/5	1/5	1/5	2	1/4	1/4	2	2	2	1

5 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	2	1/2	8	3	5	6	3	4	8	5	9	7
Unambiguous	1/2	1	1/3	8	2	4	6	3	4	8	6	8	6
Complete	2	3	1	8	3	5	7	4	4	9	6	9	8
Verifiable	1/8	1/8	1/8	1	1/6	1/4	1/3	1/5	1/4	2	1/3	3	1/2
Consistent	1/3	1/2	1/3	6	1	3	4	2	3	7	4	8	5
Understandable by Customer	1/5	1/4	1/5	4	1/3	1	3	1/3	1/2	4	2	4	3
Modifiable	1/6	1/6	1/7	3	1/4	1/3	1	1/4	1/3	3	1/2	4	2
Traced	1/3	1/3	1/4	5	1/2	3	4	1	2	3	3	7	4
Traceable	1/4	1/4	1/4	4	1/3	2	3	1/2	1	5	3	6	4
Design Independent	1/8	1/8	1/9	1/2	1/7	1/4	1/3	1/3	1/5	1	1/4	2	1/3
Annotated	1/5	1/6	1/6	3	1/4	1/2	2	1/3	1/3	4	1	4	3
Concise	1/9	1/8	1/9	1/3	1/8	1/4	1/4	1/7	1/6	1/2	1/4	1	1/3
Organized	1/7	1/6	1/8	2	1/5	1/3	1/2	1/4	1/4	3	1/3	3	1

Survey Data – Pairwise Comparison Materiel Solution (cont'd)

Survey Number

6 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	3	1/2	2	3	6	5	3	4	7	8	8	9
Unambiguous	1/3	1	1/4	1/3	1/2	5	4	2	3	6	7	8	9
Complete	2	4	1	2	3	4	5	4	6	7	7	8	9
Verifiable	1/2	3	1/2	1	2	5	5	4	5	7	7	8	9
Consistent	1/3	2	1/3	1/2	1	4	3	3	4	7	7	8	9
Understandable by Customer	1/6	1/5	1/4	1/5	1/4	1	1/2	1/3	1/3	2	3	4	5
Modifiable	1/5	1/4	1/5	1/5	1/3	2	1	1/2	1/2	2	3	4	5
Traced	1/3	1/2	1/4	1/4	1/3	3	2	1	2	3	4	5	6
Traceable	1/4	1/3	1/6	1/5	1/4	3	2	1/2	1	2	2	3	4
Design Independent	1/7	1/6	1/7	1/7	1/7	1/2	1/2	1/3	1/2	1	2	3	4
Annotated	1/8	1/7	1/7	1/7	1/7	1/3	1/3	1/4	1/2	1/2	1	2	3
Concise	1/8	1/8	1/8	1/8	1/8	1/4	1/4	1/5	1/3	1/3	1/2	1	2
Organized	1/9	1/9	1/9	1/9	1/9	1/5	1/5	1/6	1/4	1/4	1/3	1/2	1

7 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	2	4	7	4	9	5	2	3	1/2	9	8	7
Unambiguous	1/2	1	3	6	3	8	4	2	2	1/2	8	7	5
Complete	1/4	1/3	1	3	1/2	5	2	1/3	1/3	1/5	4	4	2
Verifiable	1/7	1/6	1/3	1	1/3	3	1/2	1/4	1/4	1/6	2	2	1/2
Consistent	1/4	1/3	2	3	1	5	2	1/2	1/2	1/4	4	4	3
Understandable by Customer	1/9	1/8	1/5	1/3	1/5	1	1/4	1/6	1/6	1/9	1/2	1/2	1/5
Modifiable	1/5	1/4	1/2	2	1/2	4	1	1/3	1/3	1/5	3	3	2
Traced	1/2	1/2	3	4	2	6	3	1	2	1/3	6	6	5
Traceable	1/3	1/2	3	4	2	6	3	1/2	1	1/3	6	6	5
Design Independent	2	2	5	6	4	9	5	3	3	1	8	8	7
Annotated	1/9	1/8	1/4	1/2	1/4	2	1/3	1/6	1/6	1/8	1	1/2	1/3
Concise	1/8	1/7	1/4	1/2	1/4	2	1/3	1/6	1/6	1/8	2	1	1/2
Organized	1/7	1/5	1/2	2	1/3	5	1/2	1/5	1/5	1/7	3	2	1

8 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	3	2	4	5	4	9	2	9	6	9	9	5
Unambiguous	1/3	1	1/2	2	4	4	8	2	8	5	8	8	4
Complete	1/2	2	1	4	5	4	9	2	9	5	9	9	5
Verifiable	1/4	1/2	1/4	1	2	2	7	2	8	4	6	6	3
Consistent	1/5	1/4	1/5	1/2	1	2	2	2	2	2	2	2	2
Understandable by Customer	1/4	1/4	1/4	1/2	1/2	1	4	1/4	4	2	2	2	2
Modifiable	1/9	1/8	1/9	1/7	1/2	1/4	1	1/4	1/2	1/2	1/2	1/2	1/2
Traced	1/2	1/2	1/2	1/2	1/2	4	4	1	2	2	2	2	2
Traceable	1/9	1/8	1/9	1/8	1/2	1/4	2	1/2	1	2	2	2	2
Design Independent	1/6	1/5	1/5	1/4	1/2	1/2	2	1/2	1/2	1	3	3	2
Annotated	1/9	1/8	1/9	1/6	1/2	1/2	2	1/2	1/2	1/3	1	2	2
Concise	1/9	1/8	1/9	1/6	1/2	1/2	2	1/2	1/2	1/3	1/2	1	2
Organized	1/5	1/4	1/5	1/3	1/2	1/2	2	1/2	1/2	1/2	1/2	1/2	1

9 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	3	5	2	5	4	9	7	7	7	9	7	9
Unambiguous	1/3	1	3	1/3	4	2	8	6	6	6	8	6	8
Complete	1/5	1/3	1	1/5	2	1/3	7	3	3	3	7	3	7
Verifiable	1/2	3	5	1	5	4	9	7	7	7	9	7	9
Consistent	1/5	1/4	1/2	1/5	1	1/3	7	3	3	3	7	3	7
Understandable by Customer	1/4	1/2	3	1/4	3	1	7	4	4	4	8	4	8
Modifiable	1/9	1/8	1/7	1/9	1/7	1/7	1	1/5	1/5	1/3	1/2	1/3	1/2
Traced	1/7	1/6	1/3	1/7	1/3	1/4	5	1	1/2	2	3	3	5
Traceable	1/7	1/6	1/3	1/7	1/3	1/4	5	2	1	2	3	3	5
Design Independent	1/7	1/6	1/3	1/7	1/3	1/4	3	1/2	1/2	1	3	2	4
Annotated	1/9	1/8	1/7	1/9	1/7	1/8	2	1/3	1/3	1/3	1	1/3	3
Concise	1/7	1/6	1/3	1/7	1/3	1/4	3	1/3	1/3	1/2	3	1	4
Organized	1/9	1/8	1/7	1/9	1/7	1/8	2	1/5	1/5	1/4	1/3	1/4	1

10 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	5	2	4	2	6	5	5	3	5	9	7	7
Unambiguous	1/5	1	1/3	3	1/3	3	4	4	2	4	5	5	6
Complete	1/2	3	1	4	1/2	6	5	5	4	5	6	7	8
Verifiable	1/4	1/3	1/4	1	1/5	3	2	2	1/2	3	5	6	7
Consistent	1/2	3	2	5	1	6	7	5	3	5	7	8	9
Understandable by Customer	1/6	1/3	1/6	1/3	1/6	1	1/2	1/4	1/6	1/3	4	3	5
Modifiable	1/5	1/4	1/5	1/2	1/7	2	1	1/2	1/4	1/2	3	5	6
Traced	1/5	1/4	1/5	1/2	1/5	4	2	1	1/3	2	5	3	5
Traceable	1/3	1/2	1/4	2	1/3	6	4	3	1	3	4	3	5
Design Independent	1/5	1/4	1/5	1/3	1/5	3	2	1/2	1/3	1	4	2	4
Annotated	1/9	1/5	1/6	1/5	1/7	1/4	1/3	1/5	1/4	1/4	1	1/3	1/2
Concise	1/7	1/5	1/7	1/6	1/8	1/3	1/5	1/3	1/3	1/2	3	1	2
Organized	1/7	1/6	1/8	1/7	1/9	1/5	1/6	1/5	1/5	1/4	2	1/2	1

Survey Data – Pairwise Comparison Materiel Solution (cont'd)

Survey Number

11 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	4	1/2	2	3	5	4	3	4	8	7	9	7
Unambiguous	1/4	1	1/4	1/3	4	5	3	2	2	7	5	8	7
Complete	2	4	1	4	4	6	5	4	4	7	5	9	7
Verifiable	1/2	3	1/4	1	2	4	5	3	4	6	4	8	6
Consistent	1/3	1/4	1/4	1/2	1	5	4	3	4	6	3	8	6
Understandable by Customer	1/5	1/5	1/6	1/4	1/5	1	5	1/4	1/3	2	1/2	3	3
Modifiable	1/4	1/3	1/5	1/5	1/4	1/5	1	1/3	1/2	4	1/2	4	1/2
Traced	1/3	1/2	1/4	1/3	1/3	4	3	1	1/2	5	3	5	4
Traceable	1/4	1/2	1/4	1/4	1/4	3	2	2	1	4	2	5	4
Design Independent	1/8	1/7	1/7	1/6	1/6	1/2	1/4	1/5	1/4	1	1/4	2	1/4
Annotated	1/7	1/5	1/5	1/4	1/3	2	2	1/3	1/2	4	1	6	5
Concise	1/9	1/8	1/9	1/8	1/8	1/3	1/4	1/5	1/5	1/2	1/6	1	1/4
Organized	1/7	1/7	1/7	1/6	1/6	1/3	2	1/4	1/4	4	1/5	4	1

12 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	6	7	2	6	9	5	3	3	8	6	9	8
Unambiguous	1/6	1	1/4	1/3	2	4	1/2	1/4	1/3	3	2	3	3
Complete	1/7	4	1	1/3	3	5	2	1/2	1/2	6	3	4	4
Verifiable	1/2	3	3	1	6	8	4	2	2	8	5	8	7
Consistent	1/6	1/2	1/3	1/6	1	3	1/2	1/4	1/4	3	2	3	2
Understandable by Customer	1/9	1/4	1/5	1/8	1/3	1	1/5	1/6	1/6	1/2	1/3	1/2	1/3
Modifiable	1/5	2	1/2	1/4	2	5	1	1/3	2	3	2	4	3
Traced	1/3	4	2	1/2	4	6	3	1	2	6	5	7	5
Traceable	1/3	3	2	1/2	4	6	1/2	1/2	1	7	4	8	5
Design Independent	1/8	1/3	1/6	1/8	1/3	2	1/3	1/6	1/7	1	1/2	2	1/2
Annotated	1/6	1/2	1/3	1/5	1/2	3	1/2	1/5	1/4	2	1	2	2
Concise	1/9	1/3	1/4	1/8	1/3	2	1/4	1/7	1/8	1/2	1/2	1	1/2
Organized	1/8	1/3	1/4	1/7	1/2	3	1/3	1/5	1/5	2	1/2	2	1

13 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	5	1/2	2	3	6	6	5	6	4	7	9	6
Unambiguous	1/5	1	1/3	1/2	1/3	3	4	3	4	2	4	5	5
Complete	2	3	1	5	3	4	5	4	5	3	7	7	7
Verifiable	1/2	2	1/5	1	2	4	4	4	5	4	6	7	7
Consistent	1/3	3	1/3	1/2	1	4	4	4	6	3	5	7	7
Understandable by Customer	1/6	1/3	1/4	1/4	1/4	1	1/2	1/3	3	1/3	2	4	5
Modifiable	1/6	1/4	1/5	1/4	1/4	2	1	1/2	3	1/3	3	2	4
Traced	1/5	1/3	1/4	1/4	1/4	3	2	1	4	1/2	3	5	5
Traceable	1/6	1/4	1/5	1/5	1/6	1/3	1/3	1/4	1	1/5	1/2	3	3
Design Independent	1/4	1/2	1/3	1/4	1/3	3	3	2	5	1	4	4	4
Annotated	1/7	1/4	1/7	1/6	1/5	1/2	1/3	1/3	2	1/4	1	3	3
Concise	1/9	1/5	1/7	1/7	1/7	1/4	1/2	1/5	1/3	1/4	1/3	1	1/2
Organized	1/6	1/5	1/7	1/7	1/7	1/5	1/4	1/5	1/3	1/4	1/3	2	1

14 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	6	1/2	2	3	9	8	4	5	9	7	9	9
Unambiguous	1/6	1	1/7	1/5	1/4	4	3	1/3	1/2	6	2	6	5
Complete	2	7	1	2	3	9	8	4	5	9	8	9	9
Verifiable	1/2	5	1/2	1	2	8	6	3	4	9	6	9	9
Consistent	1/3	4	1/3	1/2	1	7	6	2	3	9	5	9	7
Understandable by Customer	1/9	1/4	1/9	1/8	1/7	1	1/2	1/5	1/4	3	1/3	4	2
Modifiable	1/8	1/3	1/8	1/6	1/6	2	1	1/4	1/3	4	1/2	5	3
Traced	1/4	3	1/4	1/3	1/2	5	4	1	2	8	4	9	7
Traceable	1/5	2	1/5	1/4	1/3	4	3	1/2	1	6	3	8	6
Design Independent	1/9	1/6	1/9	1/9	1/9	1/3	1/4	1/8	1/6	1	1/4	2	1/2
Annotated	1/7	1/2	1/8	1/6	1/5	3	2	1/4	1/3	4	1	6	4
Concise	1/9	1/6	1/9	1/9	1/9	1/4	1/5	1/9	1/8	1/2	1/6	1	1/3
Organized	1/9	1/5	1/9	1/9	1/7	1/2	1/3	1/7	1/6	2	1/4	3	1

15 **MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	5	2	5	7	4	8	5	3	7	2	3	4
Unambiguous	1/5	1	1/6	1/3	2	1/3	3	1/2	1/6	2	2	1/2	1/3
Complete	1/2	6	1	2	5	3	5	4	1/2	5	7	4	3
Verifiable	1/5	3	1/2	1	5	2	6	3	1/2	4	5	3	2
Consistent	1/7	1/2	1/5	1/5	1	1/8	2	1/3	1/6	2	2	1/3	1/2
Understandable by Customer	1/4	3	1/3	1/2	8	1	4	2	1/5	4	3	3	2
Modifiable	1/8	1/3	1/5	1/6	1/2	1/4	1	1/4	1/8	2	1/8	1/5	1/5
Traced	1/5	2	1/4	1/3	3	1/2	4	1	1/3	4	3	3	2
Traceable	1/3	6	2	2	6	5	8	3	1	8	7	4	3
Design Independent	1/7	1/2	1/5	1/4	1/2	1/4	1/2	1/4	1/8	1	1/3	1/4	1/6
Annotated	1/2	1/2	1/7	1/5	1/2	1/3	8	1/3	1/7	3	1	1/2	1/5
Concise	1/3	2	1/4	1/3	3	1/3	5	1/3	1/4	4	2	1	1/2
Organized	1/4	3	1/3	1/2	2	1/2	5	1/2	1/3	6	5	2	1

Survey Data – Pairwise Comparison Materiel Solution (cont'd)

Survey Number

16 MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	2	3	4	3	2	3	1/2	2	3	2	3	9
Unambiguous	1/2	1	1/2	2	2	6	6	1/5	3	3	7	2	5
Complete	1/3	2	1	2	2	2	2	1/2	2	2	2	7	8
Verifiable	1/4	1/2	1/2	1	5	3	1/4	1/7	2	9	8	8	9
Consistent	1/3	1/2	1/2	1/5	1	3	1/6	1/3	1/4	9	9	8	9
Understandable by Customer	1/2	1/6	1/2	1/3	1/3	1	1/2	1/2	1/2	1/3	1/6	1/2	1/2
Modifiable	1/3	1/6	1/2	4	6	2	1	1/2	3	4	5	3	3
Traced	2	5	2	7	3	2	2	1	4	7	9	8	9
Traceable	1/2	1/3	1/2	1/2	4	2	1/3	1/4	1	4	4	9	9
Design Independent	1/3	1/3	1/2	1/9	1/9	3	1/4	1/7	1/4	1	6	2	1/2
Annotated	1/2	1/7	1/2	1/8	1/9	6	1/5	1/9	1/4	1/6	1	2	1/2
Concise	1/3	1/2	1/7	1/8	1/8	2	1/3	1/8	1/9	1/2	1/2	1	1/2
Organized	1/9	1/5	1/8	1/9	1/9	2	1/3	1/9	1/9	2	2	2	1

17 MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	3	2	4	4	7	5	5	6	6	7	8	9
Unambiguous	1/3	1	1/3	2	3	6	4	4	5	5	6	7	7
Complete	1/2	3	1	3	4	6	4	5	5	6	7	7	8
Verifiable	1/4	1/2	1/3	1	2	5	3	4	4	5	6	6	7
Consistent	1/4	1/3	1/4	1/2	1	5	2	3	4	4	5	6	6
Understandable by Customer	1/7	1/6	1/6	1/5	1/5	1	1/5	1/2	1/4	1/3	2	3	4
Modifiable	1/5	1/4	1/4	1/3	1/2	5	1	2	3	4	5	5	6
Traced	1/5	1/4	1/5	1/4	1/3	2	1/2	1	2	3	4	5	5
Traceable	1/6	1/5	1/5	1/4	1/4	4	1/3	1/2	1	2	4	4	5
Design Independent	1/6	1/5	1/6	1/5	1/4	3	1/4	1/3	1/2	1	3	4	4
Annotated	1/7	1/6	1/7	1/6	1/5	1/2	1/5	1/4	1/4	1/3	1	2	3
Concise	1/8	1/7	1/7	1/6	1/6	1/3	1/5	1/5	1/4	1/4	1/2	1	3
Organized	1/9	1/7	1/8	1/7	1/6	1/4	1/6	1/5	1/5	1/4	1/3	1/3	1

18 MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	3	2	2	3	4	5	3	4	7	5	7	7
Unambiguous	1/3	1	1/2	1/2	2	2	3	3	3	7	4	7	7
Complete	1/2	2	1	2	2	2	3	3	3	7	4	7	7
Verifiable	1/2	2	1/2	1	2	2	2	2	2	6	3	6	6
Consistent	1/3	1/2	1/2	1/2	1	1/2	2	1/3	1/3	4	3	4	4
Understandable by Customer	1/4	1/2	1/2	1/2	2	1	2	1/2	1/2	3	2	3	3
Modifiable	1/5	1/3	1/3	1/2	1/2	1/2	1	1/2	1/2	3	2	3	3
Traced	1/3	1/3	1/3	1/2	3	2	2	1	2	3	2	3	3
Traceable	1/4	1/3	1/3	1/2	3	2	2	1/2	1	3	2	3	3
Design Independent	1/7	1/7	1/7	1/6	1/4	1/3	1/3	1/3	1/3	1	1/2	2	1/2
Annotated	1/5	1/4	1/4	1/3	1/3	1/2	1/2	1/2	1/2	2	1	2	2
Concise	1/7	1/7	1/7	1/6	1/4	1/3	1/3	1/3	1/3	1/2	1/2	1	1/2
Organized	1/7	1/7	1/7	1/6	1/4	1/3	1/3	1/3	1/3	2	1/2	2	1

19 MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	2	3	2	3	9	6	4	5	9	7	9	8
Unambiguous	1/2	1	3	2	4	8	6	4	5	9	7	8	7
Complete	1/3	1/3	1	1/4	2	8	5	3	4	9	6	8	7
Verifiable	1/2	1/2	4	1	4	8	6	5	5	9	6	9	7
Consistent	1/3	1/4	1/2	1/4	1	5	4	2	3	6	4	6	5
Understandable by Customer	1/9	1/8	1/8	1/8	1/5	1	1/2	1/4	1/3	2	1/3	2	1/2
Modifiable	1/6	1/6	1/5	1/6	1/4	2	1	1/3	1/2	3	2	3	2
Traced	1/4	1/4	1/3	1/5	1/2	4	3	1	2	6	3	5	4
Traceable	1/5	1/5	1/4	1/5	1/3	3	2	1/2	1	5	3	4	3
Design Independent	1/9	1/9	1/9	1/9	1/6	1/2	1/3	1/6	1/5	1	1/4	1/2	1/3
Annotated	1/7	1/7	1/6	1/6	1/4	3	1/2	1/3	1/3	4	1	3	2
Concise	1/9	1/8	1/8	1/9	1/6	1/2	1/3	1/5	1/4	2	1/3	1	1/3
Organized	1/8	1/7	1/7	1/7	1/5	2	1/2	1/4	1/3	3	1/2	3	1

20 MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	5	1/2	3	4	5	5	5	7	8	6	8	8
Unambiguous	1/5	1	1/3	2	3	6	4	5	7	7	5	8	8
Complete	2	3	1	3	4	6	4	6	8	7	6	8	8
Verifiable	1/3	1/2	1/3	1	3	5	2	4	6	5	3	7	7
Consistent	1/4	1/3	1/4	1/3	1	5	3	5	7	7	4	7	7
Understandable by Customer	1/5	1/6	1/6	1/5	1/5	1	1/4	1/2	3	2	1/3	4	3
Modifiable	1/5	1/4	1/4	1/2	1/3	4	1	3	4	5	2	6	6
Traced	1/5	1/5	1/6	1/4	1/5	2	1/3	1	4	3	1/2	5	4
Traceable	1/7	1/7	1/8	1/6	1/7	1/3	1/4	1/4	1	1/2	1/5	3	2
Design Independent	1/8	1/7	1/7	1/5	1/7	1/2	1/5	1/3	2	1	1/4	3	3
Annotated	1/6	1/5	1/6	1/3	1/4	3	1/2	2	5	4	1	4	4
Concise	1/8	1/8	1/8	1/7	1/7	1/4	1/6	1/5	1/3	1/3	1/4	1	1/2
Organized	1/8	1/8	1/8	1/7	1/7	1/3	1/6	1/4	1/2	1/3	1/4	2	1

Survey Data – Pairwise Comparison Non-Materiel Solution

Survey Number

1 **NON-MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	1/2	3	1/3	2	2	1/2	6	4	9	5	8	7
Unambiguous	2	1	5	1/2	3	4	2	7	6	9	7	9	9
Complete	1/3	1/5	1	1/6	1/2	1/2	1/4	3	2	6	2	6	5
Verifiable	3	2	6	1	4	5	2	8	6	9	7	9	9
Consistent	1/2	1/3	2	1/4	1	2	1/2	5	3	8	4	7	6
Understandable by Customer	1/2	1/4	2	1/5	1/2	1	1/3	4	2	7	3	6	5
Modifiable	2	1/2	4	1/2	2	3	1	7	5	9	6	9	8
Traced	1/6	1/7	1/3	1/8	1/5	1/4	1/7	1	1/2	3	1/2	2	2
Traceable	1/4	1/6	1/2	1/6	1/3	1/2	1/5	2	1	5	2	4	3
Design Independent	1/9	1/9	1/6	1/9	1/8	1/7	1/9	1/3	1/5	1	1/4	1/2	1/2
Annotated	1/5	1/7	1/2	1/7	1/4	1/3	1/6	2	1/2	4	1	3	2
Concise	1/8	1/9	1/6	1/9	1/7	1/6	1/9	1/2	1/4	2	1/3	1	1/2
Organized	1/7	1/9	1/5	1/9	1/6	1/5	1/8	1/2	1/3	2	1/2	2	1

2 **NON-MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	4	7	2	6	5	8	8	9	9	3	9	9
Unambiguous	1/4	1	3	1/3	3	2	5	7	8	9	1/2	9	8
Complete	1/7	1/3	1	1/5	1/2	1/3	2	3	4	6	1/4	5	4
Verifiable	1/2	3	5	1	5	4	6	7	8	9	2	9	8
Consistent	1/6	1/3	2	1/5	1	1/2	3	4	5	6	1/3	6	5
Understandable by Customer	1/5	1/2	3	1/4	2	1	3	4	5	7	1/3	9	8
Modifiable	1/8	1/5	1/2	1/6	1/3	1/3	1	2	3	5	1/5	4	3
Traced	1/8	1/7	1/3	1/7	1/4	1/4	1/2	1	2	5	1/5	4	3
Traceable	1/9	1/8	1/4	1/8	1/5	1/5	1/3	1/2	1	4	1/6	3	2
Design Independent	1/9	1/9	1/6	1/9	1/6	1/7	1/5	1/5	1/4	1	1/9	1/2	1/3
Annotated	1/3	2	4	1/2	3	3	5	5	6	9	1	7	6
Concise	1/9	1/9	1/5	1/9	1/6	1/9	1/4	1/4	1/3	2	1/7	1	1/2
Organized	1/9	1/8	1/4	1/8	1/5	1/8	1/3	1/3	1/2	3	1/6	2	1

3 **NON-MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	2	2	6	3	4	5	5	4	6	6	7	7
Unambiguous	1/2	1	1/2	5	2	2	4	4	3	5	6	6	6
Complete	1/2	2	1	5	2	3	5	4	4	6	6	6	7
Verifiable	1/6	1/5	1/5	1	1/4	1/4	1/2	1/2	1/3	2	2	3	4
Consistent	1/3	1/2	1/2	4	1	2	4	3	2	5	5	6	6
Understandable by Customer	1/4	1/2	1/3	4	1/2	1	3	2	2	4	5	5	6
Modifiable	1/5	1/4	1/5	2	1/4	1/3	1	1/2	1/2	2	3	4	4
Traced	1/5	1/4	1/4	2	1/3	1/2	2	1	1/2	3	4	4	5
Traceable	1/4	1/3	1/4	3	1/2	1/2	2	2	1	4	4	5	5
Design Independent	1/6	1/5	1/6	1/2	1/5	1/4	1/2	1/3	1/4	1	2	2	3
Annotated	1/6	1/6	1/6	1/2	1/5	1/5	1/3	1/4	1/4	1/2	1	2	2
Concise	1/7	1/6	1/6	1/3	1/6	1/5	1/4	1/4	1/5	1/2	1/2	1	2
Organized	1/7	1/6	1/7	1/4	1/6	1/6	1/4	1/5	1/5	1/3	1/2	1/2	1

4 **NON-MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	2	1/3	2	2	2	5	4	4	5	6	6	5
Unambiguous	1/2	1	1/3	1/3	1/2	2	5	4	4	5	6	6	5
Complete	3	3	1	3	3	3	5	4	4	5	6	6	5
Verifiable	1/2	3	1/3	1	2	3	5	4	4	5	6	6	5
Consistent	1/2	2	1/3	1/2	1	3	5	4	4	5	6	6	5
Understandable by Customer	1/2	1/2	1/3	1/3	1/3	1	5	4	4	5	6	6	5
Modifiable	1/5	1/5	1/5	1/5	1/5	1/5	1	1/3	1/3	2	4	4	2
Traced	1/4	1/4	1/4	1/4	1/4	1/4	3	1	2	3	5	5	4
Traceable	1/4	1/4	1/4	1/4	1/4	1/4	3	1/2	1	3	5	5	4
Design Independent	1/5	1/5	1/5	1/5	1/5	1/5	1/2	1/3	1/3	1	4	4	1/2
Annotated	1/6	1/6	1/6	1/6	1/6	1/6	1/4	1/5	1/5	1/4	1	2	1/2
Concise	1/6	1/6	1/6	1/6	1/6	1/6	1/4	1/5	1/5	1/4	1/2	1	1/2
Organized	1/5	1/5	1/5	1/5	1/5	1/5	1/2	1/4	1/4	2	2	2	1

5 **NON-MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	2	1/2	8	3	3	8	8	8	7	4	4	5
Unambiguous	1/2	1	1/3	5	2	3	9	8	8	6	3	4	4
Complete	2	3	1	7	3	4	9	8	9	8	4	5	6
Verifiable	1/8	1/5	1/7	1	1/4	1/4	4	3	3	2	1/3	1/3	1/2
Consistent	1/3	1/2	1/3	4	1	2	8	6	7	5	3	3	4
Understandable by Customer	1/3	1/3	1/4	4	1/2	1	7	5	6	4	2	3	3
Modifiable	1/8	1/9	1/9	1/4	1/8	1/7	1	1/3	1/2	1/3	1/6	1/5	1/4
Traced	1/8	1/8	1/8	1/3	1/6	1/5	3	1	2	1/3	1/4	1/4	1/3
Traceable	1/8	1/8	1/9	1/3	1/7	1/6	2	1/2	1	1/3	1/5	1/4	1/4
Design Independent	1/7	1/6	1/8	1/2	1/5	1/4	3	3	3	1	1/4	1/3	1/3
Annotated	1/4	1/3	1/4	3	1/3	1/2	6	4	5	4	1	2	3
Concise	1/4	1/4	1/5	3	1/3	1/3	5	4	4	3	1/2	1	2
Organized	1/5	1/4	1/6	2	1/4	1/3	4	3	4	3	1/3	1/2	1

Survey Data – Pairwise Comparison Non-Materiel Solution (cont'd)

Survey Number

6 NON-MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	3	2	3	2	4	5	5	4	6	8	9	8
Unambiguous	1/3	1	1/3	1/3	1/2	2	3	2	4	5	7	9	8
Complete	1/2	3	1	2	2	4	5	4	6	7	7	9	8
Verifiable	1/3	3	1/2	1	1/2	2	3	2	4	5	6	7	6
Consistent	1/2	2	1/2	2	1	3	4	3	6	6	7	8	7
Understandable by Customer	1/4	1/2	1/4	1/2	1/3	1	2	1/2	3	5	6	7	6
Modifiable	1/5	1/3	1/5	1/3	1/4	1/2	1	1/2	2	3	4	5	4
Traced	1/5	1/2	1/4	1/2	1/3	2	2	1	3	3	4	5	4
Traceable	1/4	1/4	1/6	1/4	1/6	1/3	1/2	1/3	1	2	3	4	3
Design Independent	1/6	1/5	1/7	1/5	1/6	1/5	1/3	1/3	1/2	1	2	3	2
Annotated	1/8	1/7	1/7	1/6	1/7	1/6	1/4	1/4	1/3	1/2	1	3	2
Concise	1/9	1/9	1/9	1/7	1/8	1/7	1/5	1/5	1/4	1/3	1/3	1	1/2
Organized	1/8	1/8	1/8	1/6	1/7	1/6	1/4	1/4	1/3	1/2	1/2	2	1

7 NON-MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	1/3	4	1/4	1/2	1/2	2	1/4	1/3	3	3	4	2
Unambiguous	3	1	6	1/2	3	2	4	1/2	2	5	5	7	4
Complete	1/4	1/6	1	1/8	1/5	1/6	1/4	1/7	1/6	1/2	1/2	2	1/3
Verifiable	4	2	8	1	4	3	5	2	3	7	7	9	6
Consistent	2	1/3	5	1/4	1	1/2	2	1/3	1/2	4	4	5	3
Understandable by Customer	2	1/2	6	1/3	2	1	3	1/3	1/2	5	5	6	4
Modifiable	1/2	1/4	4	1/5	1/2	1/3	1	1/4	1/3	3	3	4	2
Traced	4	2	7	1/2	3	3	4	1	2	6	6	8	5
Traceable	3	1/2	6	1/3	2	2	3	1/2	1	5	5	6	4
Design Independent	1/3	1/5	2	1/7	1/4	1/5	1/3	1/6	1/5	1	1/2	2	1/2
Annotated	1/3	1/5	2	1/7	1/4	1/5	1/3	1/6	1/5	2	1	3	1/2
Concise	1/4	1/7	1/2	1/9	1/5	1/6	1/4	1/8	1/6	1/2	1/3	1	1/3
Organized	1/2	1/4	3	1/6	1/3	1/4	1/2	1/5	1/4	2	2	3	1

8 NON-MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	3	2	4	5	4	9	2	9	6	9	9	5
Unambiguous	1/3	1	1/2	2	4	4	8	2	8	5	8	8	4
Complete	1/2	2	1	4	5	4	9	2	9	5	9	9	5
Verifiable	1/4	1/2	1/4	1	2	2	7	2	8	4	6	6	3
Consistent	1/5	1/4	1/5	1/2	1	2	2	2	2	2	2	2	2
Understandable by Customer	1/4	1/4	1/4	1/2	1/2	1	4	1/4	4	2	2	2	2
Modifiable	1/9	1/8	1/9	1/7	1/2	1/4	1	1/4	1/2	1/2	1/2	1/2	1/2
Traced	1/2	1/2	1/2	1/2	1/2	4	4	1	2	2	2	2	2
Traceable	1/9	1/8	1/9	1/8	1/2	1/4	2	1/2	1	2	2	2	2
Design Independent	1/6	1/5	1/5	1/4	1/2	1/2	2	1/2	1/2	1	3	3	2
Annotated	1/9	1/8	1/9	1/6	1/2	1/2	2	1/2	1/2	1/3	1	2	2
Concise	1/9	1/8	1/9	1/6	1/2	1/2	2	1/2	1/2	1/3	1/2	1	2
Organized	1/5	1/4	1/5	1/3	1/2	1/2	2	1/2	1/2	1/2	1/2	1/2	1

9 NON-MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	3	6	2	5	6	9	5	7	9	6	7	9
Unambiguous	1/3	1	5	1/3	5	6	9	5	7	9	6	7	9
Complete	1/6	1/5	1	1/6	1/3	3	6	1/4	3	6	1/2	4	6
Verifiable	1/2	3	6	1	5	6	9	5	7	9	6	7	9
Consistent	1/5	1/5	3	1/5	1	4	8	1/2	5	8	3	5	7
Understandable by Customer	1/6	1/6	1/3	1/6	1/4	1	5	1/5	2	5	1/2	3	5
Modifiable	1/9	1/9	1/6	1/9	1/8	1/5	1	1/7	1/5	2	1/6	1/4	1/4
Traced	1/5	1/5	4	1/5	2	5	7	1	6	8	3	6	7
Traceable	1/7	1/7	1/3	1/7	1/5	1/2	5	1/6	1	5	1/3	3	5
Design Independent	1/9	1/9	1/6	1/9	1/8	1/5	1/2	1/8	1/5	1	1/7	1/5	1/5
Annotated	1/6	1/6	2	1/6	1/3	2	6	1/3	3	7	1	5	6
Concise	1/7	1/7	1/4	1/7	1/5	1/3	4	1/6	1/3	5	1/5	1	2
Organized	1/9	1/9	1/6	1/9	1/7	1/5	4	1/7	1/5	5	1/6	1/2	1

10 NON-MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	4	3	5	2	6	7	6	4	5	8	9	8
Unambiguous	1/4	1	1/3	3	1/3	3	3	2	1/2	2	5	6	7
Complete	1/3	3	1	4	1/2	4	5	4	3	3	5	6	7
Verifiable	1/5	1/3	1/4	1	1/3	3	3	2	1/3	1/2	4	5	6
Consistent	1/2	3	2	3	1	4	5	5	4	4	6	7	8
Understandable by Customer	1/6	1/3	1/4	1/3	1/4	1	2	1/2	1/4	1/3	2	4	3
Modifiable	1/7	1/3	1/5	1/3	1/5	1/2	1	1/3	1/2	1/3	2	4	3
Traced	1/6	1/2	1/4	1/2	1/5	2	3	1	1/3	1/2	2	4	3
Traceable	1/4	2	1/3	3	1/4	4	2	3	1	3	6	7	8
Design Independent	1/5	1/2	1/3	2	1/4	3	3	2	1/3	1	5	6	7
Annotated	1/8	1/5	1/5	1/4	1/6	1/2	1/2	1/2	1/6	1/5	1	3	2
Concise	1/9	1/6	1/6	1/5	1/7	1/4	1/4	1/4	1/7	1/6	1/3	1	1/2
Organized	1/8	1/7	1/7	1/6	1/8	1/3	1/3	1/3	1/8	1/7	1/2	2	1

Survey Data – Pairwise Comparison Non-Materiel Solution (cont'd)

Survey Number

11 **NON-MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	5	1/3	3	4	6	2	3	3	8	7	9	7
Unambiguous	1/5	1	1/5	1/3	2	5	2	1/3	3	4	4	8	7
Complete	3	5	1	4	6	6	3	4	4	6	7	9	7
Verifiable	1/3	3	1/4	1	3	3	4	2	2	7	6	8	6
Consistent	1/4	1/2	1/6	1/3	1	2	5	1/3	5	4	3	4	3
Understandable by Customer	1/6	1/5	1/6	1/3	1/2	1	7	1/3	5	4	3	4	3
Modifiable	1/2	1/2	1/3	1/4	1/5	1/7	1	1/5	4	7	6	8	6
Traced	1/3	3	1/4	1/2	3	3	5	1	2	6	6	7	5
Traceable	1/3	1/3	1/4	1/2	1/5	1/5	1/4	1/2	1	5	1/3	6	4
Design Independent	1/8	1/4	1/6	1/7	1/4	1/4	1/7	1/6	1/5	1	1/3	2	1/2
Annotated	1/7	1/4	1/7	1/6	1/3	1/3	1/6	1/6	3	3	1	3	2
Concise	1/9	1/8	1/9	1/8	1/4	1/4	1/8	1/7	1/6	1/2	1/3	1	1/3
Organized	1/7	1/7	1/7	1/6	1/3	1/3	1/6	1/5	1/4	2	1/2	3	1

12 **NON-MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	6	2	2	5	7	5	3	3	9	6	9	8
Unambiguous	1/6	1	1/4	1/4	2	2	1/2	1/3	1/2	4	2	3	3
Complete	1/2	4	1	1/2	4	4	3	2	2	7	3	4	4
Verifiable	1/2	4	2	1	4	5	4	2	3	8	5	8	6
Consistent	1/5	1/2	1/4	1/4	1	2	1/2	1/3	1/3	3	2	3	2
Understandable by Customer	1/7	1/2	1/4	1/5	1/2	1	1/2	1/3	1/3	3	2	2	2
Modifiable	1/5	2	1/3	1/4	2	2	1	1/3	1/2	4	2	4	3
Traced	1/3	3	1/2	1/2	3	3	3	1	2	6	4	8	5
Traceable	1/3	2	1/2	1/3	3	3	2	1/2	1	5	4	7	5
Design Independent	1/9	1/4	1/7	1/8	1/3	1/3	1/4	1/6	1/5	1	1/2	1/2	1/2
Annotated	1/6	1/2	1/3	1/5	1/2	1/2	1/2	1/4	1/4	2	1	2	2
Concise	1/9	1/3	1/4	1/8	1/3	1/2	1/4	1/8	1/7	2	1/2	1	1/2
Organized	1/8	1/3	1/4	1/6	1/2	1/2	1/3	1/5	1/5	2	1/2	2	1

13 **NON-MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	4	2	3	4	5	4	3	5	5	5	7	6
Unambiguous	1/4	1	1/5	1/3	3	3	1/2	1/5	3	4	5	7	4
Complete	1/2	5	1	3	4	5	4	2	4	5	6	7	6
Verifiable	1/3	3	1/3	1	4	5	2	1/2	4	5	6	7	5
Consistent	1/4	1/3	1/4	1/4	1	4	1/3	1/4	2	3	4	7	6
Understandable by Customer	1/5	1/3	1/5	1/5	1/4	1	1/5	1/7	1/4	2	4	5	1/2
Modifiable	1/4	2	1/4	1/2	3	5	1	1/4	3	5	5	6	4
Traced	1/3	5	1/2	2	4	7	4	1	4	5	6	7	6
Traceable	1/5	1/3	1/4	1/4	1/2	4	1/3	1/4	1	4	5	6	2
Design Independent	1/5	1/4	1/5	1/5	1/3	1/2	1/5	1/5	1/4	1	2	4	1/3
Annotated	1/5	1/5	1/6	1/6	1/4	1/4	1/5	1/6	1/5	1/2	1	2	1/3
Concise	1/7	1/7	1/7	1/7	1/7	1/5	1/6	1/7	1/6	1/4	1/2	1	1/4
Organized	1/6	1/4	1/6	1/5	1/6	2	1/4	1/6	1/2	3	3	4	1

14 **NON-MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	6	1/2	2	8	9	3	4	5	9	7	9	9
Unambiguous	1/6	1	1/7	1/5	3	4	1/4	1/3	1/2	6	2	6	5
Complete	2	7	1	2	9	9	4	4	5	9	8	9	9
Verifiable	1/2	5	1/2	1	7	8	2	3	4	9	6	9	9
Consistent	1/8	1/3	1/9	1/7	1	7	1/6	1/5	1/4	9	1/2	9	7
Understandable by Customer	1/9	1/4	1/9	1/8	1/7	1	1/7	1/5	1/4	3	1/3	4	2
Modifiable	1/3	4	1/4	1/2	6	7	1	2	3	4	5	5	3
Traced	1/4	3	1/4	1/3	5	5	1/2	1	2	8	4	9	7
Traceable	1/5	2	1/5	1/4	4	4	1/3	1/2	1	6	3	8	6
Design Independent	1/9	1/6	1/9	1/9	1/9	1/3	1/4	1/8	1/6	1	1/4	2	1/2
Annotated	1/7	1/2	1/8	1/6	2	3	1/5	1/4	1/3	4	1	6	4
Concise	1/9	1/6	1/9	1/9	1/9	1/4	1/5	1/9	1/8	1/2	1/6	1	1/3
Organized	1/9	1/5	1/9	1/9	1/7	1/2	1/3	1/7	1/6	2	1/4	3	1

15 **NON-MATERIEL SOLUTIONS**

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	1/2	2	1/4	1/5	1/3	4	1/4	3	6	4	5	2
Unambiguous	2	1	2	1/4	1/2	1/2	5	1/2	3	4	3	3	2
Complete	1/2	1/2	1	1/7	1/4	1/6	4	1/3	2	3	3	4	2
Verifiable	4	4	7	1	3	2	5	2	4	7	6	6	4
Consistent	5	2	4	1/3	1	1/2	4	1/2	3	4	3	4	3
Understandable by Customer	3	2	6	1/2	2	1	5	1/2	4	5	4	5	4
Modifiable	1/4	1/5	1/4	1/5	1/4	1/5	1	1/4	1/3	1/2	1/3	1/2	1/3
Traced	4	2	3	1/2	2	2	4	1	4	6	5	5	4
Traceable	1/3	1/3	1/2	1/4	1/3	1/4	3	1/4	1	2	2	3	2
Design Independent	1/6	1/4	1/3	1/7	1/4	1/5	2	1/6	1/2	1	1/2	1/2	1/3
Annotated	1/4	1/3	1/3	1/6	1/3	1/4	3	1/5	1/2	2	1	2	1/2
Concise	1/5	1/3	1/4	1/6	1/4	1/5	2	1/5	1/3	2	1/2	1	1/2
Organized	1/2	1/2	1/2	1/4	1/3	1/4	3	1/4	1/2	3	2	2	1

Survey Data – Pairwise Comparison Non-Materiel Solution (cont'd)

Survey Number

16 NON-MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	1/2	2	2	2	1/4	1/6	1/3	9	1/3	7	3	1/7
Unambiguous	2	1	2	2	2	1/2	3	1/2	3	2	4	6	1/2
Complete	1/2	1/2	1	3	1/4	1/3	1/4	1/3	4	1/5	2	3	1/2
Verifiable	1/2	1/2	1/3	1	1/4	1/3	1/6	1/5	1/2	1/6	1/7	1/4	1/4
Consistent	1/2	1/2	4	4	1	1/4	1/3	1/2	3	1/3	5	8	1/4
Understandable by Customer	4	2	3	3	4	1	2	4	3	3	3	8	2
Modifiable	6	1/3	4	6	3	1/2	1	1/4	2	1/4	3	2	1/2
Traced	3	2	3	5	2	1/4	4	1	3	9	8	6	1/3
Traceable	1/9	1/3	1/4	2	1/3	1/3	1/2	1/3	1	1/6	9	9	1/4
Design Independent	3	1/2	5	6	3	1/3	4	1/9	6	1	5	3	1/5
Annotated	1/7	1/4	1/2	7	1/5	1/3	1/3	1/8	1/9	1/5	1	1/3	1/6
Concise	1/3	1/6	1/3	4	1/8	1/8	1/2	1/6	1/9	1/3	3	1	1/5
Organized	7	2	2	4	4	1/2	2	3	4	5	6	5	1

17 NON-MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	4	2	4	5	3	5	6	6	7	7	8	9
Unambiguous	1/4	1	1/4	2	3	1/3	4	4	5	5	6	6	7
Complete	1/2	4	1	4	4	2	5	5	6	6	7	7	8
Verifiable	1/4	1/2	1/4	1	2	1/4	3	4	4	5	5	6	6
Consistent	1/5	1/3	1/4	1/2	1	1/6	2	3	4	4	5	5	6
Understandable by Customer	1/3	3	1/2	4	6	1	4	5	5	6	6	7	7
Modifiable	1/5	1/4	1/5	1/3	1/2	1/4	1	2	3	4	4	5	5
Traced	1/6	1/4	1/5	1/4	1/3	1/5	1/2	1	2	3	4	5	6
Traceable	1/6	1/5	1/6	1/4	1/4	1/5	1/3	1/2	1	2	3	4	4
Design Independent	1/7	1/5	1/6	1/5	1/4	1/6	1/4	1/3	1/2	1	2	3	3
Annotated	1/7	1/6	1/7	1/5	1/5	1/6	1/4	1/4	1/3	1/2	1	2	3
Concise	1/8	1/6	1/7	1/6	1/5	1/7	1/5	1/5	1/4	1/3	1/2	1	3
Organized	1/9	1/7	1/8	1/6	1/6	1/7	1/5	1/6	1/4	1/3	1/3	1/3	1

18 NON-MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	3	2	2	4	4	5	2	2	6	7	7	6
Unambiguous	1/3	1	1/4	1/2	2	2	3	1/3	1/3	5	6	6	5
Complete	1/2	4	1	2	4	4	5	2	2	6	7	7	6
Verifiable	1/2	2	1/2	1	3	3	3	1/2	1/2	4	5	5	4
Consistent	1/4	1/2	1/4	1/3	1	1/2	2	1/3	1/3	3	4	4	3
Understandable by Customer	1/4	1/2	1/4	1/3	2	1	2	1/4	1/4	3	3	3	3
Modifiable	1/5	1/3	1/5	1/3	1/2	1/2	1	1/4	1/4	2	3	3	3
Traced	1/2	3	1/2	2	3	4	4	1	2	6	6	6	6
Traceable	1/2	3	1/2	2	3	4	4	1/2	1	6	6	6	6
Design Independent	1/6	1/5	1/6	1/4	1/3	1/3	1/2	1/6	1/6	1	3	3	2
Annotated	1/7	1/6	1/7	1/5	1/4	1/3	1/3	1/6	1/6	1/3	1	2	1/2
Concise	1/7	1/6	1/7	1/5	1/4	1/3	1/3	1/6	1/6	1/3	1/2	1	1/2
Organized	1/6	1/5	1/6	1/4	1/3	1/3	1/3	1/6	1/6	1/2	2	2	1

19 NON-MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	2	3	2	3	9	6	4	5	9	7	9	8
Unambiguous	1/2	1	3	2	4	8	6	4	5	9	7	8	7
Complete	1/3	1/3	1	1/4	2	8	5	3	4	9	6	8	7
Verifiable	1/2	1/2	4	1	4	8	6	5	5	9	6	9	7
Consistent	1/3	1/4	1/2	1/4	1	5	4	2	3	6	4	6	5
Understandable by Customer	1/9	1/8	1/8	1/8	1/5	1	1/2	1/4	1/3	2	1/3	2	1/2
Modifiable	1/6	1/6	1/5	1/6	1/4	2	1	1/3	1/2	3	2	3	2
Traced	1/4	1/4	1/3	1/5	1/2	4	3	1	2	6	3	5	4
Traceable	1/5	1/5	1/4	1/5	1/3	3	2	1/2	1	5	3	4	3
Design Independent	1/9	1/9	1/9	1/9	1/6	1/2	1/3	1/6	1/5	1	1/4	1/2	1/3
Annotated	1/7	1/7	1/6	1/6	1/4	3	1/2	1/3	1/3	4	1	3	2
Concise	1/9	1/8	1/8	1/9	1/6	1/2	1/3	1/5	1/4	2	1/3	1	1/3
Organized	1/8	1/7	1/7	1/7	1/5	2	1/2	1/4	1/3	3	1/2	3	1

20 NON-MATERIEL SOLUTIONS

a \ b	Correct	Unambiguous	Complete	Verifiable	Consistent	Understandable by Customer	Modifiable	Traced	Traceable	Design Independent	Annotated	Concise	Organized
Correct	1	3	1/2	2	5	6	3	4	6	7	6	8	8
Unambiguous	1/3	1	1/5	1/4	3	5	1/2	2	5	6	5	7	7
Complete	2	5	1	3	5	6	3	4	7	7	6	8	8
Verifiable	1/2	4	1/3	1	4	5	2	3	6	7	6	8	8
Consistent	1/5	1/3	1/5	1/4	1	2	1/3	1/2	3	4	3	5	5
Understandable by Customer	1/6	1/5	1/6	1/5	1/2	1	1/4	1/2	2	3	2	5	5
Modifiable	1/3	2	1/3	1/2	3	4	1	3	5	5	4	7	7
Traced	1/4	1/2	1/4	1/3	2	2	1/3	1	4	4	3	5	5
Traceable	1/6	1/5	1/7	1/6	1/3	1/2	1/5	1/4	1	2	1/2	4	4
Design Independent	1/7	1/6	1/7	1/7	1/4	1/3	1/5	1/4	1/2	1	1/3	3	2
Annotated	1/6	1/5	1/6	1/6	1/3	1/2	1/4	1/3	2	3	1	4	3
Concise	1/8	1/7	1/8	1/8	1/5	1/5	1/7	1/5	1/4	1/3	1/4	1	1/2
Organized	1/8	1/7	1/8	1/8	1/5	1/5	1/7	1/5	1/4	1/2	1/3	2	1