Complex Acquisition Requirements Analysis Using a Systems Engineering Approach

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Dedication

Dedicated to Scarlet and William for their love, patience, tolerance, perspective, encouragement, and support during this journey. It could not have happened without you. I love you both.

"It is always in season for old men to learn."

Aeschylus (Goodreads 2016)

"It is the mark of an educated mind to be able to entertain a thought without accepting it."

Aristotle (Kentucky 2016)

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Abstract

Complex Acquisition Requirements Analysis Using a Systems Engineering Approach

Over the last several decades the technology revolution has compounded system complexity with the integration of multi-spectral sensors and interactive command and control systems. These complexities create additional challenges for requirement developers to produce an encompassing set of requirements. As a result, beginning programs with effective requirements has become imperative. Research indicates there is a gap in requirement attributes (e.g. holistic, adaptable, achievable, or verifiable) for a family of systems and complex systems, and the acquisition community lacks consistent knowledge as to which attributes would best enable more informed trade-offs.

This research provides prioritized key requirement attributes to account for integration, globalization, and revolutionary technology complexities using expert judgment of a diverse panel of acquisition professionals from the Air Force, Army, and Navy, as well as industry and additional government organizations. This research evaluates requirement attributes and provides a select group of attributes tailored specifically for simple systems, family of systems, and complex systems. Comprised of industrial, academic, and governmental personnel, each with over 25 years of experience in acquisition, systems engineering, development, logistics, and operations, this panel uses its expert judgment by employing a Bradley-Terry pairwise comparison. This expert judgment methodology allows the panel to rank the selected requirement attributes by their relative importance in

systems, family of systems, and complex systems requirement development. Utilizing surveyed data from experts verifies the Bradley-Terry model and provides rankings of requirement attributes for the acquisition community to consider. Sensitivity analysis further verifies the robustness of the Bradley-Terry model analysis and approach.

Data for systems, family of systems, and complex systems, using a 5% null and a 90% confidence interval, show tiered grouping of data. For systems the top tier of attributes is correct, achievable, and verifiable. For family of systems the top tier of attributes is achievable and correct. For complex systems the top tier of attributes is technical, holistic, interdependent, and adaptable. This paper provides a guide for today's acquisition leaders to establish effective requirements using validated requirement attributes for family of systems and complex systems needed for informed cost, schedule, and performance trade-off decisions.

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List of Acronyms

AHP	Analytic Hierarchy Process
ANSI	American National Standards Institute
AT&L	Acquisition, Technology, and Logistics
CASoS	Complex Adaptive System of Systems
DoD	Department of Defense
EIA	Electronic Industries Alliance
FoS	Family of Systems
GAO	Government Accountability Office
IEEE	Institute of Electrical and Electronics Engineers
INCOSE	International Council on Systems Engineering
IRB	Institutional Review Board
ISO/IEC	International Organization for Standardization/International Electrotechnical Commission
JP	Joint Publication
NASA	National Aeronautics and Space Administration
SoS	System of Systems

List of Mathematical Symbols

e = expert

t = number of objects

“n = number of experts

A(*1*) ….. A(*t*) = Objects to be compared” (Cooke 1991, 211)

“a(*i, e*) = number of times expert, e, prefers A(*i*)” (Cooke 1991, 212)

R(*i,e*) = the rank of A(*i*) from expert, e

V(*i*) = true values of the objects

“V(*i, e*) = internal value of expert, e, for object *i*” (Cooke 1991, 211)

Chapter 1: Introduction

Recent Government Accountability Office (GAO) reports outline concerns with requirements development. One study found programs with unachievable requirements cause program managers to trade away performance and found that informed trade-offs between cost and capability establish better defined requirements (GAO 2015). In another key report, the GAO noted that the Department of Defense (DoD) could benefit from ranking or prioritizing requirements based on significance (GAO 2011). Developing a complete and full set of exacting requirements for programs is imperative to meet the user's intended capability. Establishing a key list of prioritized requirement attributes increases the focus on the development of program requirements and aids in requirements and design trade-off decisions.

An attribute is a quality, characteristic, or trait that defines a requirement and supports well-defined requirements development. An example of an attribute is correct, verifiable, achievable, or interdependent. The focus of this research is to identify requirement attributes, and amend and expand their definitions from research for simple systems, family of systems (FoS) and complex systems to create an encompassing set of prioritized requirement attributes for decision makers while supporting requirements development across a spectrum of system types.

Complex systems and family of systems are becoming more prevalent. There needs to be increased focus on FoS and complex systems requirement attribute development and prioritization to develop a full range of requirements for decision makers. In this research,

we use the terms systems, FoS, complex systems, and their associated requirements attributes. All of these categories are explored, developed, and expanded with prioritized requirement attributes. The terms systems, FoS, and complex systems are used in the acquisition community today. This research considers complex systems as a subset or focus area of system of systems. These key terms are defined as:

"*Systems:* An interdependent group of people, objectives, and procedures constituted to achieve defined objectives or some operational role by performing specified functions. A complete system includes all of the associated equipment, facilities, material, computer programs, firmware, technical documentation, services, and personnel required for operations and support to the degree necessary for self-sufficient use in its intended environment" (IEEE 1998).

Family of Systems: A collection of component systems, simple or complex, that are managed, operated, developed, funded, maintained and sustained independently of their overarching principal system that creates a new capability.

Complex Systems: A collection of large, multifaceted, and interrelated component systems that are dependent on the entirety of the principal system for management, operations, development, funding, maintenance, and sustainment. Complex systems are non-deterministic, adaptive, holistic, and have non-linear interfaces between attributes.

As markets and relationships become more interconnected with global perspectives, programs and products become more complex with transnational partnerships. Likewise, software and technology maturation further infuse complexities and dependencies in product development, execution, operations, logistics, and sustainability. Therefore, a systems engineering approach was applied to establish and validate effective requirement attributes for FoS and complex systems. This research provides an approach for companies, organizations, and programs to develop early and strong requirements using prioritized, key requirement attributes across all system types and to make informed trade-off decisions.

1.1. Background

Requirements are the building blocks and genetic make-up that create and define programs and products. Industry and government rely on requirements to ensure success for programs that span from small, relatively simple programs to large, complex ones with worldwide capability. Commercial capital programs, information technology programs, manufacturing, and the federal government, to include its largest department, the Department of Defense, all utilize some form of the requirements process to develop and manage programs. Figure 1-1 shows various approaches that have elicitation of user requirements as a clear and vital step early in the process (INCOSE 2011; DOT 2009).

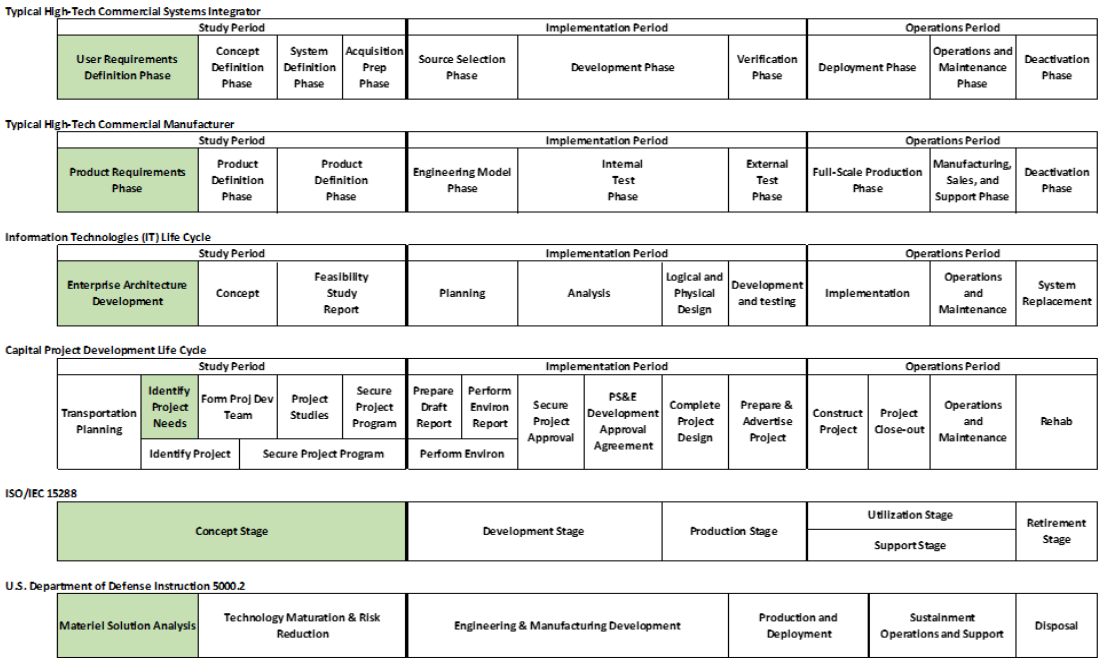


Figure 1-1 Program Life Cycle Comparisons

Requirements are central to sound program development, production, operations, and sustainment. The recently retired Chairman of the Senate Armed Services Committee, Senator Carl Levin, states, "We learned that as a rule of thumb it can cost 10 times more to fix a program after you've built a weapon system than it does to get it right the first time" (Erwin 2014). The International Council on Systems Engineering (INCOSE) places the cost to extract defects during production and testing at up to 1000-fold compared to the cost of discovery during concept development (INCOSE 2011). Ensuring that programs develop appropriately, and ultimately operate and perform to fill a needed requirement or capability gap with well-understood and established requirements, is imperative at the commencement of these programs (GAO 2015, 7). Well-developed requirements allow for informed decision making on vital program trade-offs on cost, schedule, and performance factors for program success.

The discretionary budget authority for defense programs in Fiscal Year 2015 was approximately 3.4 percent of the United States Gross Domestic Product, and for non-defense programs it was approximately 2.9 percent (Comptroller 2015; OMB 2015). These combined authorities have a budget totaling over $1 trillion dollars and 6.4 percent of the Gross Domestic Product (Comptroller 2015; OMB 2015). Public industry and commercial sectors allocate billions of dollars domestically and internationally to develop programs. Thus, beginning programs with strong fundamentals becomes crucial from a budgetary perspective alone.

A GAO expert recently testified to Congress. The testimony confirmed what most acquisition, operational, and education professionals have long known: that program cost

and schedule are typically underestimated by 20 - 50% because firm and feasible requirements are not clearly defined (Francis 2015, i & 3). To improve the control of cost and schedule overruns, comprehensive requirements are foundational to program success (GAO 2015, 16). The GAO further states, “Establishing a sound business case for individual programs depends on disciplined requirements and funding processes” (Francis 2015). A key enabler to optimize requirements and good business cases is ”…firm, feasible requirements where requirements should be clearly defined, affordable, and clearly informed” (Francis 2015, 3). Another key enabler is an “Incremental, knowledge-based acquisition strategy: rigorous systems engineering coupled with more achievable requirements are essential to achieve faster delivery of needed capability to the warfighter” (Francis 2015, 3). This enabler combines the need to develop system requirements with mature technologies and within a program’s cost, schedule, and performance plans.

Systems, FoS, and complex systems programs need an optimized solution set of requirement attributes to establish and provide a solid foundation for program execution success. The United States Senate Permanent Subcommittee on Investigations Report, Defense Acquisition Reform: Where do we go from here?, provides a thorough collection of observations by prominent experts. Nearly half of the experts interviewed ". . . believe that DoD needs to attain realistic requirements at the start of a major acquisition program that includes budget-informed decisions" (Senate 2014, 1). Establishing well-defined and strong requirements that are achievable within cost, schedule and performance are vital for programmatic success from the user to Congress.

Early researchers within the systems engineering community established a definition of system of systems with key attributes to establish sound requirements; however, this approach was software centric (Maier 1998). Many organizations have adopted these early tenants and applied them more broadly. Academia, government, and industry have expanded earlier works and provided unique approaches (Keating, Padilla & Adams 2008; Katina & Keating 2014; Ncube 2011; AT&L 2008; NASA 1995; DHS 2010; Ames et al. 2011; Butterfield, Shivananda & Schwarz 2009; Korent 2015). Extensive literature research cataloged and provided a common definition for systems, FoS, complex systems, and their requirement attributes.

As programs, products, and services become more global and interconnected, so must the approach to develop requirements and their associated program and products. A family of systems focuses on the independence of managerial, systems engineering, production, operations, and sustainment between the principal systems and their component systems. By expanding and providing a more focused definition of the independent relationships, this description generates an improved set of requirement attributes for program development, execution, and success.

Likewise, system of systems does not sufficiently define the increased complexities of global perspectives for complex systems. Complex systems, as a focused subset of system of systems, need a set of requirement attributes to fully capture relationships and requirements for program development. Recent authors suggest predominately mathematical and technical definitions (Katina & Keating 2014; Svetinovic 2013; Jain, Rashmi, Chandrasekaran, Elias & Cloutier 2008; Bartolomei, Hastings, de Nuefville &

Rhobes 2012; Nescolarde-Selva & Uso-Donenech 2012 & 2013). The area of complex systems necessitates broad review of all technical and non-technical influences that are internal and external to the program to develop an encompassing set of requirement attributes. These combined attribute focuses provide a complete set of requirements for informed trade-off decisions that affect system development and production.

1.2. Research Problem

Program integration and technical complexities in today's global environments are creating a challenge for programs to develop well informed requirements that are achievable within planned cost, schedule, and performance goals. Sound requirements are fundamental for decision makers to make key trade-offs on program cost, schedule, and performance factors during development, production, and operations. Currently, a wide variety of approaches define requirement attributes from standards organizations and literature (Davis 1993; INCOSE 2011; Pohl 2010; van Lamsweerde 2009; Rettaliata, Mazzuchi & Sarkani 2014; Mannion & Keepence 1995). The challenge for the acquisition and systems engineering communities is to define attributes beyond those for simple systems to fully capture and elicit requirements in an evolving, complex world. Research indicates there is a gap in requirement attributes for FoS and complex systems, and the acquisition community lacks consistent knowledge as to which attributes would best enable more informed trade-offs (GAO 2015; GAO 2015(2)). Specific requirement attributes need to be established and implemented for FoS and complex systems. Establishing a key list of attributes enables requirement development and assessment for systems, FoS, and complex

systems and aids the program manager and decision makers with informed trade-off decisions during development, production, and operations. Some noted trade-off decision shortfalls are unrealistic requirements development and less system capability traded for cost and schedule (GAO 2015; GAO 2015(2)). The impacts of unrealistic requirements development is shown to be that 36% of programs have a significant cost variance of over 10 percent from the approved baseline and over 47% of programs have a significant schedule variance of over 10 percent from the baseline (GAO 2013).

1.3. Approach

To meet the need of obtaining well informed requirements that are achievable within program cost, schedule, and performance goals, we first select and expand a common set of definitions for requirements, systems, FoS, and complex systems. Using these definitions, we then select an encompassing set of requirement attributes with amended and expanded definitions that focus on systems, FoS, and complex systems. Lastly, experts in the field rank the requirement attributes to provide areas of additional emphasis for requirement developers.

The Bradley-Terry methodology, as amplified by Roger Cooke, will be used to implement expert judgment to validate the requirement attributes (Bradley & Terry 1952; Cooke 1991). An expert panel was formed using members with over 25 years of experience each who are in senior leadership positions from industry, government, and academia. This research sets twenty-five years each and in a senior leadership position as the benchmark for experts to have the experience, knowledge, and perspective to validate requirement

attributes and to evaluate how they integrate into and affect acquisition programs. Through a series of surveys, we apply their expert judgment to verify the selected requirement attributes for systems, FoS, and complex systems using a pairwise comparison. Finally, using the Bradley-Terry methodology, we rank order the experts' judgment on requirement attributes and provide a validated set of requirement attributes for users, program managers, and leaders to consider when developing requirements.

1.4. Research Significance

Developing sound requirements is necessary for program success and for informed cost, schedule, and performance trade-offs for decision makers. The importance and value of accurate, detailed, and achievable requirements cannot be understated. As major programs become larger, more interconnected with increased complexity, and with broader global dependencies, requirements become more critical to successfully develop programs and products. From a government perspective, programs like the Department of Homeland Security's Global Entry, which allows United States Citizens and international travelers expedited entry into the Unites States, is a large, complex program with multiple international connections. The F-35 Joint Strike Fighter program is the most complex aircraft built with over 17 million lines of software code and interfaces that must accommodate multiple international partners (GAO 2005; GAO 2006). From a commercial perspective, companies like Amazon, UPS, and FedEx must be able to navigate national and international constraints, deliveries, and local processes on a daily basis. Systems, FoS, and complex systems need focused requirement attributes to enable

system success. This research expands the systems engineering requirements body of knowledge and selects, refines, and expands requirement attributes for simple to complex systems for the systems engineering and acquisition communities to apply to their programs and to facilitate more informed trade-off decisions.

To improve cost control and schedule overruns, comprehensive requirements are critical to program success. The GAO states, "Establishing a sound business case for individual programs depends on disciplined requirements and funding processes" (Francis 2015, 3). Disciplined requirements enable user needs to be valid; ensure requirements are reasonable, programs can be executed with program cost, schedule and performance goals; and provide for well-informed trade-off decisions for program development. Two of the four key enablers of a good business case are:

1. " Firm, Feasible Requirements: requirements should be clearly defined, affordable, and clearly informed—thus tempered—by systems engineering; once programs begin, requirements should not change without assessing their potential disruption to the program" (Francis 2015, 3 & 4).

2. "Incremental, Knowledge-based Acquisition Strategy: rigorous systems engineering coupled with more achievable requirements are essential to achieve faster delivery of needed capability to the warfighter. Building on mature technologies, such a strategy provides time, money, and other resources for a stable design, building and testing of prototypes, and demonstration of mature production processes" (Francis 2015, 3 - 4). Knowledge based strategies provide the framework for programs to deliver a product within set resources.

The United States Department of Defense Service Secretaries and Chiefs of Staff further affirmed the significance of requirements to the overarching acquisition process. "Some service chiefs believed that applying systems engineering to arrive at well-defined requirements before the start of system development at Milestone B can go a long way toward solving some of their dissatisfaction with the acquisition process and improving outcomes" (GAO 2015, 12). This group of government experts provided five key recommendations to improve the acquisition process, with three of them directly related to the importance and value of establishing sound, comprehensive requirements.

1. "Require, as a condition for starting a new weapon system program, that sufficient evidence exists to show there is a match between a weapon's system requirement and the resources the program manager has to develop that weapon" (GAO 2015, 7).

2. "Require program officials to demonstrate that they have captured appropriate knowledge at program start (Milestone B), which includes ensuring that requirements for the product are informed by the systems engineering process, and establishing cost and schedule estimates on the basis of knowledge from preliminary design using system engineering tools" (GAO 2015, 7).

3. "Have contractors perform more detailed systems engineering analysis to develop sound requirements before DoD selects a prime contractor for the systems development contract" (GAO 2015, 7).

While these insights, concerns, and recommendations are government centric, they have broad application for use in industry and academia. In Fiscal Year 2014, the federal government obligated over $445 billion for the acquisition of goods and services

(Schwartz, Ginsberg & Sargent 2015, 2). In addition, research and development in commercial industry also totals in the billions of dollars. As programs become more technically complex and programmatically interconnected with global linkages, the impact to cost, schedule, execution, performance, and sustainment all require solid requirements to be developed. Achievable, sound requirements create early building blocks for programs, provide for informed trade-offs for decision makers, and are the critical future genetic makeup for program development, production, and operations.

1.5. Dissertation Organization

This dissertation contains six chapters. Chapter 1 is the introduction which includes sections for an overall primer, research problem, approach, research significance, and organization. Chapter 2 provides an extensive literature review of in-depth and encompassing definitions of requirements, systems, FoS, and complex systems as well as uniquely developed definitions. Focus areas with respect to FoS and complex systems are researched and expanded. Chapter 3 researches and selects requirement attributes, and expands their definitions for systems, FoS, and complex systems. Chapter 4 encompasses the Bradley-Terry expert judgment methodology, and its associated potential biases and mitigation. It also includes a background in expert judgment approaches, the expert survey design and delivery approach, and the experts used as survey participants. Chapter 5 provides the analysis of the data that includes expert demographics, sensitivity analysis, and comprehensive analysis of requirement attributes for systems, FoS, and complex systems. Analysis reveals groups of requirement attributes for requirement developers to

consider for additional emphasis while developing a thorough and complete set of requirements. Finally, Chapter 6 provides conclusions of this dissertation, study limitations, and a concluding summary. It recommends further research of attributes for the FoS and complex systems focus areas.

Chapter 2: Literature Review and Terms Defined

As this research is intended as guidance for the government and industry acquisition communities to generate encompassing requirements for programs with systems, family of systems (FoS) , and complex systems, we begin with an in-depth literature review from a broad base of reference material, reports, and journal articles from academia, industry, and government. From there, we converge on a set of definitions for use in this study, select a set of requirement attributes for each definition that support well-written requirements, and conduct a case study using the Bradley-Terry methodology that will determine the rankings for requirement attributes.

Systems engineers and acquisition practitioners interact with a wide variety of programs that encompass differing relationships between the stakeholders and end users within their programs to develop, operate, and sustain a system. A system can be small, narrow, and focused to capture a simple capability, such as a rake or a door. As user capabilities expand and become more complicated, the types of systems also start to increase. The two major categories of higher order systems are Systems of Systems (SoS) and FoS. These differ based on the capabilities that are being developed and the relationships between the principal systems and their component systems (AT&L 2008; AT&L 2013).

The Department of Defense defines SoS as:

"An SoS is defined as a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities" (AT&L 2008).

An example of a SoS could be a smart phone, computer, or an information technology (IT) business network. With these examples, there is an arrangement of smaller systems that are integrated into a larger system. A computer is composed of a motherboard, sister board, graphic drivers, key board, and monitor to create a system of systems that develops a capability for the user. The larger system, the computer, is dependent on all of the smaller dependent systems to create a capability.

Another category of systems is a Family of Systems (FoS) and the Department of Defense defines a FoS as:

"A family of systems (FoS) is defined as a set of systems that provide similar capabilities through different approaches to achieve similar or complementary effects" (AT&L 2008).

An example of a FoS could be a national command and communications center operating with local, state, and federal law enforcement. Each entity has their own independent or unconstrained programmatic cost, schedule, and performance while achieving a complementary effect of communications.

For simple systems, SoS, or FoS to successfully develop their unique capability, a full range of requirements is needed to be developed to meet the user's intended capability. For programs to be successful, well defined requirements need to be developed (GAO 2015). In addition to requirements being developed they need to be affordable and informed by systems engineering processes (Francis 2015). Requirements, acquisition program management, and funding must be in balance to make informed decision trade-

offs. To aid in the informed decision making process, the GAO reports that DoD needs to identify and prioritize requirements (GAO 2008). The military Service Chiefs also confirm the need to identify and prioritize requirements to determine requirements feasibility and to make informed trade-off decisions (GAO 2011; GAO 2015). Furthermore, the defense industry is actively involved with government and interfacing with Congress to suggest reform recommendations (NDIA 2014).

To support a well-written, prioritized, feasible, and complete set of requirements, this research reviews and selects an encompassing set of requirement attributes. These attributes provide the qualities, traits, and features that create well developed requirements. This research also groups requirement attributes to help developers with areas of emphasis by community experts and provide focus in developing well-written requirements.

2.1. Systems Defined

The definitions of systems are documented by multiple government organizations at the national- and state-level as well as industry and standards organizations (AT&L 2008; JP 2015; JP 2011; AT&L 2013; INCOSE 2011; DHS 2010; Ames et al. 2011; EIA 1999; ISO/IEC 2008; ISO/IEC/IEEE 2013; ISO/IEC/IEEE 2011; NASA 2013; NASA 2012; USCG 2013; CBP 2011; DOE 2002; DOT 2007; DOT 2009; DHS 2011). Our literature review determines at least 20 existing approaches to defining a system. Table 2-1 provides an in-depth list of systems definitions.

The International Council on Systems Engineering (INCOSE), Electronic Industries Alliance (EIA), International Organization for Standardization/International

Electrotechnical Commission (ISO/IEC), and the Institute of Electrical and Electronics Engineers (IEEE) systems and software engineering have similar high-level definitions that express systems as those that achieve their stated purpose or objectives. While the United States Coast Guard takes a pure operational approach, the Department of Defense's approach focuses on functional, physical, and behavioral interactions (JP 2015).

An in-depth description from IEEE provides for a more detailed definition that includes "…equipment, facilities, material, computer programs, firmware, technical documentation, services, and personnel" (IEEE 1998). The Department of Energy and National Aeronautics and Space Administration (NASA) Systems Engineering Methodologies closely follow the IEEE Guide definition. For this research, we use a broader and more in-depth application definition as defined by IEEE as shown in Table 2-1. It encompasses simple systems whether they are independent or dependent with a higher-level, overarching principal system (IEEE 1998). Furthermore, the IEEE definition is not a government or commercial specific definition making its application more broadly applicable to the larger systems engineering and acquisition communities.

Table 2-1 System Definitions

Document	Definition
Systems Engineering Handbook (INCOSE 2011, 5)	"A combination of interacting elements organized to achieve one or more stated purposes."
American National Standards Institute (ANSI) Electronic Industries Alliance (EIA) Standard (EIA 1999, 68)	"An aggregation of end products and enabling products to achieve a given purpose."
Systems and software engineering – Software life cycle processes 12207 (ISO/IEC 2008, 7)	"Combination of interacting elements organized to achieve one or more stated purposes."
IEEE Guide for Developing System Requirements Specifications (IEEE 1998, 3)	"An interdependent group of people, objectives, and procedures constituted to achieve defined objectives or some operational role by performing specified functions. A complete system includes all of the associated equipment, facilities, material, computer programs, firmware, technical documentation, services, and personnel required for operations and support to the degree necessary for self-sufficient use in its intended environment."
Systems and software engineering – System life cycle processes (ISO/IEC/IEEE 2013, 8)	"Combination of interacting elements organized to achieve one or more stated purposes." (identical to ISO/IEC 12207)
Systems and software engineering—Life cycle processes—Requirements engineering 29148 (ISO/IEC/IEEE 2011, 7)	'System-of-Interest': "System whose life cycle is under consideration in the context of this international standard."
Department of Defense Dictionary of Military and Associated Terms (JP 2015 (1-02), 246)	"A functionally, physically, and/or behaviorally related group of regularly interacting or interdependent elements; that group of elements forming a unified whole."
Department of Defense Joint Operations (JP 2011(3-0), GL-17)	"A functionally, physically, and/or behaviorally related group of regularly interacting or interdependent elements; that group of elements forming a unified whole." (identical to JP 1-02)
Systems Engineering Guide for System of systems (AT&L 2008, 3)	"A functionally, physically, and/or behaviorally related group of regularly interacting or interdependent elements; that group of elements forming a unified whole." (identical to JP 1-02 & JP 3-0)
Defense Acquisition Guidebook (AT&L 2013, 4)	"An aggregation of system elements and enabling system elements to achieve a given purpose or to provide a capability."
NASA Procedural Requirements 7123.1A (NASA 2013, 41)	"The combination of elements that function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose. "
NASA Systems Engineering Handbook (NASA 1995, 3)	"A system is a set of interrelated components which interact with one another in an organized fashion toward a common purpose."
NASA Procedural Requirements 7120.5E (NASA 2012, 56)	"The combination of elements that function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose."
Department of Homeland Security Systems Engineering Life Cycle (DHS 2010, 220)	"An aggregation of end products and enabling products to achieve a given purpose." (identical and cited from ANSI/EIA-632-1998)
Coast Guard Capability Management (USCG 2013, 1-5)	"…systems that are physical assets, such as planes, ships, building, information systems, etc."
OTIA Requirements Handbook (CBP 2011, B-7)	"An integrated set of elements, segments, and/or subsystems intended to accomplish a defined objective."

Table 2-1 System Definitions (Cont)

Document	Definition
DoE Systems Engineering Methodology Version 3 (DOE 2012, 301 - 302)	"A product and the documentation, hardware, and communications needed to implement and operate the products and accomplish a specific function or set of functions. A collection of hardware, software, firmware, and documentation components organized to accomplish a specific function or set of functions."
Complex Adaptive System of Systems (CASoS) Engineering Framework (Ames et al. 2011, 9)	"A system is a set of entities, real or abstract, comprising a whole in which each component entity interacts with or is related to at least one other component entity and all entities serve a common objective."
Systems Engineering for Intelligent Transportation Systems (DOT 2007, 218)	"A combination of interacting elements organized to achieve one or more stated purposes." (identical and cited from INCOSE)
Systems Engineering Guidebook for Intelligent Transportation Systems (DOT 2009, 5)	"An integrated composite of people, products, and processes, which provide a capability to satisfy a stated need or objective."

2.2. Family of Systems (FoS) Defined

The definition of FoS centers on the independence of managerial, engineering, production, operational, and sustainment relationships between the principal system and the independent, unconstrained component systems. For this research, we use the definition of unconstrained as "not limited or restricted; or not to force by imposed structure, restriction, or limitation" (Merriam-Webster 2015). A FoS does not explicitly depend on a principal system. The vital discriminators for FoS systems are just that: the collection of systems are managed and operated independently from the whole (Maier 1998). The component systems within the principal system operate and are managed without constraint from the principal system. When operating collectively, the component systems explicitly create a unique and expanded capability. We uniquely define FoS by emphasizing the independent relationship between the principal system and the component systems. For this research we define the term Family of Systems as:

Family of Systems: A collection of component systems, simple or complex, that are managed, operated, developed, funded, maintained and sustained independently of their overarching principal system that creates a new capability.

This definition also aligns with the broader qualities from the engineering and acquisition community that shows managerial and operational independence (AT&L 2008; AT&L 2013; Maier 1998; Keating et al. 2008; Ncube 2011; Ames et al. 2011; Madni & Sievers 2014; Lewis, Morris, Simanta & Smith 2011; Corsello 2008; Clark 2009).

The Systems and Software Engineering Directorate, within the Under Secretary of Defense for Acquisition, Technology and Logistics (AT&L) organization, published a foundational guidebook (AT&L 2008) that further defines managerial system approaches from early methodologies (Maier 1998). Though these definitions apply directly to SoS, they also relate to FoS. These vary based on the amount of independent program management authority and influence the program manager has over the collection of independent or unconstrained systems. For FoS, the approaches are typically virtual and collaborative whereby the principal system is unconstrained from the independent component systems. These approaches are shown in Table 2-2 below.

Table 2-2 DoD Management Approaches

Approach	Definition
Virtual	"Lack a central management authority and a centrally agreed upon purpose for the system-of-systems" (AT&L 2008, 4-5).
Collaborative	"The component systems interact more or less voluntarily to fulfill agreed upon central purpose" (AT&L 2008, 4-5).
Acknowledged	"Have recognized objectives, a designated manager, and resources for the SOS; however, the constituent systems retain their independent ownership, objectives, funding, and development and sustainment approaches" (AT&L 2008, 4-5).
Directed	"Those in which the integrated system-of-systems is built and managed to fulfill specific purposes. It is centrally managed during long-term operation to continue to fulfill those purposes as well as any new ones the system owner might wish to address. The component systems maintain an ability to operate independently, but there normal operational mode is subordinated to the central management purpose" (AT&L 2008, 4-5).

The definition in this research for FoS aligns with these management approaches and the broader definitions by the systems engineering community, but it explicitly states the independence between the principal system and the component systems to create a new capability. By explicitly defining FoS in this manner, it provides additional focus on the independent aspect when developing requirements.

2.3. Complex Systems Defined

The acquisition and systems engineering communities have attempted to define 'system of systems' (SoS) for decades. Most definitions can be traced back to Mark W. Maier's (1998) research which provides an early definition and set of attributes (AT&L 2008; AT&L 2013; INCOSE 2011; Maier 1998; Keating et al. 2008, Ncube 2011; NASA 1995; Ames et al. 2011; Butterfield et al. 2009; Korent 2015; NASA 2012; DHS 2011; Corsello 2008; Madni & Sievers 2013). As acquisition and development programs became larger

with higher technological complexities, more stringent design intricacies, and expanded functional interdependencies, the definitions of system of systems expanded and evolved. Table 2-3 shows a comprehensive list of system of systems definitions.

Table 2-3 System of Systems

Document	Definition
Architecting Principles for System-of-Systems (Maier 1998, 267 - 268)	"A system of systems or collaborative system are (1) Its components fulfilled valid purposes in their own right and continue to operate to fulfill those purposes if disassemble from the over system, and (2) the components system are managed (at least in part) for their own purposes rather than the purposes of the whole."
Systems Engineering Handbook (INCOSE 2011, 5)	"System of systems applies to a system-of-interest whose system elements are themselves systems; typically these entail large scale inter-disciplinary problems with multiple, heterogeneous, distributed systems."
Systems Engineering Guide for System of systems (AT&L 2008, 13)	"An SoS is defined as a set or arrangement of systems that results when independent and useful system are integrated into a larger system that delivers unique capabilities."
Defense Acquisition Guidebook (AT&L 2013, 13)	"An SoS is defined as a set of arrangement of systems that results when independent and useful system are integrated into a larger system that delivers unique capabilities."
NASA Systems Engineering Handbook (NASA 1995, 2)	"Every system exists in the context of a broader super system, i.e., a collection of related systems. It is in that context that the system must be judged."
NASA Procedural Requirements (NASA 2012, 57)	"Tightly Coupled Programs. Programs with multiple projects that execute portions of mission(s). No single project is capable of implementing a complete mission. The program may also include other agency or international partner contributions."
Department of Homeland Security Instruction 102-01-001 (DHS 2011, 83)	"A composite system comprised itself of sub-systems that are closely coupled and all contribute to a common set of goals, objectives, and performance measures. Often used for "ultra-large" systems that must be acquired and developed as a set of major programs whose products interface and work together. Often System of systems (SoS) cross organizational boundaries."
On the Engineering of System of systems: key challenges for the requirements engineering community (Ncube 2011, 70)	"Systems-of-Systems engineering is an interdisciplinary approach that focuses on ultra-large scale interoperation of many independent, self-contained constituent systems in order to satisfy a global need."
Complex Adaptive System of systems (CASoS) Engineering Framework - Sandia National Laboratories (Ames et al. 2011, 21)	"A Complex Adaptive System of Systems (CASoS) is composed of component system ("of systems"). System of systems have the following properties: 1. Operational independence of the individual systems, 2. Managerial independence of the individual systems, 3. Geographic distribution, 4. Emergent behavior, and 5. Evolutionary and adaptive development."
System of systems Engineering Requirements: Challenges and Guidelines (Keating et al. 2008, 24)	"A metasystem, comprised of multiple embedded and interrelated autonomous complex subsystems that can be diverse in technology, context, operation, geography, and conceptual frame. These complex subsystems must function as an integrated metasystem to produce desirable results in performance to achieve a higher-level mission subject to constraints."

Table 2-3 System of Systems (cont)

Document	Definition
System of systems Integration: Key Considerations and Challenges (Madni & Sievers 2013, 330)	"A system of systems (SoS) is a collection of systems that were originally designed as stand-alone systems for specific and different purposes but that have been brought together within the SoS umbrella to create a new capability needed for a particular mission."
System-of-System Architectural Considerations for Complex Environments and Evolving Requirements (Corsello 2008, 312)	"Component system contribute to the whole through some physical interaction."
Boeing System of systems Engineering Process and Its Use in Developing Legacy-Based Net-Centric System of systems (Butterfield 2009, Slide 5)	"A System-of-System (SoS) is a 'super-system" comprised of elements that are themselves complex, independent systems which interact to achieve a common goal."
Lockheed Martin (Korent 2015)	"A SoS is defined as a set or arrangement of systems that results when independent and useful system are integrated into a larger system that delivers unique capabilities. (Identical to Systems Engineering Guide for System of Systems." (AT&L 2008, 13)

These existing definitions of SoS detail top-level of definitions and begin to show some early traits of complex SoS. However, as programs become more technically complex and programmatically inter-connected, there is a need for a specific focus area within SoS dedicated to complex systems. For instance, NASA discusses SoS as tightly coupled programs with multiple projects and super systems as a collection of related systems (NASA 1995; NASA 2012). The academic community discusses stand-alone systems being brought together for a new capability (Madni & Sievers 2013) and subsystems being integrated into a metasystem (Keating et al. 2008).

The systems engineering communities from industry, academia, and government have also further endeavored to specifically define complex systems in addition to that of an SoS (Katina & Keating 2014; Svetinovic 2013; Jain et al. 2008; Bartolomei et al. 2012; Chittister & Haimes 2010; Haber & Verhaegen 2014; Konrad & Gall 2008;

Hawryszkiewycz 2009; Liang, Avgeriou, He & Xu 2010; Glass et al. 2011; Butterfield et al. 2009; Korent 2015; Nescolarde-Selva & Uso-Donenech 2012 & 2013). Some authors describe attributes that complex systems demonstrate versus a singular definition without attributes associated with complexity (Katina & Keating 2014; Bartolomei et al. 2012; Chittister & Haimes 2010; Haber & Verhaegen 2014; Glass et al. 2011; Konrad & Gall 2008; Hawryszkiewycz 2009). Table 2-4 provides a literature review and list of definitions that help describe complex systems attributes.

Table 2-4 Literature Review of Complex Systems Attributes

Attribute	Definition
Adaptive	Components adapt "…to changes in others, as well as to changes in personnel, funding, and application, shift from being static to dynamic systems" (Glass et al. 2011, 7; Svetinovic 2012; Chittister & Haimes 2010).
Aspirational	"To influence design, control, and manipulate complex systems to solve problems" to predict, prevent of cause, and to define decision, robustness of decision, and enabling resilience (Glass et al. 2011,.2; Svetinovic 2013).
Boundary Liquidity	"Complex systems do not have a well-defined boundary. The boundary and boundary criteria for complex systems are dynamic and must evolve with new understanding" (Katina & Keating 2014, 53; Glass et al. 2011).
Contextual Dominance	"A complex situation can exhibit contextual issues that can stem from differing managerial world views, and other nontechnical aspects stemming from the elicitation process" (Katina & Keating 2014, 53).
Emergent	Complex systems may "…exist in an unstable environment and be subject to emergent behavioral, structural, and interpretation patterns that cannot be known in advance and lie beyond the ability of requirements to effectively capture and maintain" (Katina & Keating 2014, 53).
Environmental	"Exogenous components that affect or are affected by the engineering system", that which acts, grows, and evolves with internal and external components (Bartolomei et al. 2012, 43; Glass et al. 2011; Hawryszkiewycz 2009).
Functional	Range of fulfilling "goals and purposes of the engineering system", "ease of adding new functionality or ease of upgrade existing functionality", the goals and purposes of the engineering systems, ability to organize connections (Bartolomei et al. 2012, 43; Jain et al. 2007, 215; Konrad & Gall 2008; Hawryszkiewycz 2009).
Holistic	Consider the whole of the system, consider the role of the observer and the broad influence of the system on the environment (Katina & Keating 2014; Svetinovic 2012; Haber & Verhaegen 2012).
Interdependencies	"A number of systems are dependent on one other to produce the required results" (Katina & Keating 2014, 53; Korent 2015).
Multifinality	"…Two seemingly identical initial complex systems can have different pathways toward different end states" (Katina & Keating 2014, 53).

Table 2-4 Literature Review of Complex Systems Attributes (cont)

Process	Processes and steps to perform tasks within the system, methodology "framework to support and improve the analysis of systems", hierarchy of system requirements (Bartolomei et al. 2012, 27; Liang et al. 2010; Konrad & Gall 2008; Haber & Verhaegen 2012).
Predictive	"Proactively analyze requirements arising due to the implementation of the system underdevelopment and the system's interaction with the environment and other systems" (Svetinovic 2013, 169).
Social	"Social network consisting of the human components and the relationships that holds among them", social network "essential in supporting innovation in dynamic processes, centers on groups which can assume roles with defined responsibilities" (Bartolomei et al. 2012, 43; Hawryszkiewycz, 2009, 342; Liang et al. 2010).
Technical	"Physical, nonhuman components of the system to include hardware, infrastructure, software, and information", complexity of "integration technologies required to achieve system capabilities and functions" (Bartolomei et al. 2012, 43; Jain et al. 2008, 242; Chittister & Haimes 2010; Haber & Verhaegen 2013).

Complex systems, which are large and multifaceted with interrelated dependent systems, are challenged with national-level or multiple nation, state-level intricacies as social, political, environmental, and technical issues evolve. Non-complex systems, or 'systems,' do not have these higher order complexities and relationships.

Complex systems and SoS have similar properties; however, for our research we consider complex systems to be a distinct subset within SoS and different from FoS. Complex systems differ from FoS depending on whether the component systems within the principal system are dependent on or independent of the principal system. The differences are shown in Figure 2-1. Additionally, complex systems are comprised of large, multifaceted, and interrelated component systems that are dependent on the entirety of the principal system for management and operations. They are large national or international programs with a broad range of functional and physical external interfaces. Within SoS for complex systems, the governance authority of the principal system and the dependent component system are explicitly linked. Thus, the component systems are operationally and

managerially dependent on the principal system. The definition of SoS is a broad top-level definition while complex systems are larger with a distinct external view with highly distributed yet tightly interrelated systems as shown in Table 2-4. The *contextual dominance* and *holistic* perspectives, as shown in Table 2-4, describe a broad external world view, which aligns with large multi-national, complex systems.

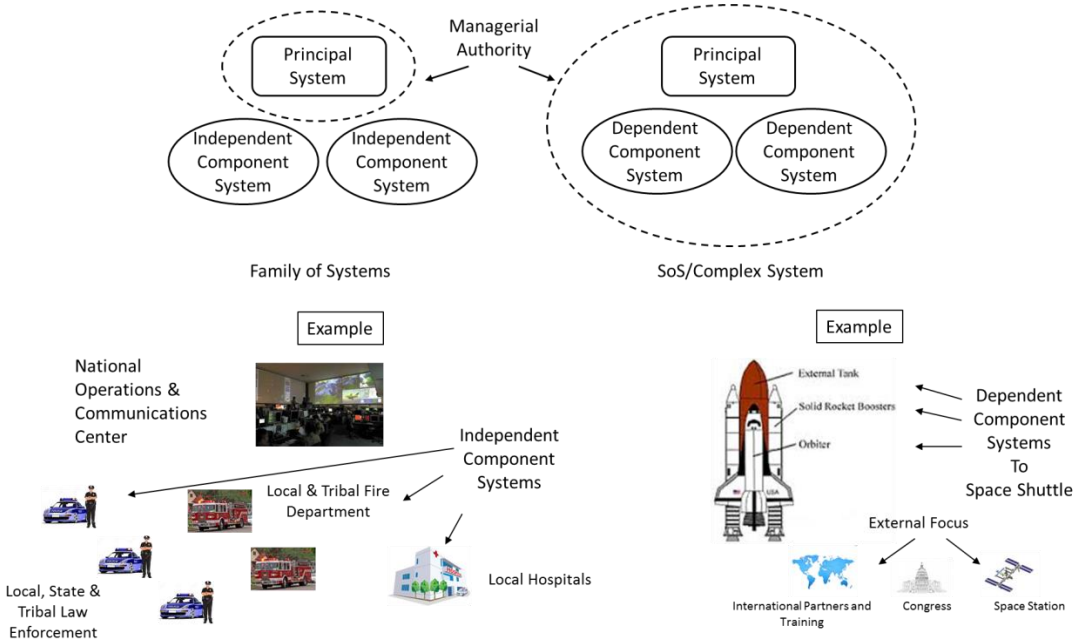


Figure 2-1 FoS and SoS Complex Systems

2.4. Requirements Defined

Literature research reveals varying definitions for system requirements (AT&L 2008; JP 2015; JP 2011; CJCSI 2012; INCOSE 2011; DHS 2010; IEEE 1998; IEEE (2) 1998; EIA 1999; ISO/IEC 2008; ISO/IEC/IEEE 2011; NASA 2012; NASA 2013; USCG 2013; CBP 2011; DOE 2002; DOT 2007; DOT 2009). Table 2-5 provides a detailed list of requirements definitions. INCOSE (2011) provides a top-level definition for requirements that entails the system, product, or process. The Department of Homeland Security and the Department of Transportation use the EIA 632 definition that explains what conditions are necessary for a product or a system to achieve its purpose (EIA 1999). Taking a different approach, the Department of Defense describes requirements in relation to task lists (CJCSI 2012). NASA has a consistent approach that covers needs and wants in the form of 'shall' statements (NASA 2013). In our study, we use the IEEE's requirements definition that provides a broad, universal, and vetted foundation that can be applied to industry, government, and academia.

"Requirement

A) A condition or capability needed by a user to solve a problem or achieve an objective.

B) A condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed document.

C) A documented representation of a condition or capability as in definition (A) or (B)" (IEEE 1998).

Table 2-5 Literature Review of Requirements Definitions

Document	Definition
Systems Engineering Handbook (INCOSE 2011, C-4)	"A statement that identifies a system, product or process' characteristic or constraint, which is unambiguous, clear, unique, consistent, stand-alone (not grouped), and verifiable, and is deemed necessary for stakeholder acceptability."
Electronic Industries Alliance Standard (EIA 1999, 67)	(1) "Something that governs what, how well, and under what conditions a product will achieve a given purpose. (2) Normative elements that govern implementation of this Standard, including certain documents such as agreements, plans, or specifications."
Systems and software engineering – Software life cycle processes 12207 (ISO/IEC 2008, 6)	"Qualification requirement: set of criteria or conditions that have to be met in order to qualify a software product as complying with its specifications and being ready for use in its target environment or integration with its containing system."
IEEE Guide for Developing System Requirements Specifications (IEEE 1998, 3)	(A) "A condition or capability needed by a user to solve a problem or achieve an objective. (B) A condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed document. (C) A documented representation of a condition or capability as in definition (A) or (B)."
Systems and software engineering—Life cycle processes—Requirements engineering 29148 (ISO/IEC/IEEE 2011, 5)	"Statement which translates or expresses a need and its associated constraints and conditions."
Chairman of the Joint Chiefs of Staff Instruction 3170.01H (CJCSI 2012, GL-5)	"A capability (or requirement) required to meet an organization's roles, functions, and missions in current or future operations. To the greatest extent possible, capability requirements are described in relation to tasks, standards, and conditions in accordance with the Universal Joint Task List or equivalent DoD Component Task List."
Systems Engineering Guide for System of systems (AT&L 2008, 3)	"A capability to achieve a desired effect under specified standards and conditions through combinations of ways and means to perform a set of tasks."
NASA Procedural Requirements 7123.1A (NASA 2013, 45)	"The agreed upon need, desire, want, capability, capacity, or demand for personnel, equipment, facilities, or other resources or services by specified quantities for specific periods of time or at a specified time expressed as a "shall" statement."
NASA Procedural Requirements 7120.5E (NASA 2012, 40)	"The agreed upon need, desire, want, capability, capacity, or demand for personnel, equipment, facilities, or other resources or service by specified quantities for specific periods of time or at a specified time expressed as a "shall" statement."
Department of Homeland Security Systems Engineering Life Cycle (DHS 2010, 218)	Identical and cited from ANSI/EIA-632-1998
Coast Guard Capability Management (USCG 2013)	"A documented user need of what a specific system should be or do. It identifies a necessary attribute, capability, characteristic or quality a system must possess to provide value or utility to the user."

Table 2-5 Literature Review of Requirements Definitions (cont)

OTIA Requirements Handbook (CBP 2011, B-7)	"A condition or capability that must be met or possessed by a system, product, service, result, or component to satisfy a contract, standard, specification, or other formally imposed documents. Requirements include the quantified and documented needs, wants, and expectation of the sponsor, customer, and other stakeholders."
DoE Systems Engineering Methodology Version 3 (DOE 2002, 300)	"A condition or capability needed by a system owner/user to solve a problem or achieve an objective. A condition or capability that must be met or possessed by the software product or system to satisfy a contract, standard, specification, or other formally imposed documents."
Systems Engineering for Intelligent Transportation Systems (DOT 2007, 34)	Identical and cited from ANSI/EIA-632-1998
Systems Engineering Guidebook for Intelligent Transportation Systems (DOT 2009, 218)	"The total consideration as the WHAT is to be done [functional], HOW well it is to perform [performance], and under WHAT CONDITIONS it is to operate." [Environmental and non-functional]

Literature research from the broad systems engineering and acquisition communities provided the background and input to define four key terms used in this research. The term complex systems is a subset of SoS that focuses on large, external, complex national and international programs. Our definition of FoS is similar to the definition from the broader systems engineering community, but it explicitly links the independence of principal system to unconstrained and independent component systems. The terms 'systems' and 'requirements' are selected from IEEE which broadly encompasses the systems engineering community to include industry, government, and academia.

Chapter 3: Attributes Selected

Using the research, terms, and definitions as defined in Section 2, we select and expand the definitions of the requirement attributes for systems, family of systems (FoS), and complex systems. These attributes provide the foundational factors for our research.

3.1. Systems Requirement Attributes

Various authors and organizations have articulated and defined requirement attributes that contribute to developing well-defined requirements for systems (Davis 1993; INCOSE 2011; Pohl 2010; van Lamsweerde 2009; Rettaliata et al. 2014; Georgiadis, Mazzuchi & Sarkani 2012; Mannion & Keepence 1995). Davis (1993) was one of the earliest authors to provide an extensive list of requirement attributes, though his primary focus concentrated on software requirements. Subsequent to Davis' (1993) work, researchers have adapted attributes more broadly for use with all types systems. Recently, researchers provided a wide-ranging review of attributes for materiel and non-materiel systems (Rettaliata et al. 2014). Using Rettaliata's study, we expand his research on requirement attributes using the systems definition as defined in Section 2.1. We also broaden the literature research to include sources from the Department of Energy, United States Coast Guard, EIA, ISO/IEC, INCOSE, and IEEE.

The attributes provided in Davis (1993) consist of eight attributes for content and five attributes for format. As a result of our literature research, we added a ninth content attribute of '*achievable*' to Davis' list and we uniquely define it. For clarity, we also expanded Davis' existing 13 definitions beyond a software focus to integration and

hardware (Davis 1993; GAO 2015; GAO 2011). INCOSE and IEEE denote the '*achievable*' attribute, which ensures systems are attainable to be built and operated as specified (INCOSE 2011, 77; ISO/IEC/IEEE 2011, 12). This expanded list of requirement attributes also aligns with recent GAO and congressional testimony, in which the testimony emphasizes requirement attributes should contribute to establishing *comprehensive, achievable, clear, verifiable* and *understandable* requirements (GAO 2015; GAO 2011; Francis 2015; Erwin 2014). The 14 system attributes with their expanded definitions are listed in Table 3-1 (Davis 1993; INCOSE 2011; ISO/IEC/IEEE 2011; Rettaliata et al. 2014; GAO 2015; GAO 2011). We focus our research on the nine content attributes. Only the nine content attributes are used for expert judgment data collection. While the five format attributes are necessary, the nine content attributes are more central to capturing system requirements (Rettaliata et al. 2014).

Furthermore, based on our literature review of requirement attributes with standards and government organizations, Davis' initial list 13 attributes correlate with the selected lists of key requirement attributes for requirement development (Davis 1993; INCOSE 2011; IEEE 1998; Rettaliata 2014; AT&L 2013; CBP 2011). For instance INCOSE lists attributes of *traceable, consistent, verifiable,* and *unique* (INCOSE 2011, I-5). The GAO along with INCOSE and IEEE additionally define the added attribute of *achievable* and when added to Davis' list provides for an encompassing list of attributes (GAO 2015; GAO 2011; Francis 2015; INCOSE 2011).

Table 3-1 Systems Attributes

Attribute	Type	Definition
Correct	Content	**Correct** if and only if every requirement stated therein represents something required of the system to be built.
Unambiguous	Content	**Unambiguous** if and only if every requirement stated therein has only one interpretation and includes only one requirement (unique)
Complete	Content	**Complete** if it possesses these qualities: 1) Everything it is supposed to do is included. 2) Definitions of the responses of software to all situations are included. 3) All pages are numbered. 4) No sections are marked "To be determined." 5) Is necessary
Verifiable	Content	**Verifiable** if and only if every requirement stated therein is verifiable.
Consistent	Content	**Consistent** if and only if (1) no requirement stated therein is in conflict with other preceding documents, and (2) no subset of requirements stated therein conflict.
Understandable by Customer	Content	**Understandable by customer** if there exists a complete unambiguous mapping between the formal and informal representations.
Achievable	Content	**Achievable** – the designer should have the expertise to assess the achievability of the requirements to include subcontractors, manufacturing and customers/users within the constraints of the cost and schedule lifecycle.
Design Independent	Content	**Design independent** if it does not imply a specific architecture or algorithm.
Concise	Content	**Concise** if given two requirements for the same system, each exhibiting identical level of all previous mentioned attributes, the shorter is better.
Modifiable	Format	**Modifiable** if its structure and style are such that any necessary changes to the requirement can be made easily, completely, and consistently.
Traced	Format	**Traced** if the origin of each of its requirements is clear.
Traceable	Format	**Traceable** if it is written in a manner that facilitates the referencing of each individual requirement stated therein.
Annotated	Format	**Annotated** if there is guidance to the development organization such as relative necessity (ranked) and relative stability.
Organized	Format	**Organized** if the requirements contained therein are easy to locate.

(Davis 1993; INCOSE 2011; ISO/IEC/IEEE 2011)

3.2. FoS Requirement Attributes

For our research the requirement attributes for FoS systems are identical to the attributes for systems as listed in Table 3-1. We again focus on the nine content attributes for expert judgment data collection. Based on our literature review with academia, government, and standards organizations, the attribute list as defined in Table 3-1, correlates to attribute lists for FoS attributes to develop requirements with independent,

unconstrained component systems (CBP 2011; DHS 2010; INCOSE 2011; IEEE 1998; NASA 1995).

INCOSE does not make a distinction of requirement attributes between simple systems and FoS. INCOSE's list of eight requirement attributes supports the list as presented in Table 3-1 with correlated attributes of *complete, verifiable, consistent, achievable, concise* and *traceable* (INCOSE 2011, 76). In addition, unconstrained systems or FoS within the academic realm are discussed where examples of key attributes are *verifiable, traced, traceable,* and *achievable* (Mannion, Keepence, Kaindl & Wheadon 1999; Monzon 2008). Our literature research shows Table 3-1 addresses the requirement attributes for FoS.

3.3. Complex Systems Requirement Attributes

Complex systems are a subset of SoS that focus on large, distributed, national and international systems. They have diverse integration complexities across multiple external boundaries. For example, the F-35 Joint Strike Fighter has millions of lines of software code that must accommodate multiple international partners with their own sets of unique requirements and interfaces. Another example is the Department of Homeland Security's Global Entry program that involves complex facial recognition and biometrics software and hardware that must operate across multiple airports within the United States 24 hours a day and interface with millions of citizens within the United States as well as with international partners within the United Kingdom and Canada.

Comprised of integrated, dependent, and simple systems, complex systems are tightly interrelated and have dependent internal connections as shown in Figure 3-1. Dependent

systems within the inner boundary conditions derive a set of requirements attributes that must be clear and precise. Our research uses the attributes from simple systems, as shown in Table 3-1, to define internal perspective requirements. As complex systems interface with their external environment, an additional set of requirements attributes is selected to support requirements development across external outward facing boundaries.

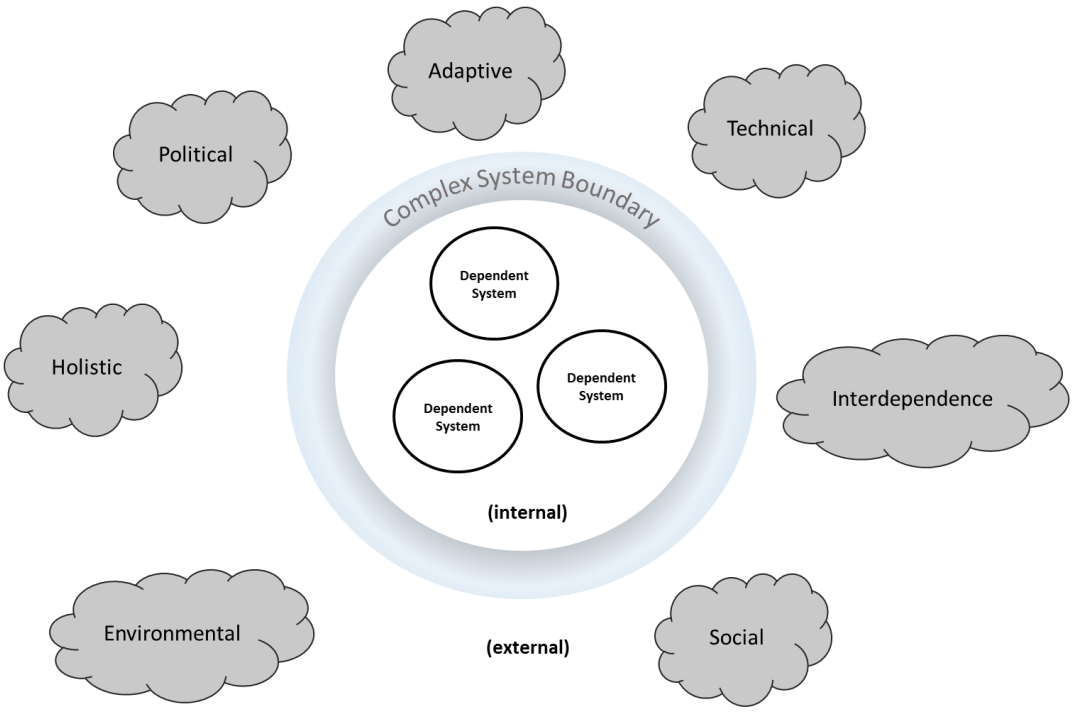


Figure 3-1 Complex Systems Internal and External Perspectives

Complex systems have a strong external focus. As complex systems interface with their external sphere of influence, another set of requirement attributes is needed to ensure an encompassing set of well-defined requirements is generated. The outer

complex boundary conditions become more qualitative than quantitative and the external attributes reflect a broader, more qualitative set of traits that requirement developers need to consider. Using the 'space shuttle' example (Figure 2-1), the external focuses include Congress, the space station, the interface with internationally developed space station modules, and international partners, training, management relations, and standards.

Using our definition of complex systems and literature research, we selected seven complex external system attributes as shown in Table 3-2. The seven attributes (*holistic, social, political, adaptable, technical, interdependent,* and *environmental*) provide a key set of attributes that align input from the acquisition and systems engineering communities to consider when developing complex, external requirements (Katina & Keating 2014; Nescolarde-Selva & Uso-Demenech 2012; Nescolarde-Selva & Uso-Domenech 2013; Jain et al. 2018; Bartolomei et al. 2011; Konrad & Gall 2008; Liang et al. 2010; Sevetinovic 2012; Ames et al. 2011; Glass et al. 2011; Hawryszkiewycz 2009). The external attributes in Table 3-2 that focus on qualitative complex integration drivers across external boundaries together with the attributes for systems that provide the quantitative internal focus, as shown in Table 3-1, provide a comprehensive and complementary list of attributes to develop a complete set of requirements for complex systems.

Table 3-2 Complex Systems External Requirements Attributes

Attribute	Definition
Holistic	**Holistic** considers the following: • Security & surety; scalability & openness; and legacy systems • Timing of schedules and budgets • Reliability, availability, and maintainability • Business and competition strategies • "Role of the observer, the nature of systems requirements, and the influence of the system environment" (Katina & Keating 2014, 47)
Social	**Social** considers the following: • Local, state, national, tribal, international stakeholders • Demographics & culture of consumers; culture of developing organization (Nescolarde-Selva & Uso-Domenech 2012 & 2013) • Sub-contractors, production, manufacturing, logistics, maintenance stakeholders • Human resources for program and systems integration (Jain et al. 2008) • "Social network consisting of the human components and the relationships that hold among them" (Bartolomei et al. 2011, 43) • Customer and social expectations and customer interfaces (Konrad & Gall 2008) • Uncertainty of stakeholders (Liang et al. 2010) • Use of "Web 2.0 tools and technologies" (e.g. wikis, folksonomie, and ontologies) (Liang et al. 2010, 27) • Knowledge workers ability to quickly change work connections (Hawryszkiewycz 2009)
Political	**Political** considers the following: • Local, state, national, tribal, international political circumstances and interests • Congressional circumstances and interests to include public law and funding • Company, partner, and subcontractor political circumstances and interests • Intellectual property rights, proprietary information, and patents
Adaptable	**Adaptability** considers the following: • Shifts from static to being adaptive in their nature (Svetinovic 2012) • "System's behavior changes in time in response to external stimulus" (Ames et al., 2011, 24) • Components adapt to "changes in the others, as well as changes in personnel, funding, and application" (Glass et al. 2011, 7)
Technical	**Technical** considers the following: • Technical readiness and maturity levels • Risk & safety • Modeling and simulation • Spectrum & frequency • Technical innovations (Glass et al. 2011) • "Physical, nonhuman components of the system to include hardware, software, and information" (Bartolomei et al. 2011, 43; Nescolarde-Selva & Uso-Domenech 2012 & 2013)

Table 3-2 Complex Systems External Requirements Attributes (cont)

Interdependent	**Interdependencies** consider the following: • System and system components schedules of developing components and legacy components • Product and production lifecycles • Management of organizational relationships • Funding integration from system component sources • "The degree of complication of a system or system component, determined by such factors as the number of intricacy of interfaces, number and intricacy of conditional branches, the degree of nesting and types of data structure" (Jain et al. 2008, 211) • The integration of "data transfers across multiple zones of systems & network integration" (Hooper 2009) • "Ability to organize connections and integration between system units and ability to support changed connections" (Hawryszkiewycz 2009, 343) • Connections between internal and external people, projects, and functions (Glass et al. 2011)
Environmental	**Environmental** considers the following: • Physical environment (e.g. wildlife, clean water protection) • Running a distributed environment by distributed teams and stakeholders (Liang et al. 2010) • Support "integration of platforms for modeling, simulation, analysis, education, training, and collaboration" (Glass et al. 2011, 12)

The following is a set of hypothetical requirements of a complex system that combines internally focused and externally focused attributes.

1. The system shall be interoperable with Country A's government passport documentation
2. The system shall be interoperable with Country B's government passport documentation
3. The system shall be interoperable with Country A's biometric software data
4. The system shall be interoperable with Country B's biometric software data
5. The system's hardware interface shall be interoperable with Country A's software data
6. The system's hardware interface shall be interoperable with Country B's software data

These six sample requirements demonstrate the attributes of *concise* and *correct* as shown in Table 3-1 with an internal or inner facing perspective with hardware and software functionality. These sample requirements also demonstrate the external complex attributes from Table 3-2 of *interdependent* and *social* with a broader, more qualitative perspective as they capture international stakeholders and interdependencies with multiple countries each with unique data, equipment and solutions.

Chapter 4: Methodology

Literature research provides the background, breadth, and depth of sources from industry, government, and standards organizations to develop definitions for systems, family of systems (FoS), complex systems, and requirements. These definitions are foundational to further develop, refine, and select the attributes needed to elicit requirements. Using our definitions, we selected the requirement attributes for systems, FoS, and complex systems as shown in Tables 3-1 and 3-2. Finally, to validate our selected requirement attributes for systems, FoS, and complex systems, we implement an expert judgment methodology as originally defined in Bradley and Terry (Bradley & Terry 1952) and later refined in Cooke (1991).

4.1. Expert Judgment

Expert judgment has been used for decades to support and solve complex technical problems. We use the definition of an expert as, "a person who has background in the subject areas and is recognized by his or her peers or those conducting the study as qualified to answer questions" (Meyer & Booker 1991, 3). Commonly, expert judgment is used when substantial scientific uncertainty has an impact on a decision process (Cooke & Goossens 2007, 657). Thus, expert judgment allows researchers and communities of interest to reach rational consensus when there is scientific knowledge or process uncertainty (Cooke & Goossens 2004, 643). In addition, it is used to assess outcomes of a given problem by a group of experts within a field of research who have the requisite breadth of knowledge, depth of multiple experiences, and perspective. Previous research

has shown the results from a group of experts outperform that of a single individual; however, the best performing individual can outperform the group (Clemen & Winkler 1999, 188). In addition, Meyer & Booker state "Experts are better at providing data on how a problem can be solved" (Meyer & Booker 1991). Based on such data, this research uses multiple experts from a broad range of backgrounds with in-depth experience in their relative fields to provide a diverse set of views and judgments.

Expert judgment has been adopted for numerous competencies to include applications in nuclear, chemical, and gas industry, water pollution, seismic risk, environmental risk, snow avalanches, corrosion in gas pipelines, aerospace, banking, information security risks, aircraft wiring risk assessments, and maintenance optimization (Cooke & Goossens 2007; Ryan, Mazzuchi, Ryan, de la Cruz & Cooke 2013; Mazzuchi, Linzey & Bruning 2007; van Noortwijk, Dekker, Cooke & Mazzuchi 1992; Cooke & Goossens 2004; Goossens n.d.; Lin & Chih-Hsing 2008; Winkler 1986; Lin & Lu 2012; Clemen & Winkler 1999). Various methods are employed when applying this expert judgment. Although we explored the Delphi technique, group interactions, and individual interview methods, we adopted the survey method using surveys to be filled out by each expert. This methodology develops and uses a survey for a group of experts to complete in private, and it allows them to comment openly on any of their concerns not specified by the formal survey questions. This option eliminates the role of an interviewer and any bias that role would introduce. In addition, to manage the logistics of our experts residing in multiple states, we determined that using surveys is the most expeditious method to capture data without degradation of the data collection requirement.

4.2. Bradley-Terry Methodology

We selected the Bradley-Terry expert judgment methodology because it uses pairwise comparisons to capture data via a survey from experts and uses it to rank the selected requirement attributes by their respective importance (Bradley & Terry 1952). We also reviewed the Analytic Hierarchy Process (AHP) which presents an alternative approach to Bradley-Terry. Both the Bradley-Terry and the AHP approaches provide techniques for pairwise comparison analysis and both provide similar solutions (Genest & M'Lan 1998, 99; Forman 1993). The AHP process takes "an Eigenvector solution" to estimate priorities while Bradley-Terry uses a linear model solution and a geometric mean method for deriving priorities (Genest & M'Lan 1998, 99; Saaty & Vargas 1984; Ganesh & Reddy 2014, 93). Bradley-Terry "has a more psychological appeal" than AHP and "scale restrictions traditionally associated with AHP practice are more easily accommodated in the Bradley-Terry model" (Genest & M'Lan 1998, 99). While both Bradley-Terry and AHP are credible approaches for pairwise comparison analysis, we chose Bradley-Terry because part of this research extends Rettaliata's work, which used the Bradley-Terry methodology coupled with the Unibalance-11 software (Rettaliata et al. 2014; Macutkiewicz 2006).

Bradley-Terry methodology uses a pairwise comparison of factors by multiple experts, which provides a relative ranking of factors. This methodology provides a statistical means for assessing the adequacy of individual expert responses of actual preference versus random reference. It also assesses the agreement of experts as a group. Bradley-Terry

methodology also develops a statistic to check the goodness of fit or appropriateness of the model.

The appropriateness of experts' responses is determined by their number of circular triads. Circular triads, *C(e)*, as shown in Equation 4.1, are when an expert (e) ranks one object, A, in a circular fashion such as A1 > A2, and A2 > A3, and A3 > A1 (Bradley & Terry 1952; Mazzuchi et al. 2007).

$$C(e) = \frac{t(t^2-1)}{24} - \frac{1}{2}\sum_{i=1}^{t}\left[a(i,e) - \frac{1}{2}(t-1)\right]^2 \quad (4.1)$$

The defined variables for the set of equations are:

e = expert

t = number of objects

"n = number of experts

A(*1*) ….. A(*t*) = Objects to be compared" (Cooke 1991, 211)

"a(*i, e*) = number of times expert, e, prefers A(*i*)" (Cooke 1991, 212)

R(*i,e*) = the rank of A(*i*) from expert, e

V(*i*) = true values of the objects

"V(*i, e*) = internal value of expert, e, for object *i*" (Cooke 1991, 211)

The term 'object' for our research represents a requirement attribute, such as *correct* or *verifiable*. The rankings are ordinal as presented by the Unibalance-11 software package that supports the Bradley-Terry methodology. The term *V(i,e)* is the internal value of an

expert for an attribute. An expert has an internal value of which attribute has more value to them, for example, whether attribute A or attribute B has more value when performing a pairwise comparison.

The random variable *C(e)* defined in Equation 4.1 represents the number of circular triads produced when "an expert provides his/her answers in a random fashion" (Mazzuchi et al. 2007). The random variable has a distribution approximated by a chi-squared distribution, as shown in Equation 4.2, and can be applied to each "expert to test the hypothesis that the expert answered randomly versus the alternative hypothesis that he/she followed a certain preference" (Cooke 1991). Using *C'(e)*, experts for whom this hypothesis cannot be rejected at the 5% significance level are eliminated from the study using a standard one-tailed hypothesis test.

$$C'(e) = \frac{t(t-1)(t-2)}{(t-4)^2} + \left(\frac{8}{t-4}\right) * \left[\binom{1}{4}\binom{t}{3} - c(e) + \frac{1}{2}\right] \quad (4.2)$$

The coefficient of agreement, *U*, a measure of consistency of rankings from expert to expert, is defined in Equation 4.3 (Bradley & Terry 1952, 330; Cooke 1991; Mazzuchi et al. 2007).

$$U = \frac{2\sum_{i=1}^{t}\sum_{j=1,j\neq i}^{t}\binom{a(i,j)}{2}}{\binom{n}{2}\binom{t}{2}} - 1 \quad (4.3)$$

When the experts agree 100%, U obtains its maximum of 1. The coefficient of agreement distribution, U', defines the statistic under the hypothesis that all agreements by experts are due to chance (Cooke 1991, 213; Mazzuchi et al. 2007, 725). The factor U' has an (approximate) chi-squared distribution. Experts as a group for whom this hypothesis cannot be rejected due to chance at the 5% significance level are eliminated from the study using a standard one-tailed hypothesis test.

$$U' = \frac{\sum_{i=1}^{t}\sum_{j=1,j\neq i}^{t} \frac{a(i,j)}{2} - \binom{1}{2}\binom{n}{2}\binom{t}{2}\binom{n-3}{n-2}}{n-2} \tag{4.4}$$

The sum of the ranks, R(i) is given by:

$$R(i) = \sum_e R(i,e) \tag{4.5}$$

The Bradley-Terry methodology uses a true scale value, V_i, to determine ordinal rankings, and they are solved iteratively (Cooke 1991; Mazzuchi et al. 2007). Additionally, Bradley-Terry and Cooke define the factor, F, for the goodness of fit of the data for the model as shown in Equation 4.6 (Bradley & Terry 1952; Cooke 1991). To determine if the model is appropriate (goodness of fit), it uses a null hypothesis at the 5% significance level (Cooke 1991; Mazzuchi et al. 2007). This approach approximates a chi-squared distribution using (t-1)(t-2)/2 for degrees of freedom.

$$F = 2\{\sum_{i=1}^{t}\sum_{j=1,j\neq i}^{t} a(i,j)\ln(R(i,j)) - \sum_{i=1,}^{t} a(i)\ln(V_i) + \sum_{i=1}^{t}\sum_{j=i+1}^{t} e\ln(V_i + V_j)\} \quad (4.6)$$

4.3. Bias Mitigation

We developed a survey to capture the ranking of attributes for three requirement areas: systems, FoS, and complex systems. We capture pairwise data from experts and performed a Bradley-Terry analysis on the pairwise data to determine the ranks and groupings of data. Because surveys can introduce biases from experts into the data collection process, they should be developed with fairness and neutrality, and produce repeatable data with quality controls while meeting research objectives (Cooke & Goossens 2004, 644). To ensure a comprehensive survey, we acknowledge six main areas of expert judgment biases for our research: availability bias, anchoring and adjusting bias, motivational bias, structural bias, heuristics bias, and inconsistency bias (Cook 1991, 64; Meyer & Booker 1991, 44; Mazzuchi 2015). The authors mitigate these biases when developing the expert judgment survey.

1. Availability Bias: The probability events, data, and actions are estimated by the ease with which these instances can be recalled by the experts (Cooke 1991, 64). In addition, availability bias can arise with the ease or difficulty of retrieving events from long term memory (Meyer & Booker 1991, 138). For instance a familiar or tragic event is easier to recall. Availability bias can occur when an expert does not receive information, scenarios, or events and thereby has a less of a chance of triggering the recall of less accessible memories.

Mitigation: Definitions of requirements, systems, FoS, complex systems as well as their associated requirement attributes are defined and provided in each section of the survey, thereby eliminating the expert's need to recall or assume a definition. Providing definitions accommodates a consistent level of knowledge of definitions for experts to respond to the survey.

2. Anchoring and Adjusting Bias: An expert fixes on an initial value, the anchor, and then adjusts and corrects the value based on a specific event in question (Cooke, 1991, 64). Anchoring occurs when a person's experience influences an initial value or anchor, and then does not adjust from their first impression. An anchor bias can also occur if a person has a previous written or oral position on a topic and thereby remains loyal to that position (Meyer & Booker 1991, 138)

Mitigation: This survey does not require any initial values be given for term definitions or events. In addition, no examples of systems, FoS, complex systems or attributes are provided. No numerical examples are provided in the survey. Anchoring and adjusting are mitigated.

3. Motivational Bias: Experts who report probabilities, forecasts, or "answers that do not entirely reflect their true beliefs" (Mazzuchi 2015). In addition, some experts will answer against their true beliefs if their answers are known to the public. Furthermore, an expert could select a view to best serve their responses or an attempt by the person being surveyed to consciously or unconsciously accommodate the interviewer or survey intent (Meyer & Booker 1991, 40 & 50).

Mitigation: The survey responses are anonymous and there is not an interviewer for an expert to attempt to accommodate during data collection. There are no stated positions, forecasts, or probabilities given in the survey. There is no connection between the experts as individuals and their data which allows experts to answer without fear of being specifically identified in the data analysis. Anonymity is provided. Anonymity of survey participants is required by The George Washington Office of Human Research.

4. Structural Bias: The level of detail or choice of scales for quantification for experts cannot be obtained or the surveyed individual does not understand the numerical scale of a potential answer (Mazzuchi 2015). An example could be asking for an individual response to a question and the response is either magnitudes too high or too low to the actual scale of the problem.

Mitigation: The survey is a Bradley-Terry pairwise comparison between attributes. Therefore, the only options for the experts being surveyed are a 1 or 0, or which of two attributes has more internal value to the expert, attribute A or attribute B. This approach eliminates structural bias.

5. Heuristics Bias: Typically experts do not perform mental calculations but rely on rules of thumb to assist them to make better estimates (Cooke 1991, 63). This is a broad category in which, experts can learn to improve their skills at assessing probabilities or providing predictable biases.

Mitigation: This survey used a broad range of experts from industry, academia, and government. There are no questions that are system or program specific which avoids any direct, specific, or relevant knowledge that requires any mental probability calculations,

thereby mitigating heuristic biases. In addition, by using a broad range of experts with varying backgrounds, heuristic predictability biases regarding a single system or program response are mitigated across the experts.

6. Inconsistency Bias: Typically the human mind is limited in memory capacity and "cannot discriminate between more than seven things at a time" (Meyer & Booker, 1991, 44). Most individuals have a difficult time remembering or processing over seven items at a time. The higher the number of items an individual has to remember, the more inconsistently they are answer questions or solve problems.

Mitigation: The expert judgment survey was designed around and limited to a maximum number of items, or requirement attributes, of seven plus or minus two for experts to remember and perform the requisite pairwise comparisons. For systems and FoS the number of requirement attributes are nine and for complex systems it is seven. The number of items for comparisons in this survey are seven and nine requirement attributes, for complex systems, and systems and FoS respectively, which mitigates inconsistency bias.

4.4. Survey Design

The survey contains four sections to elicit impartial and repeatable expert judgment using pairwise comparisons of requirement attributes for systems, FoS, and complex systems. The full survey is located in Appendix B and is used to capture the data from the expert panel. Section 1 captures the demographics of the participant, and it includes 15 data fields plus one data field for open comments. For example, the survey asks the experts for total years of experience, detailed experience, and education level. Section 2 captures the

systems requirement attributes for Bradley-Terry pairwise comparisons. Section 2 was fixed after the demographics section to provide the pairwise comparisons for simple systems attributes prior to the attributes for higher order systems. In addition to providing definitions of terms and the nine requirement attributes, as shown in Table 3-1, a sequence randomizer for each survey orders the pairwise comparisons. Thus, a total of 37 data fields are presented to the experts. Within these parameters, we collect data from 36 fields for system attributes in pairwise comparisons and one field for open comments. Appendix C shows the data on sequence randomization for all surveys and sections.

To order the next two sections, a sequence randomizer for each survey is employed. One section captures the Bradley-Terry pairwise comparisons for FoS requirement attributes. This section encompasses the definition of terms and the nine requirement attributes, as shown in Table 3-1. Similar to the system section, a total of 37 data fields are presented with 36 fields for the pairwise comparisons of FoS requirement attributes and one field for open comments. For each survey a sequence randomizer is used to order the 36 pairs. The next section captures the complex external systems requirement attributes using Bradley-Terry pairwise comparisons. The definition of terms and the seven requirement attributes, as shown in Table 3-2, are provided, and for each survey a sequence randomizer is used to order the pairwise comparisons. For this analysis a total of 22 fields are presented with 21 fields for the pairwise comparisons of complex systems external attributes and one field for open comments. Overall, the survey participants provide data for a total of 112 data fields which allows us to collect pairwise data, demographics, and open comments.

The survey was approved by The George Washington University prior to submitting it to the panel of acquisition and engineering experts. After the draft survey was completed and reviewed by advisors, the survey and all required documentation were submitted to the Institutional Review Board (IRB) at the Office of Human Research for University approval (See Appendix A). The survey consent form and approval memorandum from The George Washington University Office of Human Research are located in Appendix A. The study number for this research is 041525, and it was approved on April 16, 2015. The survey exemption was granted under Regulatory Category 2 and was approved to proceed without further oversight by the Office of Human Research. Regulation Category 2 is defined as: "Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless:

> *The information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects, and*
> *any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.*
> ***This category may not be applied to children, except in the observation of public behavior"*** (GWU IRB 2014).

4.5. Survey Participants

Survey participants were selected for their backgrounds in acquisition, academia, operations, and logistics. Each expert, except one, met the minimum threshold of 25 years each of experience and training in their respective fields to qualify as an expert in this study. To insure that the experts have the experience, perspective, and knowledge to be accepted as an expert by the community at large and to validate the requirement attributes, 25 years was selected as the expert benchmark as well as being in a senior leadership position within their organization. A total of 40 experts were selected by the authors as survey participants from industry and government.

4.6. Delivery Mechanism

A package consisting of two electronic files was emailed to each expert at their place of work. Each expert received an Information/Consent Sheet about the research study that provided contact information on the Principal Investigator and Principal Contact, and background information on being a survey participant. The second file was the expert judgment survey, which was a Microsoft Word file. After the survey was completed, it was sent to the Principal Contact's university email account. Once received, the surveys were saved and password protected. Participation in this research is anonymous with no association between an individual expert's identity and their respective data.

Chapter 5: Analysis

The data from 28 experts are the basis for the analysis for systems, family of systems (FoS), and complex systems. Data from pairwise requirement attributes and demographics are used for the analysis for all experts and a more in-depth analysis with government and industry experts. Sensitivity analysis is used to cross compare and validate principal data to ensure a complete analysis of the data.

5.1. Participant Demographic Data

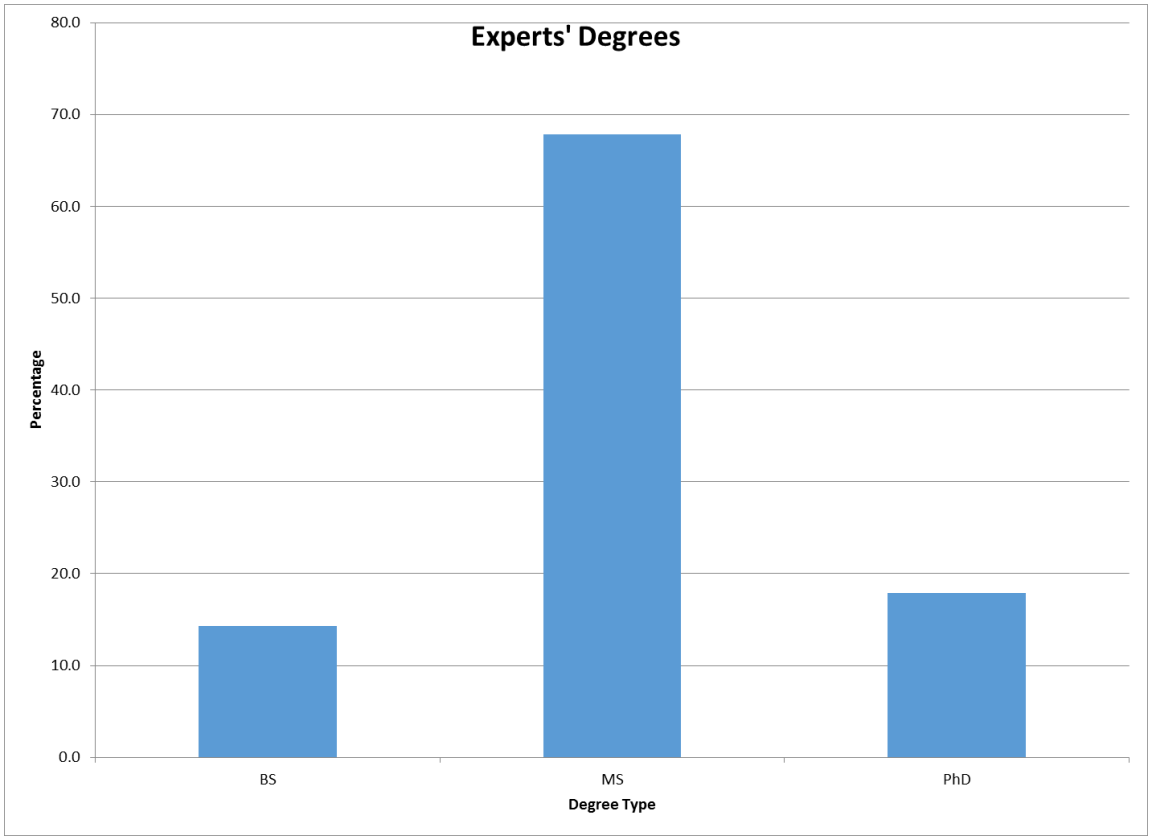
Of the 40 surveys we sent to experts electronically, 28 (70%) were returned. This response exceeds the minimum set of 10 experts required for the analysis for this research. We follow the guide for psychological scaling as detailed by Roger Cooke (1991). Cooke states "Psychological scaling models (Thurstone and Bradley-Terry) require a large number of experts, on the order of 10" to be effective for numerical analysis (Cooke 1991, 184). Of the experts responding, the average experience level is 34.2 years. All survey participants, except one, exceed the required experience level of 25 years. One expert did not meet the experience requirement of 25 years, but did meet the requirement of being in a senior leadership position within the government as a Senior Executive Service. These experience demographics are shown in Table 5-1. The industry participant seniority levels range from the Executive Director, or equivalent levels, to President and Chief Executive Officer. For government participants, the seniority levels are at the Flag Rank to include Admirals, Port Directors, and Border Patrol Chiefs, and the Senior Executive Service levels range from Executive Director, Director, and Assistant Commissioner. Government participants and

industry participants each comprise 50% of the respondents. Of the survey participants, 14% hold Bachelor Degrees, 68% hold Masters Degrees, and 18% hold Doctorate Degrees as shown in Table 5.2.

Table 5-1 Experts' Experience (Years)

	Average	Minimum	Maximum
Overall	34.2	13	48
Subcategories			
Program Management	9.8	3	30
Systems Engineering / Requirements	10.8	1	36
Operations	7.7	2	26
Logistics	6.1	1	15
Academic	6.7	1	27
Test and Evaluation	19.5	10	36
Science & Technology	8.3	4	15
Aerospace Marketing	4.0	4	4
Software Development	10.0	10	10
Congressional Staff	5.0	5	5
Contracting	13.0	13	13
System Concepts	8.0	8	8
Policy	4.0	4	4
Resource Allocation	3.0	3	3
Quality Assurance	3.0	3	3

Table 5-2 Experts' Level of Education (Percentage)



Participants show a diverse grouping of backgrounds. Within the government participants' group, they represent multiple organizations within the Department of Defense, multiple organizations within the Department of Homeland Security, National Aeronautics and Space Administration, and Federally Funded Research and Development Centers (FFRDC). Within the industry participants' group, they represent aerospace, energy, information technology, security, and defense sectors and have experience in production, congressional staff, and small entrepreneurial product companies. We do not note any inconsistences within the demographic data as shown in Table 5-3. Thus, the demographic data verifies a senior, experienced, and well-educated set of surveyed experts.

Table 5-3 Experts' Demographics

Industry			Government	
Position	Company Size	Sector	Position	Sector
Vice President	Large	Security	Senior Executive Service	DHS/CBP
Executive Director	Large	Intelligence	Senior Executive Service	DHS/CBP & DoD/USAF
CEO	Small	DoD/Aerospace	Senior Executive Service	DHS/CBP
Founder CEO	Small	Commercial Aerospace	Chief Engineer	DoD/Navy
Executive Director	Medium	Information Technology	Senior Executive Service	DoD/OSD
Program Director	Medium	Information Technology/Defense	Senior Executive Service	DoD/OSD
Vice President	Large	Health	Senior Executive Service	DoD & DHS
Director	Large	Energy	Port Director	DoD/CBP
Director	Large	Aerospace	Director	FFRDC
Director	Medium	Security	Senior Executive Service	DHS/TSA
Senior Analyst	Small	Defense	Senior Executive Service	NASA
Vice President	Medium	Commercial	Admiral	DoD/Navy
Founder CEO	Small	Commercial	Senior Executive Service	DoD/Army
Chief Scientist	Small	Defense	Chief	DHS/CBP

5.2. Interpretation and Results

Requirement attribute data were collected for systems, FoS, and complex systems and are shown in Appendix D for all experts. When evaluating p-values, we consider data from individual experts to be independent between sections. The p-value is used to either keep or remove that expert from further analysis for the systems, FoS, and complex systems sections. As defined in Equation 4.2, we posit a null hypothesis at the 5% significance level for each expert. After removing individual experts due to failing the null hypothesis for random answers using Equation 4.2, we apply the statistic as shown in Equation 4.4 to test the hypothesis that the agreement of the group is due to chance at the 5% level of significance. A goodness of fit test of the data, as defined in Equation 4.6, is performed on each overall combined set of expert data to confirm that the Bradley-Terry model is representative for systems, FoS and complex systems. A null hypothesis is successfully used at the 5% level of significance. After completing this analysis, we capture and analyze

data for the overall set of combined experts. We perform a more in-depth analysis by dividing the experts into two subsets with backgrounds in government and industry.

5.2.1. Systems Requirement Attributes

Of the 28 experts, two experts from the government category, experts 15 and 18, and one from the industry category, expert 28, are removed for failing to reject the null hypothesis for random responses using Equation 4.2. The combined expert data and the subsets of government and industry experts with the associated 90% confidence intervals are shown in Figures 5-1 & 5-2. It shows the values of the nine requirement attributes. The more experts prefer a requirement attribute over other attributes, the more value it obtains. The value is "one seeks value such that the probability of seeing outcomes (percentage)…is as large as possible" (Cooke 1991, 218) or the "maximum likely solution" (Ford 1957, David 1963). In addition for this section for systems requirement attributes, using Equation 4.6 we successfully used a 5% null hypothesis to show that the model is appropriate.

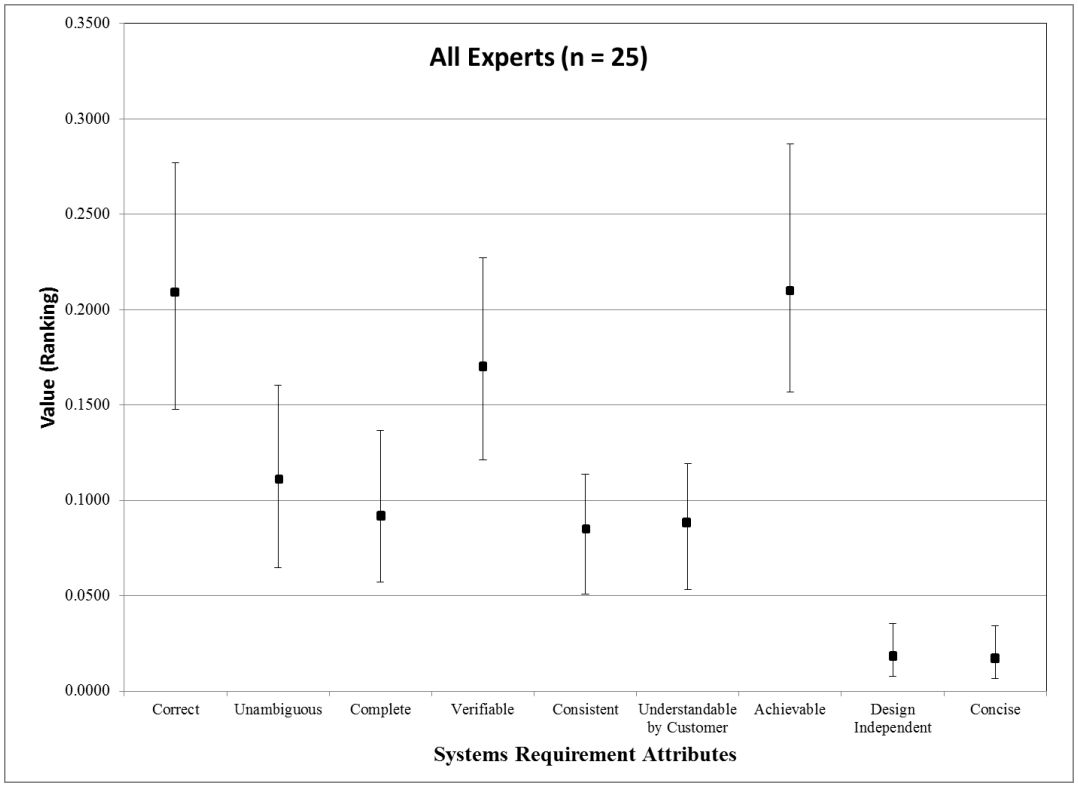


Figure 5-1 System Requirement Attribute Rankings of All Experts With 90% Confidence Intervals

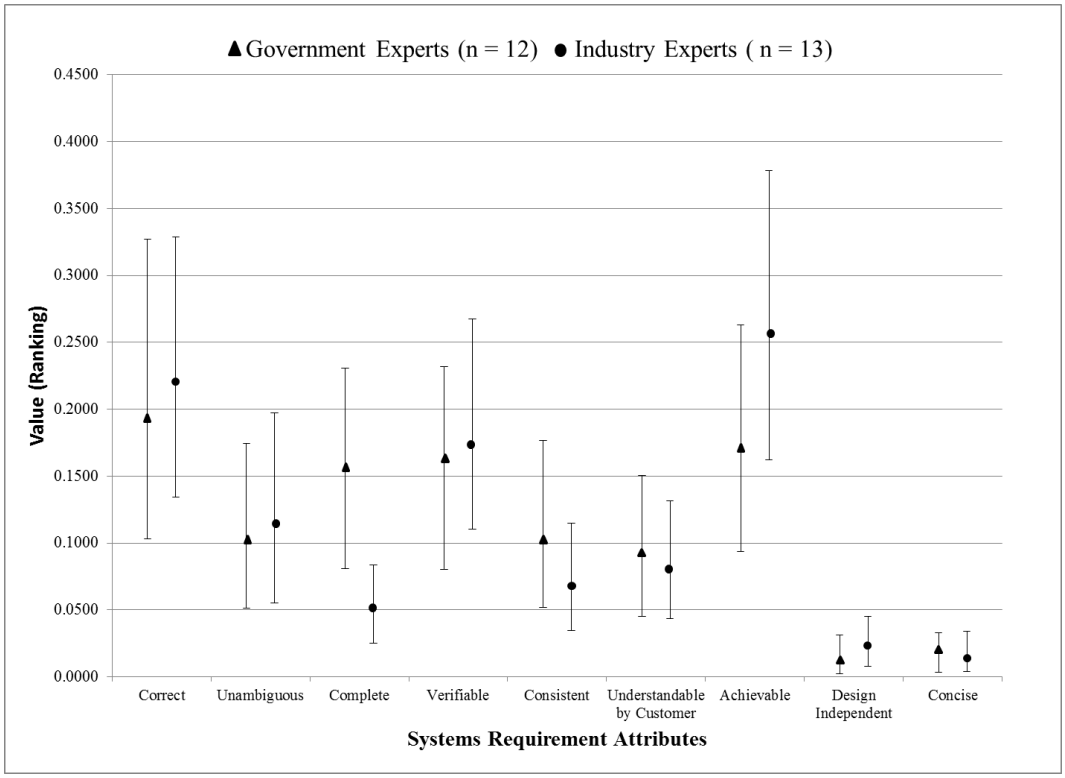


Figure 5-2 System Requirement Attribute Rankings of Government and Industry Experts With 90% Confidence Intervals

Overall, the systems requirement attribute values show the top grouping, or tier, of attributes are *achievable, correct,* and *verifiable,* and the bottom tier attributes are *design independent* and *concise*. This analysis is consistent between the government and industry subsets of experts as shown in Figure 5-2. The 90% confidence intervals of all experts and subgroups overlap which provides strength and consistency of the data. Overall, the third highest attribute is *verifiable*. This value is consistent with industry experts and government experts. The *complete* attribute shows the most difference in value between government and industry experts, but the values are within the 90% confidence intervals. Industry experts, along with the combination of all experts, show a noticeable breakout of attributes

at the 0.1500 value, which identifies the top grouping, or tier, of systems requirement attributes to be *achievable, correct,* and *verifiable.*

5.2.2. Family of Systems (FoS) Requirement Attributes

One expert from the government category, expert 18, was removed for failing to complete this section, and two experts from the industry category, experts 1 and 28, are removed for failing to reject the null hypothesis for random responses using Equation 4.2. The overall expert data along with subgroups for government and industry experts with the associated 90% confidence intervals for FoS are shown in Figures 5-3 & 5-4. This section has the strongest model goodness of fit data with a null successfully used at less than a 1% level of significance as defined in Equation 4.6.

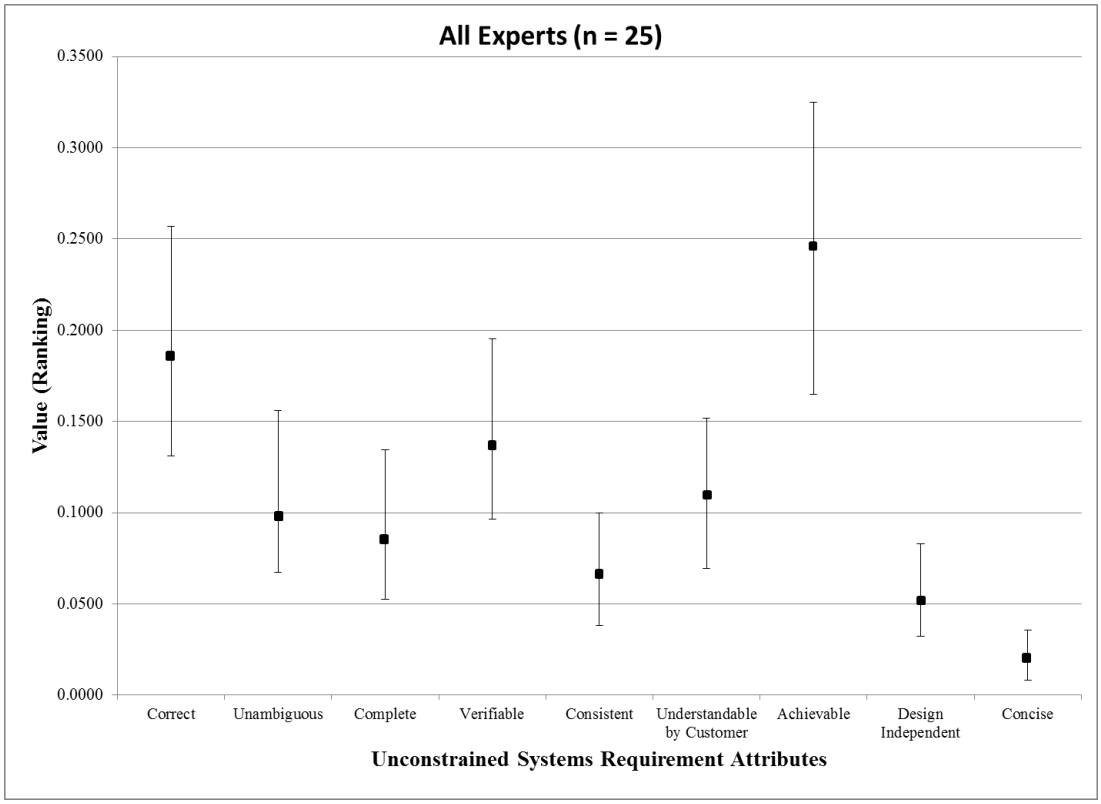


Figure 5-3 FoS Requirement Attribute Rankings for All Experts With 90% Confidence Intervals

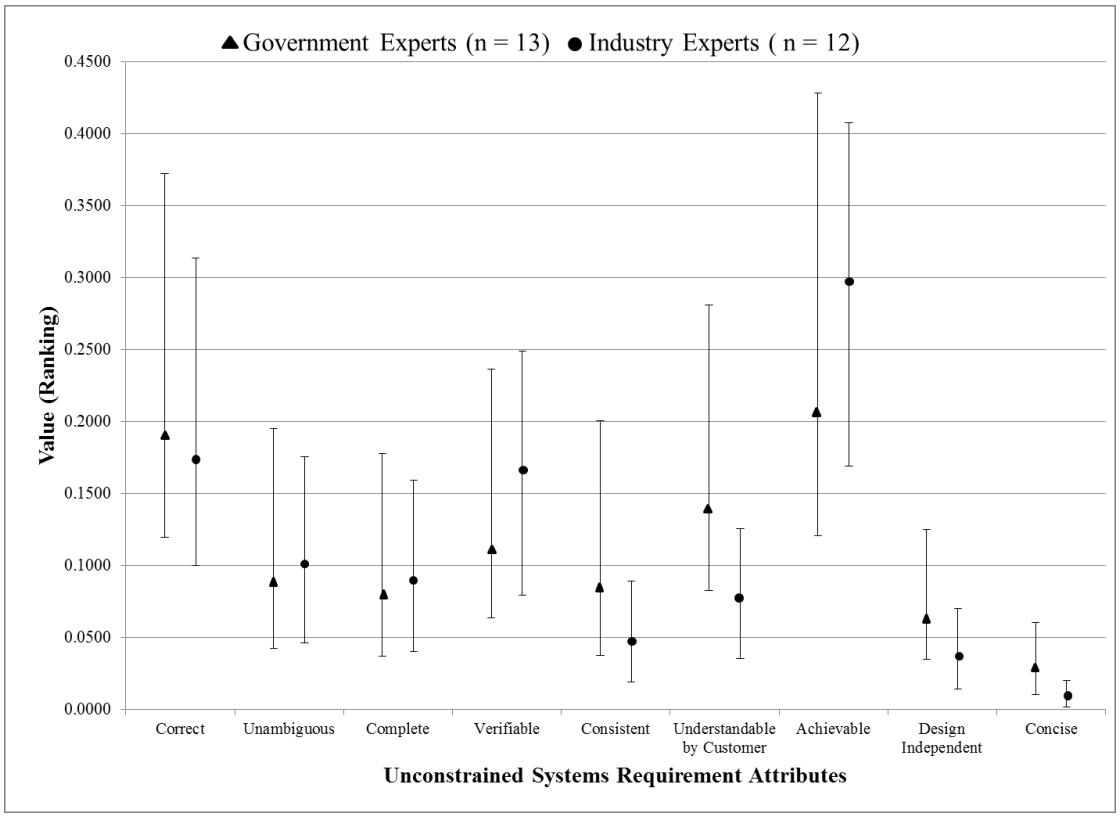


Figure 5-4 FoS Requirement Attribute Rankings of Government and Industry Experts With 90% Confidence Intervals

As indicated in Figure 5-3, the overall top tier requirement attributes are *achievable* and *correct*. This data tracks with the government and industry expert subgroups in Figure 5-4. The 90% confidence intervals of all experts and subgroups overlap which strengthens the validity and consistency of attribute groupings between all experts and subgroups. The bottom two attributes are *design independent* and *concise* and are consistent across all experts, and government and industry expert subsets. The middle six attributes *unambiguous, complete, verifiable, consistent,* and *understandable by the customer* are closely grouped together across all experts, and industry and government expert

subcategories. Overall, the top two requirement attributes by all experts as well as for industry and government experts remains *achievable* with a value of 0.2460 and *correct* with a value of 0.1862. There is a break in attribute values at the 0.1500 level.

5.2.3. Complex Systems Requirement Attributes

In this section, one expert is removed from the government category, expert 12, for failing to complete this section, and two experts are removed from the industry category, experts 1 and 28, for failing to reject the null hypothesis for random responses using Equation 4.2. The combined expert data and the subsets of government and industry experts with the associated 90% confidence intervals are shown in Figures 5-5 & 5-6 and provide the values of the seven attributes. In addition, using Equation 4.6 we successfully used a 5% null hypothesis to show that the model is appropriate.

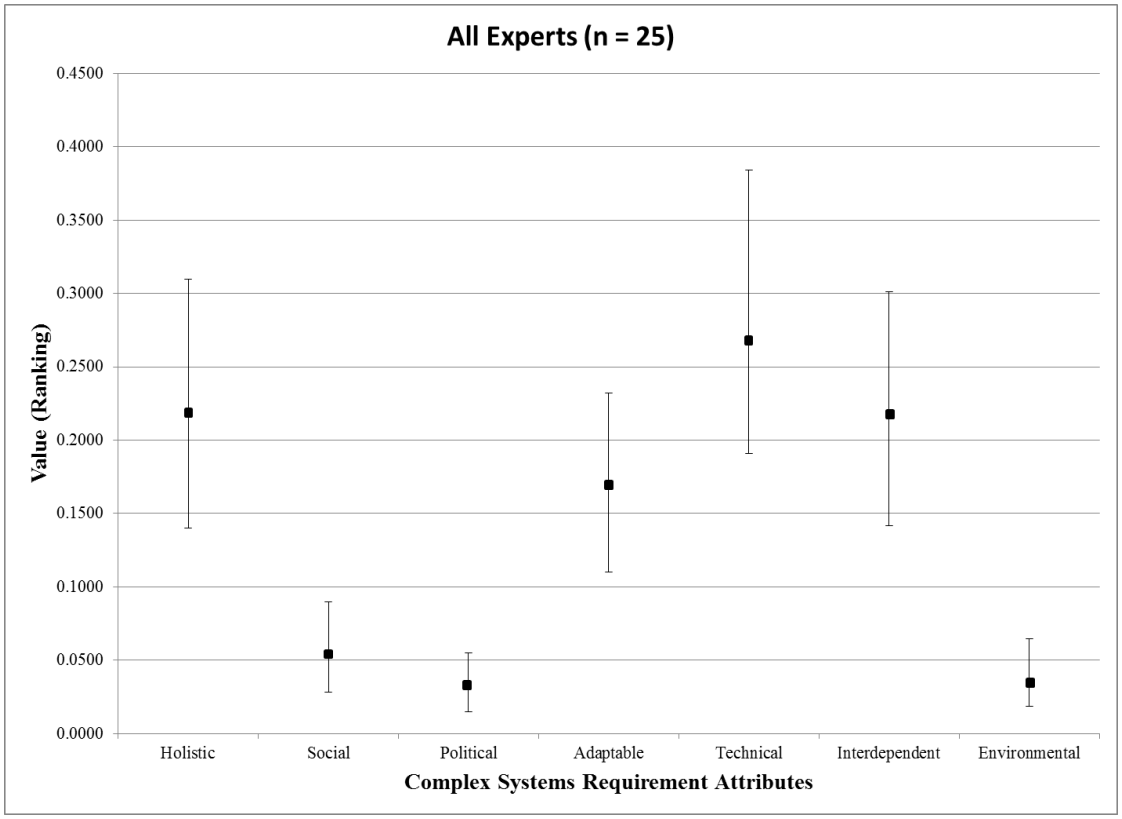


Figure 5-5 Complex Systems External Requirement Attribute Rankings for All Experts With 90% Confidence Intervals

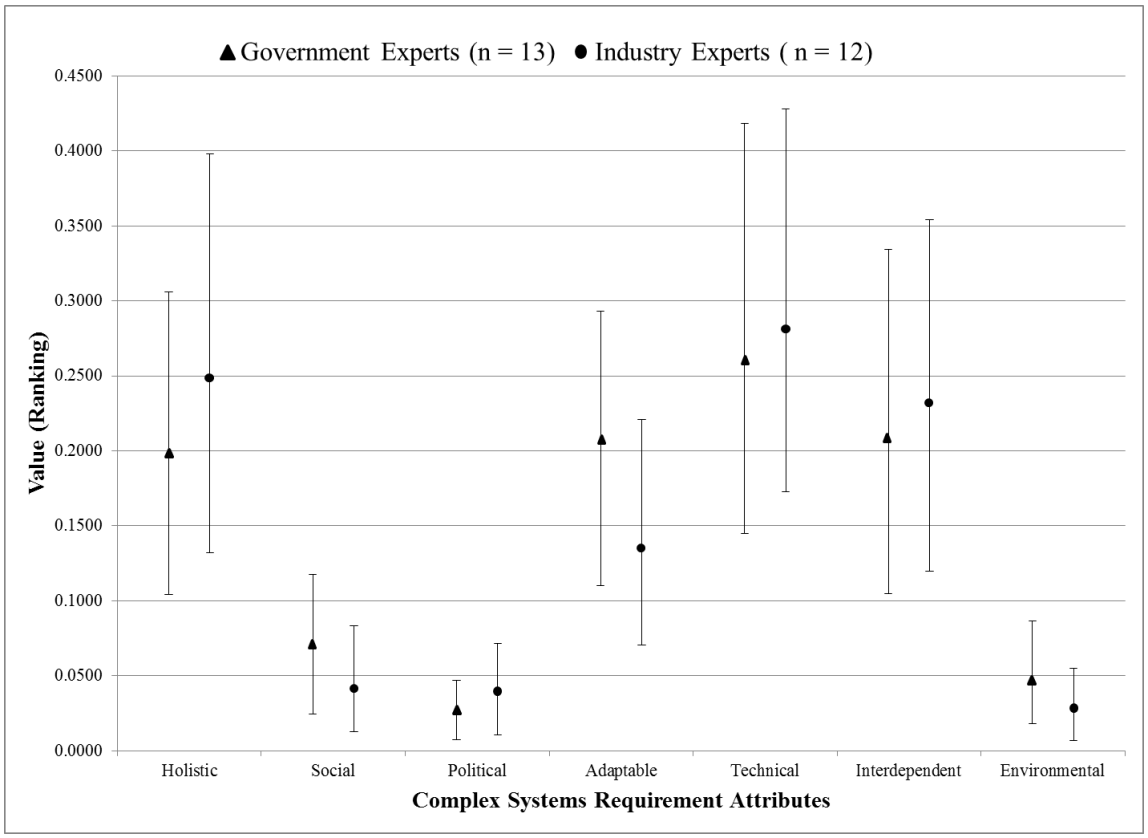


Figure 5-6 Complex Systems External Requirement Attributes for Government and Industry Experts With 90% Confidence Intervals

Complex systems have both an internal and external focus as posited in Sections 2.3 and 3.3. For this research, we use the data for systems as shown in section 5.2.1 for the internal complex requirement attributes. For the external requirement attributes, we use the data as presented in this section. Together internal and external requirement attributes provide a complementary set of complex systems attributes.

The 90% confidence intervals of all experts and subgroups overlap, confirming the consistency of the data and strengthening the validity of all rankings between expert groups. Data analysis, as shown in Figure 5-5, show a group of four top requirement

attributes for complex systems: *technical*, *interdependent*, *holistic*, and *adaptable*. These top four attributes track with the subsets of government and industry experts, as shown in Figure 5-6. Government and industry experts value *technical* as their top attribute and it is consistent with all experts. A significant difference exists in the values between the top and the bottom groupings of attributes. The bottom three attributes, consistent across all experts, as well as government and industry experts, are *political*, *environmental*, and *social*.

5.2.4. Data Conclusions

The data from Figures 5-1 to 5-6 show consistent agreement between government, industry, and all experts. Figure 5-7 shows the combined values with a 90% confidence interval for all 25 experts across systems, FoS, and complex systems. Between systems and FoS, the experts' rankings are similar, though the values differ. The *achievable* attribute for systems and FoS has the highest value in the top tier of attribute groups. Our literature research revealed this specific attribute was found to be critical and it was added to an initial set of core attributes (INCOSE 2011, 77; ISO/IEC/IEEE 2011 12). Moreover, experts additionally validate this result in the survey open response sections. Experts state, "Achievability is the top priority," and "You ultimately have to achieve the system so that you have something to verify."

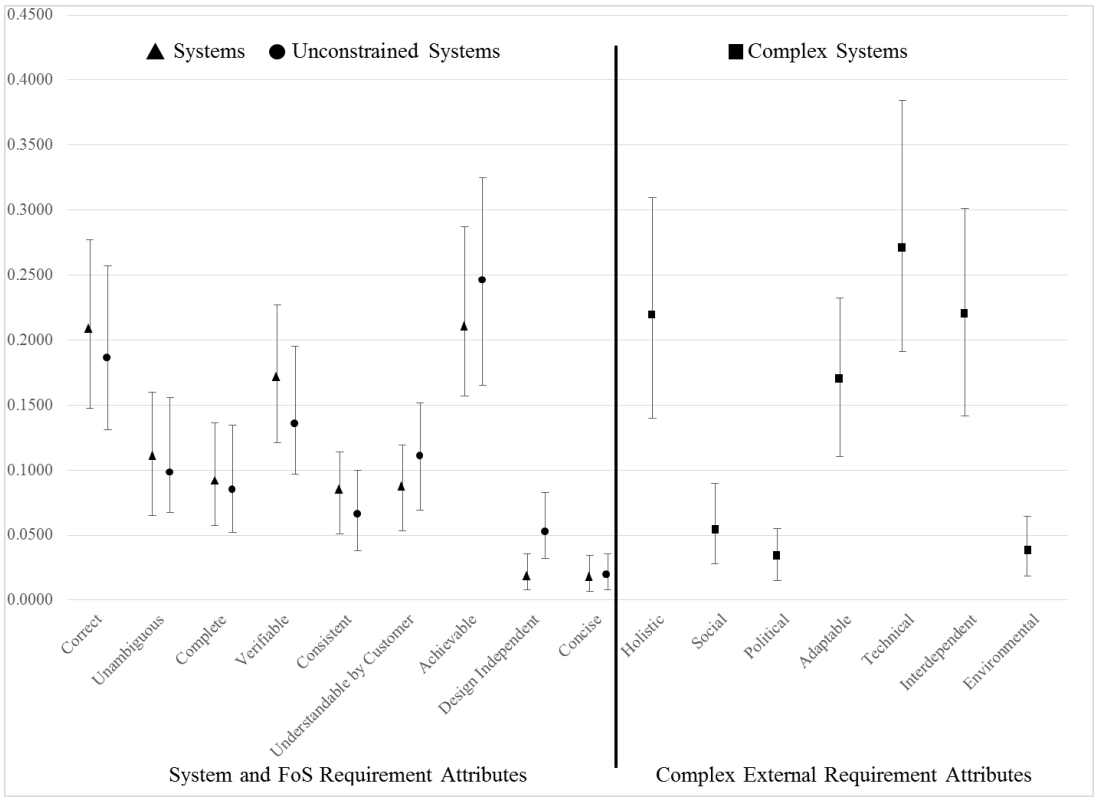


Figure 5-7 Comparison of Requirement Attributes Across Systems, FoS, and Complex Systems with 90% Confidence Intervals

While many factors influence requirements and programs, this data show the ability of management and engineering to plan, execute, and make programs achievable within their cost and schedule lifecycle, a top priority regardless of whether they are simple, FoS, or complex systems. Our research, as described in sections 2.3 and 3.3, posits for an encompassing set of requirement attributes for complex systems one must combine the internal attributes from 'systems' and the external requirement attributes for complex systems.

For complex systems external requirement attributes, experts clearly value *technical, interdependent, holistic* and *adaptable* as their top priorities. An expert indicated, "I emphasize 'interdependent' as very important because of the need to understand the interrelatedness of complex systems when developing systems." These four external requirement attributes are critical emphasis areas for program managers, engineers, and requirement developers to consider when generating requirements for complex systems with multiple and intricate external interfaces. Finally, across all systems types these validated requirement attributes provide emphasis areas to focus on when developing a complete and accurate list of requirements.

5.3. Model Sensitivity Analysis

The Unibalance-11 software has been utilized for Bradley-Terry research projects using pairwise comparisons (Macutkiewicz 2006). While the software is mature, the assumptions, items, and analysis interpretation which support this model are subject to uncertainty. Studies indicate that when parameters are uncertain, sensitivity analysis can quantify "…how robust the optimal solution is in the face of different parameter values, under what circumstances the optimal solution would change, and how the optimal solution changes in different circumstances" (Pannell 1997, 141). For this research the two major parameters or groups we analyzed are industry and government experts that combine for an overall analysis of all experts. To confirm the robustness of our analysis and to support a cross validation of the primary results of all experts, we also analyzed the data based on an expert's self-assessment of their requirements experience, and their public briefings and

public papers or journal articles experience. The "…objective is to enhance the validity of the model and minimize the risk taken in making decisions based on the model's output" (Shearer, Khasawheh, Zhang, Bowling & Rabadi 2010, 78). The data fields from the demographics section in the survey captured self-assessments by the experts on requirements knowledge based on a six point Likert scale, their experience with published papers, and their experience with major public briefings. Based on analyzing the data from experts using these three factors, the analysis should also validate the finding based on our overall experts' data set analysis of all 25 experts. By completing further analysis of the data it helps to validate the model's output and provide for increased confidence by requirement developers to use this data. Figure 5-8 shows the data collected from the experts' responding to the survey.

	Experts Self Reporting								
	Briefs & Papers Experience			Requirements Experience					
	Number of Briefs	Number of Papers		1 No Experience	2 Low Experience	3 Somewhat Experienced	4 Experienced	5 Very Experienced	6 Highly Experienced
Count	26	24		0	0	6	10	7	5
Ave	104.1	18.9							
Std Dev	171.4	64.4							
Max	750	320							
Min	1	0							

Figure 5-8 Sensitivity Analysis Data

Data on self-reported briefings accomplished are divided into a high category, 100 or more career briefs given to major public audiences, and a low category, under 100 briefs given. Data on self-reported published papers in public journals and magazines are also divided into high and low categories. The high category is defined at 5 or more papers, with the low category being less than five published papers. Experts replied with their self-assessment on the requirements knowledge. The data are 21.4% Somewhat Experienced (level-3), 35.7% Experienced (level-4), 25.0% Very Experienced (level-5), and 17.9% Highly Experienced (level-6). None of the experts replied with No Experience (1) or Low

Experience (2). Based on the responses, a high experience category is defined as the top two levels of very experienced (level-5) and highly experienced (level-6), and a low experience category that contained somewhat (level-3) and experienced (level-4) categories, are created.

Overall, six sensitivity analysis data sets are run for each of the three requirement attribute categories of systems, FoS, and complex systems for a total of 18. The results of the 18 sensitivity runs are shown in Figures 5-9 to 5-26. The sensitivity runs remain consistent across all categories when compared to the primary data. The high and low groups of requirement attributes are consistent with the primary model data for all experts. As with the primary model data, the values of the attributes in the middle grouping of attributes do vary; however, the relative range of values is consistent with the primary models. The sensitivity analysis supports a cross validation of the models' goodness.

The sensitivity analysis is shown in Figures 5-9 to 5-14 for the systems category. The results are shown below in Table 5-4 and it supports a consistent result with the overall primary data. The only area that does not directly correlate with the primary data as well as the other five sensitivity analysis categories is 'Experts Self Reporting Low Number of Briefs presented in Public.' This sensitivity category shows an extra attribute of *unambiguous*. However, overall, data show a consistent set of top requirement attributes.

Table 5-4 Sensitivity Analysis Results for Systems Data

Analysis Category	Top Attributes
Overall Primary Data of All Experts (n=25)	Achievable, Correct, Verifiable
Experts Self Reporting High Requirements Experience (n=12)	Achievable, Correct, Verifiable
Experts Self Reporting Low Requirements Experience (n=13)	Achievable, Correct, Verifiable
Experts Self Reporting High Number of Briefs presented in Public (n=7)	Achievable, Correct, Verifiable
Experts Self Reporting Low Number of Briefs presented in Public (n=18)	Achievable, Correct, Verifiable and Unambiguous
Experts Self Reporting High Number of Papers or Articles Published (n=9)	Achievable, Correct, Verifiable
Experts Self Reporting Low Number of Papers or Articles Published (n=16)	Achievable, Correct, Verifiable

The sensitivity analysis is shown in Figures 5-15 to 5-20 for the FoS category. The results are shown below in Table 5-5 and it supports a consistent result with the overall primary data. There are two areas that do not directly correlate with the primary data as well as the other four sensitivity analysis categories are 'Experts Self Reporting High Requirements Experience' and 'Experts Self Reporting Number of Briefs presented in Public.' These two sensitivity categories show an extra attribute of *verifiable*. From the overall primary data of all experts in Figure 5-3, of the remaining seven attributes below the top grouping of *achievable* and *correct* attributes, the attribute with the highest value is *verifiable*. This data show consistent attribute sensitivity analysis.

Table 5-5 Sensitivity Analysis Results for FoS Data

Analysis Category	Top Attributes
Overall Primary Data of All Experts (n=25)	Achievable, Correct
Experts Self Reporting High Requirements Experience (n=12)	Achievable, Correct, Verifiable
Experts Self Reporting Low Requirements Experience (n=13)	Achievable, Correct,
Experts Self Reporting High Number of Briefs presented in Public (n=8)	Achievable, Correct, Verifiable
Experts Self Reporting Low Number of Briefs presented in Public (n=17)	Achievable, Correct
Experts Self Reporting High Number of Papers or Articles Published (n=9)	Achievable, Correct
Experts Self Reporting Low Number of Papers or Articles Published (n=16)	Achievable, Correct

The sensitivity analysis is shown in Figures 5-21 to 5-26 for the complex systems category. The sensitivity analysis results are shown below in Table 5-6 and it supports a consistent result with the overall primary data. All sensitivity categories correlate with the overall primary data of all experts.

Table 5-6 Sensitivity Analysis Results for Complex Systems

Analysis Category	Top Attributes
Overall Primary Data of All Experts (n=25)	Holistic, Adaptable, Technical, Interdependent
Experts Self Reporting High Requirements Experience (n=12)	Holistic, Adaptable, Technical, Interdependent
Experts Self Reporting Low Requirements Experience (n=13)	Holistic, Adaptable, Technical, Interdependent
Experts Self Reporting High Number of Briefs presented in Public (n=8)	Holistic, Adaptable, Technical, Interdependent
Experts Self Reporting Low Number of Briefs presented in Public (n=17)	Holistic, Adaptable, Technical, Interdependent
Experts Self Reporting High Number of Papers or Articles Published (n=9)	Holistic, Adaptable, Technical, Interdependent
Experts Self Reporting Low Number of Papers or Articles Published (n=16)	Holistic, Adaptable, Technical, Interdependent

Based on our sensitivity analysis using the six categories for systems, FoS, and complex systems, it supports the validity of the model's output and provides for increased confidence for requirement developers to use this data.

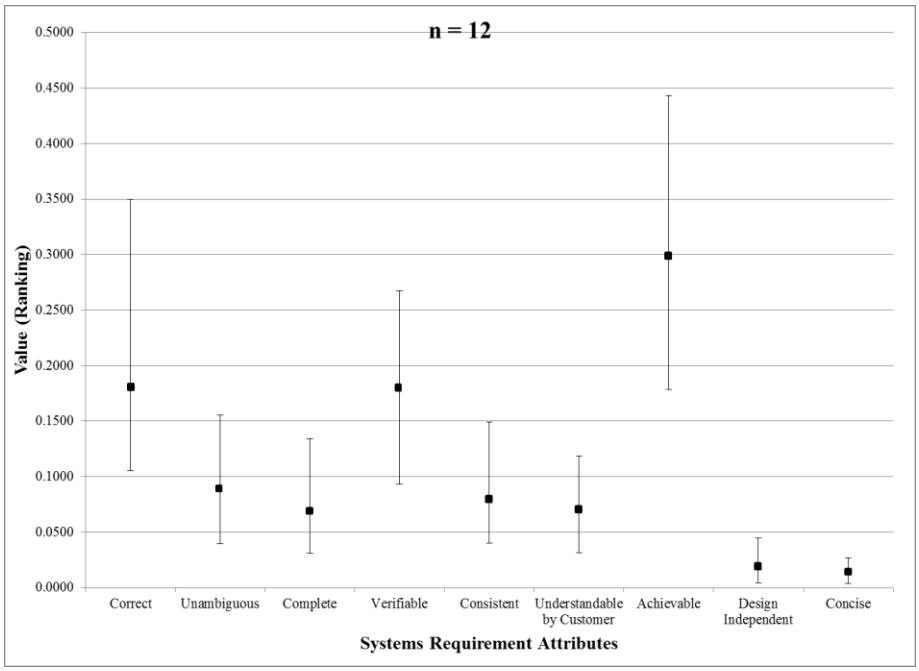


Figure 5-9 Ranking of Experts Self Reporting as Very Experienced & Highly Experienced on Requirement Attributes on Systems with 90% Confidence Intervals

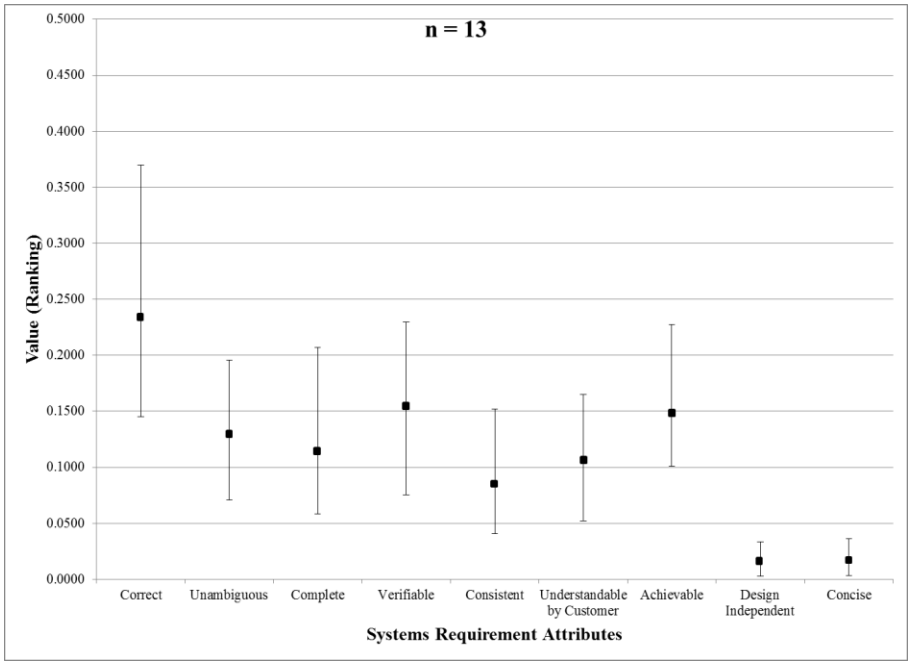


Figure 5-10 Ranking of Experts Self Reporting as Somewhat Experienced & Experienced on Requirement Attributes on Systems with 90% Confidence Intervals

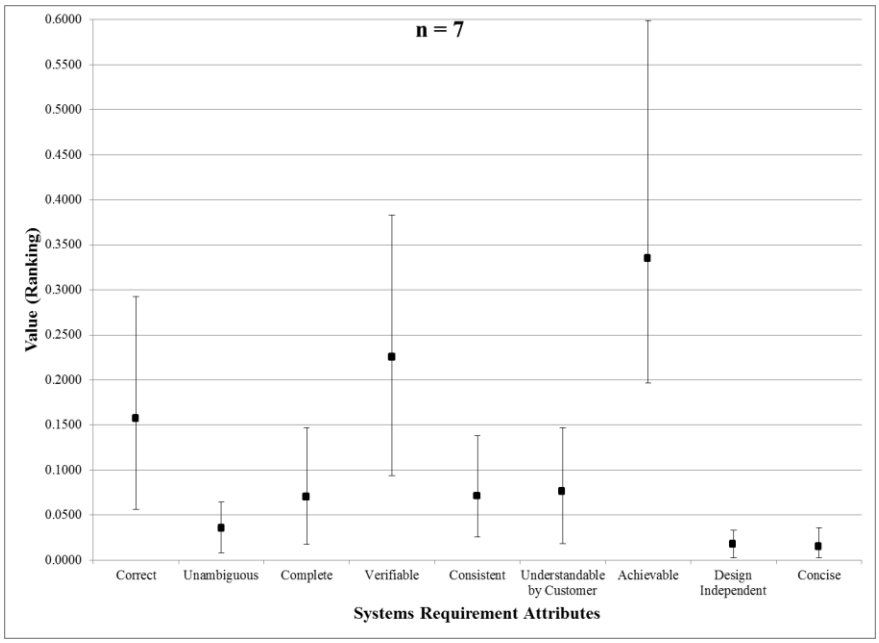


Figure 5-11 Ranking of Experts Self Reporting a High Number of Briefs (100+) Given on Requirement Attributes on Systems with 90% Confidence Intervals

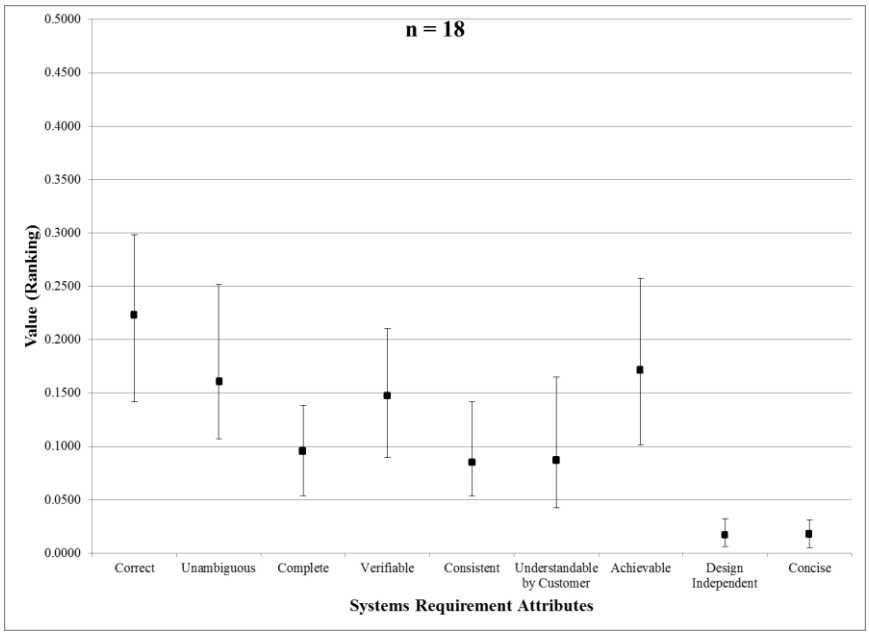


Figure 5-12 Ranking of Experts Self Reporting a Low Number (< 100) of Briefs Given on Requirement Attributes on Systems with 90% Confidence Intervals

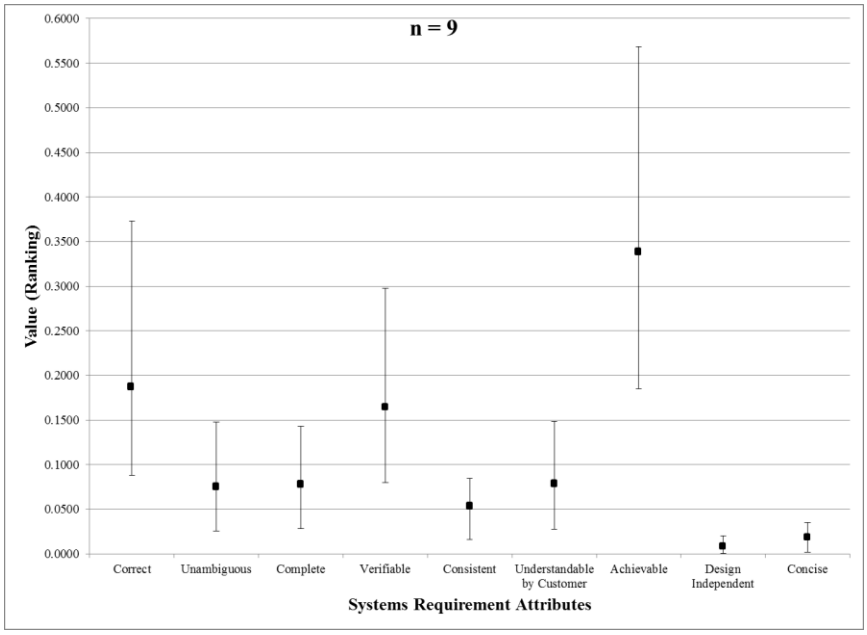


Figure 5-13 Ranking of Experts Self Reporting a High Number (5+) of Papers Published on Requirement Attributes on Systems with 90% Confidence Intervals

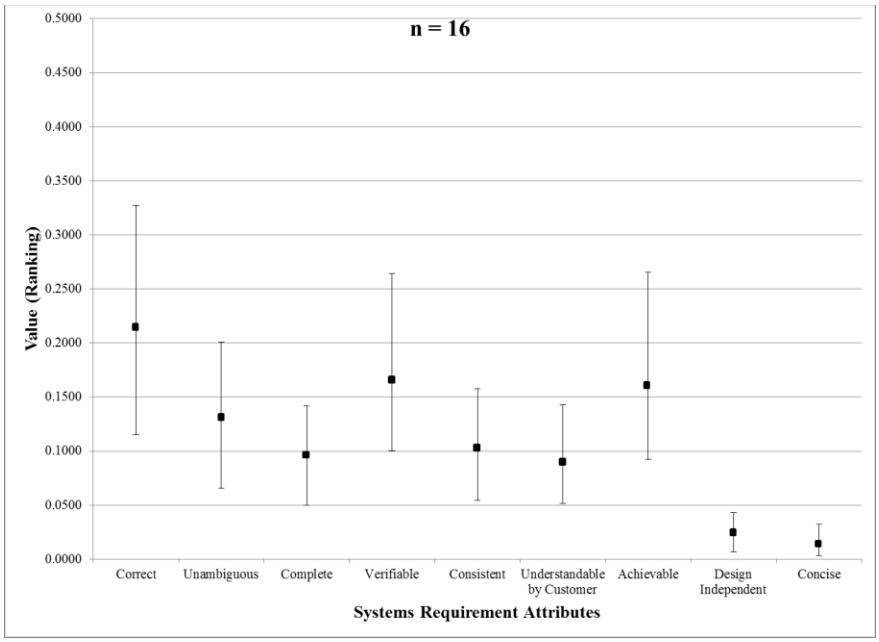


Figure 5-14 Ranking of Experts Self Reporting a Low Number (< 5) of Papers Published on Requirement Attributes on Systems with 90% Confidence Intervals

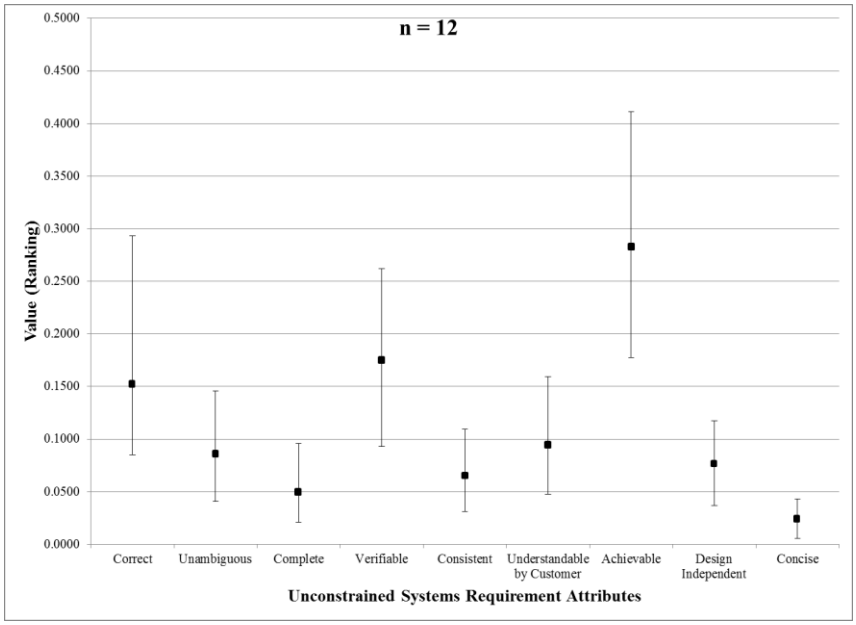


Figure 5-15 Ranking of Experts Self Reporting as Very Experienced and Highly Experienced on Requirement Attributes on FoS with 90% Confidence Intervals

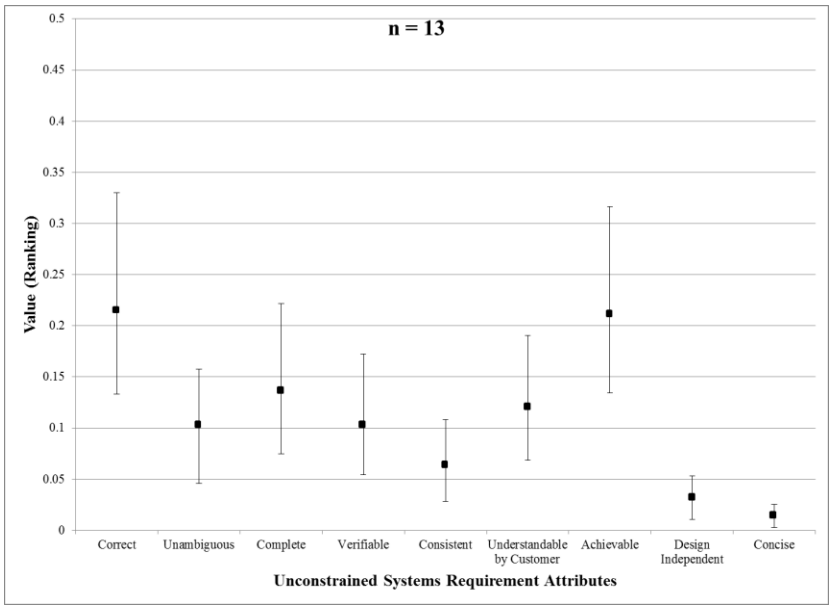


Figure 5-16 Ranking of Experts Self Reporting as Somewhat Experienced and Experienced on Requirement Attributes on FoS with 90% Confidence Intervals

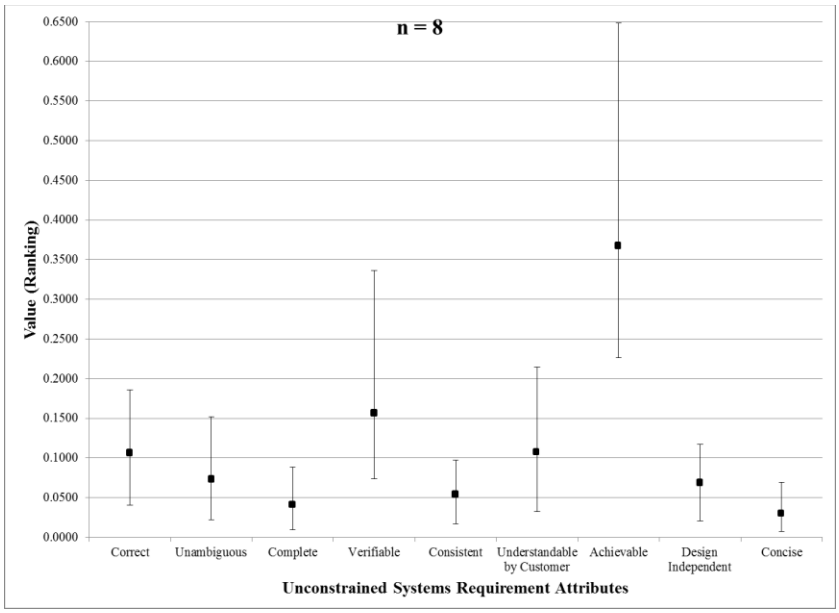


Figure 5-17 Ranking of Experts Self Reporting a High Number (100+) of Briefs Given on Requirement Attributes on FoS with 90% Confidence Intervals

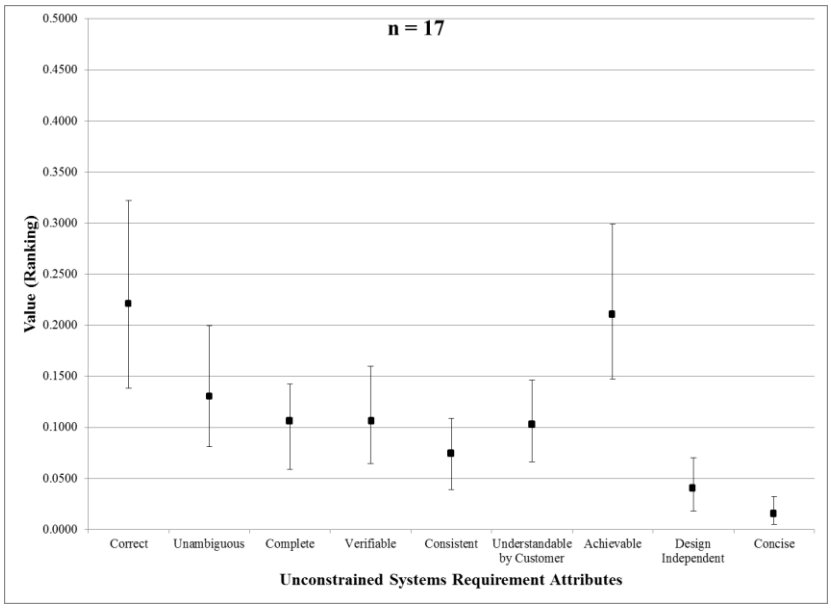


Figure 5-18 Ranking of Experts Self Reporting a Low Number (< 100) of Briefs Given on Requirement Attributes on FoS

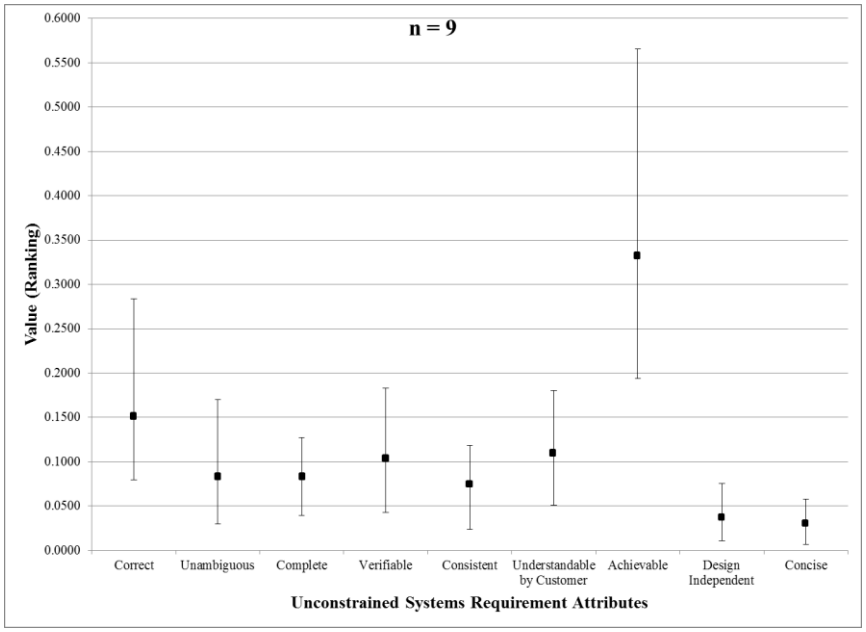


Figure 5-19 Ranking of Experts Self Reporting a High Number (5+) of Papers Published on Requirement Attributes on FoS with 90% Confidence Intervals

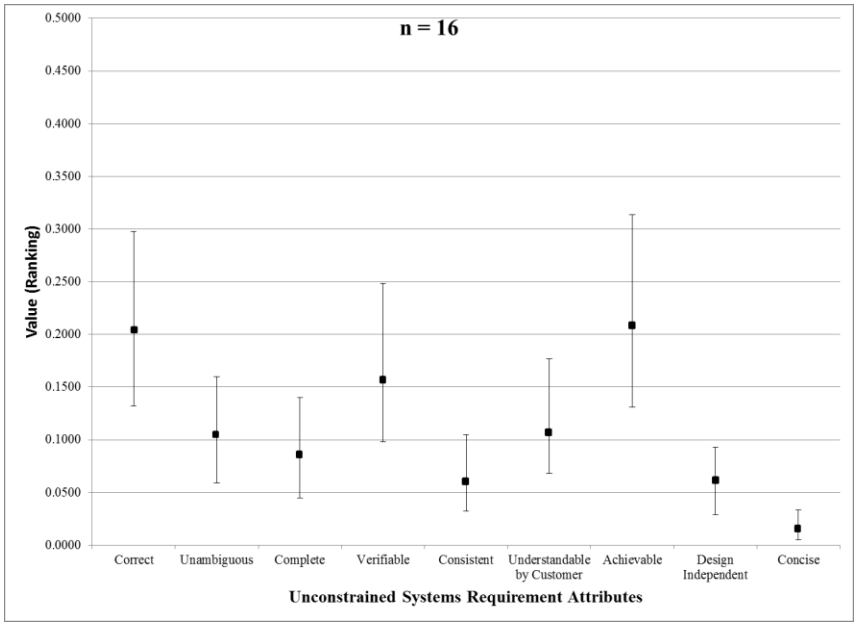


Figure 5-20 Ranking of Experts Self Reporting a Low Number (< 5) of Papers Published on Requirement Attributes on FoS with 90% Confidence Intervals

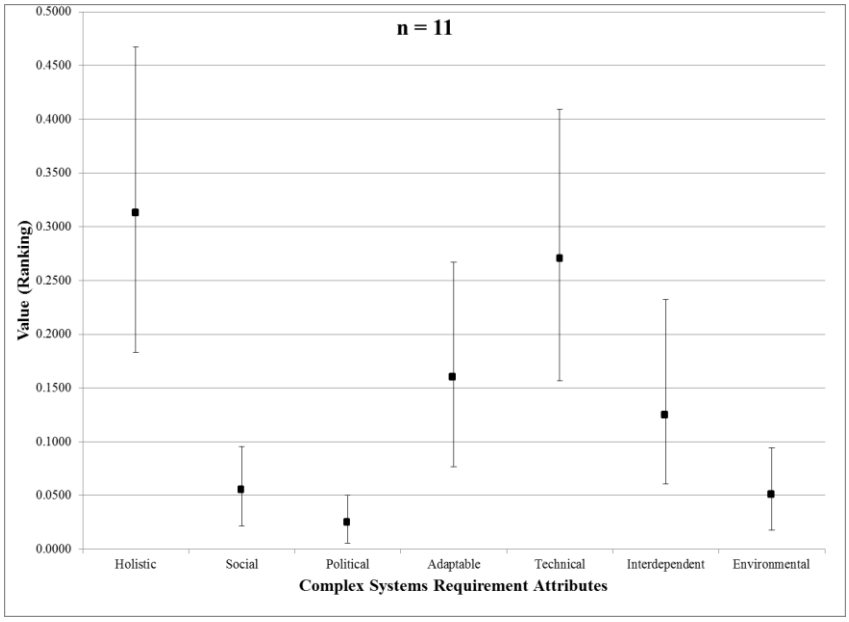


Figure 5-21 Ranking of Experts Self Reporting as Very Experienced and Highly Experienced on Requirement Attributes on Complex Systems with 90% Confidence Intervals

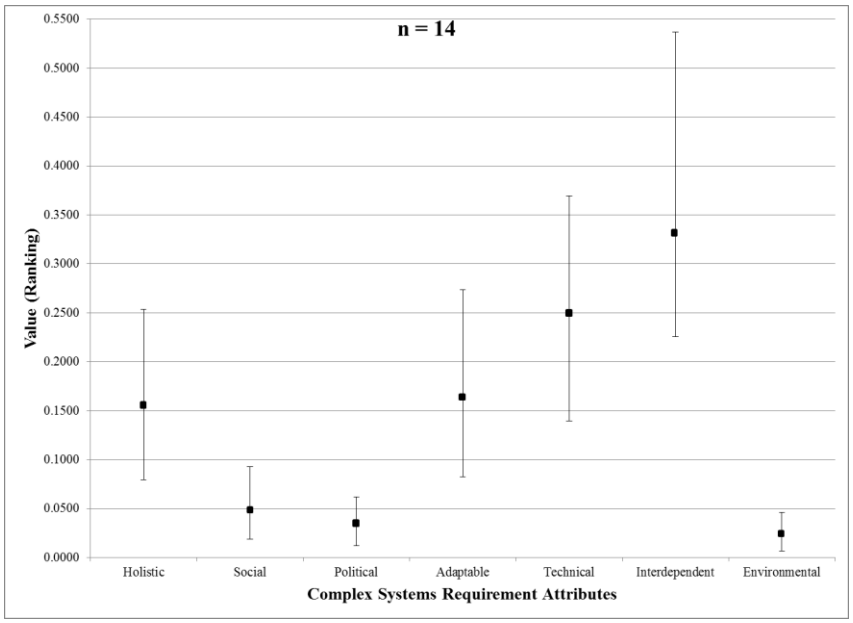


Figure 5-22 Ranking of Experts Self Reporting as Somewhat Experienced and Experienced on Requirement Attributes on Complex Systems with 90% Confidence Intervals

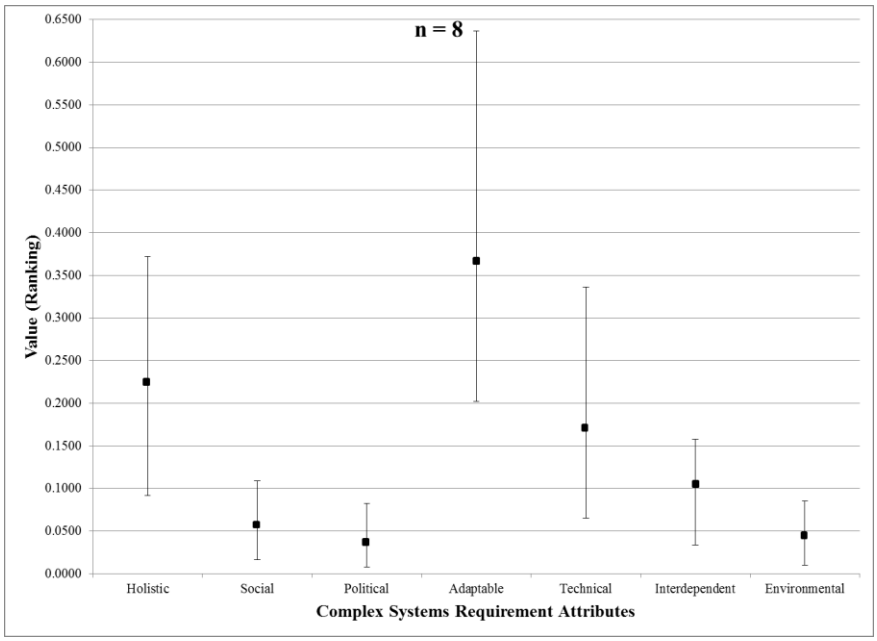


Figure 5-23 Ranking of Experts Self Reporting a High Number (100+) of Briefs Given on Requirement Attributes on Complex Systems with 90% Confidence Intervals

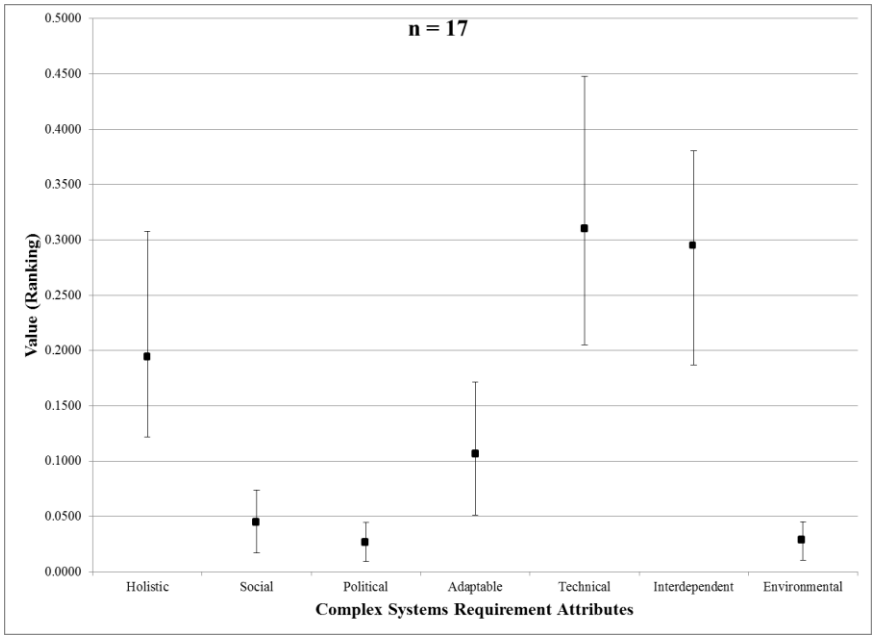


Figure 5-24 Ranking of Experts Self Reporting a Low Number (< 100) of Briefs Given on Requirement Attributes on Complex Systems with 90% Confidence Intervals

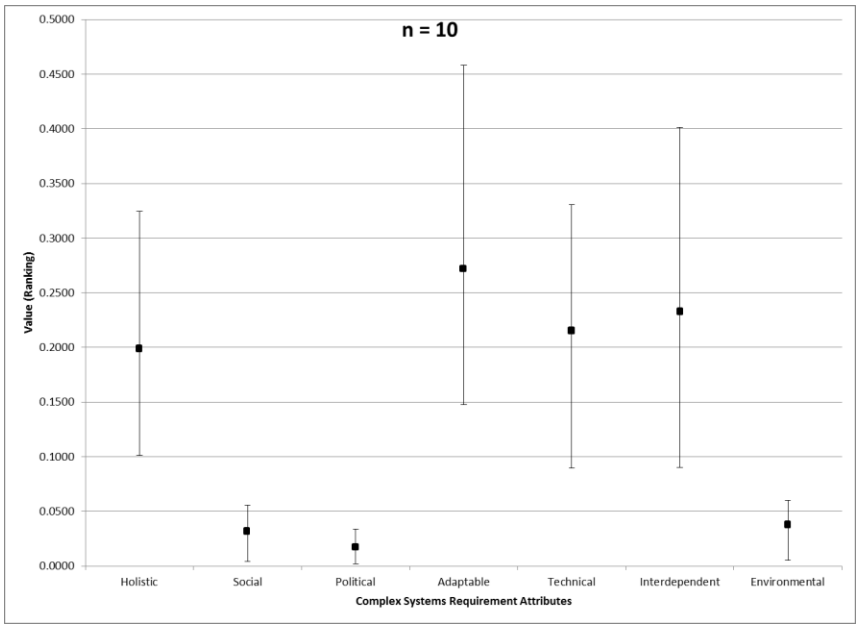


Figure 5-25 Ranking of Experts Self Reporting a High Number (5+) of Papers Published on Requirement Attributes on Complex Systems with 90% Confidence Intervals

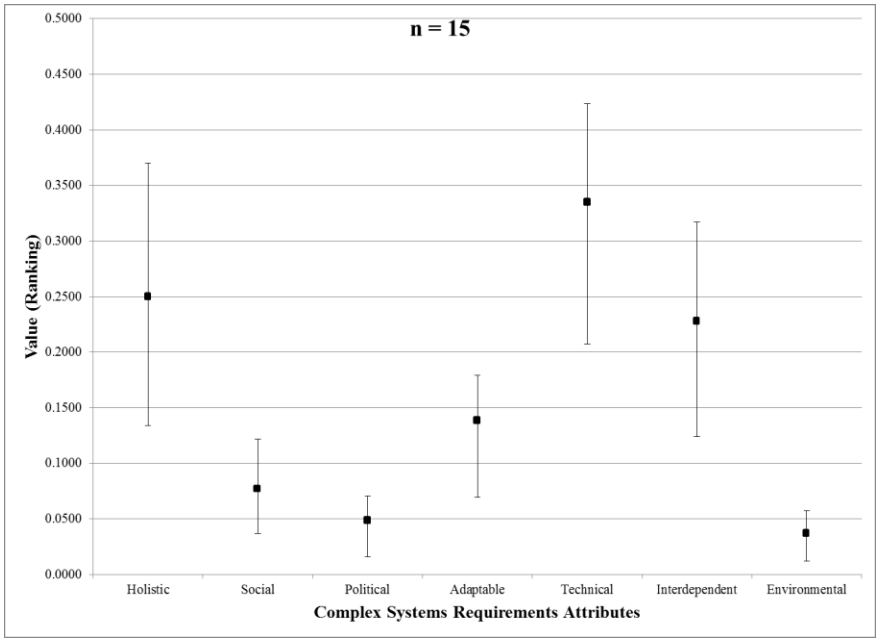


Figure 5-26 Ranking of Experts Self Reporting a Low Number (< 5) of Papers Published on Requirement Attributes on Complex Systems with 90% Confidence Intervals

Chapter 6: Conclusions and Future Work

Programs are becoming more and more global, intricate, and integrated which challenge the acquisition community to capture complex systems and family of systems (FoS) requirements upfront to enable program success. This study examined previous requirement attribute research and expanded approaches for the acquisition community to consider for an important suite of requirement attributes. Our research captured a broad range of definitions for key requirement development terms, refined the definitions for clarity, and subsequently selected and expanded the definitions of vital requirement attributes for systems, FoS, and complex systems. Using a diverse set of experts, it provided a validated and prioritized set of requirement attributes.

6.1. Survey Comments

Each of the four sections of the survey offered an open comment area for experts to provide feedback. Approximately 25% of the respondents provided additional feedback. The majority of the open response feedback centers on experts providing their attribute priorities in addition to their pairwise comparison inputs. One expert states, “Achievable is ultimately the top priority” for systems requirement attributes. For complex systems an expert states, “Though the reality is political (attribute) will always be a factor, in an ideal world, technical (attribute) will reign supreme.” Another expert states, “I value the factors achievable and verifiable as more important than other attributes.” Still another expert questions the independence between attributes, and another thinks the pairwise comparisons, while necessary, were burdensome to complete. Though the survey did not specifically ask experts to comment on attributes to add or delete, of those responding,

none suggested adding or deleting attributes. The open response feedback comments further correlate the cross validation of the sensitivity analysis with the primary data. Of the 25% of experts responding in the open response sections in the survey, their feedback responses reinforce the primary data results and support a validated set of attributes.

6.2. Boundaries of the Study and Future Research

Part of this research expanded the work of Rettaliata on requirement attributes which used Bradley-Terry pairwise comparisons with the Unibalance-11 software (Rettaliata et al. 2014). The Unibalance-11 software does not accommodate weighting factors of requirement attributes or experts. Therefore, this analysis only considers the attributes and experts with equal weighting. Future research could expand this approach to allow for various weighting scales of attributes and experts to provide greater fidelity and more comprehensive results of the requirement development process. One approach could be to use Expert Choice, which allows for weighting of experts. This expanded research would determine the cause and effect of weighting on attribute rankings to support acquisition leaders with additional fidelity for requirements development. Although the experts represented in this study have diverse experience and backgrounds within government and industry, one way to further this area of research is to expand into the commercial manufacturing sector. Commercial manufacturing can benefit from this study as some supplemental attributes and refined definitions may improve the development of requirements and manufacturing processes. Furthermore, research in the area of time phased requirements over the complete system life cycle is recommended for a more

comprehensive study of requirement attributes. A key finding in this research is the importance of the *achievable* attribute. We recommend additional research to further define and characterize this vital attribute with how it affects cost, schedule, performance, and risks on programs. We acknowledge that complex systems external requirement attributes and their definitions are embryonic concepts in the systems engineering, program management, and operational communities and we recommend further, in-depth research.

6.3. Summary

Our research captures a broad range of definitions for key requirement development terms, refines the definitions for clarity, and subsequently selects vital requirement attributes for systems, FoS, and complex systems. The Bradley-Terry methodology, using pairwise comparisons, provides the rankings of requirement attributes. Using a diverse set of experts with 34.2 years of experience, perspective, and knowledge provides a validated set of requirement attributes, definitions, and rankings for the acquisition community to consider and apply to ever increasingly complex systems, FoS, and simple systems.

These validated attributes provide an important foundation, guide, and significant step forward for the acquisition community to establish and use comprehensive, effective sets of attributes from simple to complex systems. It provides valid requirement attributes and new, focused approaches for developing sound requirements that subsequently can be used in design trade-off decisions. In addition, this research provides a compelling rationale and an improved approach for the acquisition community to channel and tailor their focus and diligence on the validated and prioritized requirement attributes to generate accurate and

effective requirements. These validated attributes enable programs to successfully develop, produce, operate, and sustain systems.

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Appendix A

Information/Consent Sheet about the Research Study:

Survey of Acquisition and Operations Experts for Ranking of Requirements Attributes

Richard M. Stuckey,* Thomas A. Mazzuchi**
*Principal Contact
**Principal Investigator
Department of Engineering Management and Systems Engineering, School of Engineering and Applied Science, The George Washington University, 1176 G Street, NW, Washington, DC 20052
IRB #041525

"You are invited to participate in a research study under the direction of Dr. Mazzuchi, of the Department of Engineering Management and Systems Engineering, George Washington University (GWU). You've been chosen to participate in this survey because of your expertise in acquisition, operations, requirements analysis, and systems engineering. Taking part in this research is entirely voluntary. The purpose of this survey is to perform a pairwise assessment on requirement attributes for systems, independent systems, and complex systems" (Georgiadis, 2011)
"If you choose to take part in this study, you will fill out the attached survey instrument. You may refuse to answer any of the questions and you may stop your participation in this study at any time" (Georgiadis, 2011). There is no expectation that you will benefit directly from your participation in the study, however, it is expected that this study will contribute to Requirements Analysis/Systems Engineering research and the body of knowledge. Please make an effort to answer all questions within the survey and indicate how many years and level of experience you have in acquisition, program management, requirements analysis, systems engineering, and operations with your response. The questions are asked to determine a rank (important to least important) of requirement attributes for systems, independent systems, and complex systems.
"Every effort will be made to keep your information confidential, however, this cannot be guaranteed. The levels of questions asked within the survey do not pose any risk to the participant. The completed survey forms will be received by the Principal Contact via emailed Microsoft Word files. These files will be saved and password protected on the Principal Contact's personal computer.
There will be no names, email addresses, or personal identifiable information forwarded with the survey instruments, nor will the Principal Contact forward any of the instruments to any other person for any reason or for further research without the prior written consent of the participant. If results of this research study are reported in journals or at scientific meetings, the people who participated in this study will not be named or identified.
The Office of Human Research of George Washington University, at telephone number (202) 994-2715, can provide further information about your rights as a research

participant" (Georgiadis, 2011). Further information regarding this study may be obtained by contacting Richard M. Stuckey, Principal Contact, at telephone number (540) 907-5996. "The Principal Investigator, Dr. Thomas Mazzuchi, and his staff may be reached at telephone number (888)-694-7934. Your willingness to participate in this research study is implied if you proceed with completing the survey/interview. Please keep a copy of this document in case you want to read it again" (Georgiadis, 2011).

THE GEORGE WASHINGTON UNIVERSITY
OFFICE OF HUMAN RESEARCH
INSTITUTIONAL REVIEW BOARD
HUMANRESEARCH.GWU.EDU

EXEMPT FROM IRB REVIEW REQUEST FORM

Before completing this form, complete the Human Subject Research Determination worksheet to ensure that you are in fact required to submit your new study to the Office of Human Research. The OHR will only review studies deemed "human subject research."

Reporting Proposed Changes in Research: This exempt from IRB review determination only applies to this form/protocol, as currently proposed. Therefore, if there are any changes that increase the risks to subjects (e.g., methodology, data gathering instruments, type of information being accessed or disclosed, etc.) the changes must be submitted to the IRB/OHR for approval PRIOR TO implementation.

INVESTIGATOR AND TEAM CONTACT INFORMATION			
IRB# *(ADMIN USE ONLY--WILL BE ASSIGNED UPON SUBMISSION)*		VERSION DATE:	
TYPE OF HIPAA AUTHORIZATION REQUESTED:		Not applicable	
PROTOCOL TITLE AND SPONSOR:			
TITLE : Survey of Acquisition and Operations Experts for Ranking of Requirements Attributes			
SPONSOR : EMSE Doctoral Program			
STUDENT-LED PROJECT: YES ☒ NO ☐			
PRINCIPAL INVESTIGATOR INFORMATION *(MUST BE GWU FACULTY)*			
LAST NAME:	MAZZUCHI	FIRST NAME:	THOMAS Degree: PhD
DEPARTMENT	EMSE	SCHOOL:	ENGINEERING AND APPLIED SCIENCE
CAMPUS ADDRESS:			
PHONE:	1 888 694 7934	EMAIL:	MAZZU@GWU.EDU
PRINCIPAL CONTACT IF OTHER THAN PI: *(THIS MAY BE THE STUDENT/TRAINEE)*			
LAST NAME:	STUCKEY	FIRST NAME:	RICHARD
CAMPUS ADDRESS:			

Recommendation:

- ☐ Study Registered as Exempt. Category: _____
- ☐ A HIPAA waiver of research subject authorization is justified for this study under 45 CFR 46 164.512 based on the following criteria:
  1. The proposed uses and disclosures of protected health information (PHI) involve no more than minimal risk to the privacy of individuals.
  2. The research could not practicably be conducted without the waiver.
  3. The research could not practicably be conducted without access to and use of the PHI.

  Please obtain permission from the privacy officer of the health care organization in which you will access protected health information before beginning your research.
- ☐ This research does **NOT** meet the regulatory/institutional requirements for exemption from IRB review. To conduct this research you must complete an IRB submission package for IRB review. For more information on completing a research submission, contact OHR at 202-994-2715.

_____ _____ _____
Authorized Designee Signature Date

This Exempt Registration does not expire nor does it require renewal.

PHONE:		EMAIL:	RICHSTUCKEY@GWMAIL.GWU.EDU

Select the category that describes the proposed research activity:

The exemptions outlined below do not apply to ANY research involving prisoners. Research involving children may be exempt with specific restrictions. See below:

☐	1. Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as research on instructional strategies; **or** research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
☒	2. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: *The information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and* *Any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.* **This category may not be applied to children, except in the observation of public behavior.**
☐	3. Research involving the use of educational tests (cognitive, diagnostic, aptitude, or achievement tests), survey procedures, interview procedures or observation of public behavior: *Of human subjects that are elected or appointed public officials or candidates for public office; or* *Conducted under a Federal statute requiring that the confidentiality of the personally identifiable information be maintained throughout the research and thereafter.*
☐ *Date range of pre-existing data:*	4. Research involving the collection or study of pre-existing data sets, documents, records, or specimens, but only if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, either directly or through identifiers linked to subjects [i.e. through use of a key]. If research team does not receive, view or handle identifiable *original source data* at any point, study may be "not human subject research" (see link above to determine). *Research involving one of more of these existing data sets may require you to obtain, prior to using and/or disclosing identifiable health Information from the existing data set, either HIPAA research subject authorization integrated into the consent form (see "HIPAA" section of Medical Consent Guidance) or a waiver of a research subject authorization granted by the GWU IRB.*
☐	5. Research/demonstration projects conducted by other federal departments designed to study or evaluate public programs, procedures for obtaining benefits or services under those programs, possible changes or alternatives to those programs, or possible changes in methods or levels of payment for benefits under those programs.
☐	6. Taste and food quality and evaluation / consumer acceptance studies, as long as safe, normal foods are being consumed, and federal guidelines regarding acceptable levels of agricultural chemical or environmental contaminants are adhered to.

RESEARCH SUMMARY *(Please see Exempt Instructions to ensure all required information is included in application)*

Research Purpose	This study establishes and evaluates the prioritization of attributes for well written requirements for systems of systems and complex systems. This research will survey acquisition experts from systems engineering, requirements, and operations for validating and ranking the attributes from most to least important. The purpose of this study is to derive the requirement attributes for systems of systems and complex systems, and have acquisition experts rank attributes by importance. This research focuses on the Bradley-Terry methodology. It will use the ranking methodology by pairwise comparison using the Bradley-Terry approach and using the associated 11-Unibalance software. By utilizing these ranking methods, a proper ordering of requirement attributes will be accomplished. Currently there are no established attributes to generate requirements for systems of systems and complex systems. Each solution can provide benefit for different requirement attributes, which will ultimately drive sound requirements and program planning, execution, and operations. This study will determine what the priority of requirement attributes is for system of systems and complex systems and gage the relative importance as a result.
Study Population	A minimum of 24, maximum of 35, acquisition experts is set as the sample size because this is

	the number approved by the EMSE department and contact information is known for this many people with 25 years of experience within the Principal Contact's professional circle. These participants are part of different organizations from government and industry all of which are involved in acquisition. The Principal Contact has been involved in acquisition for 30 years, so these experts are known through professional relationships.
Subject Recruitment Methods	Requested survey responses from acquisition experts will be offered using the attached information/consent form. The consent form will be sent by email and the survey instrument will be sent as an attachment to the information/consent form
Methodology *(Step-by-step 1,2,3 description of study design)*	1. Issue survey instrument with information/consent email (attached) 2. Conduct inferential analysis of attributes using 11-Unibalance software 3. Use the 11-Unibalance software results from experts pairwise comparison to rank order attributes 4. Sensitivity analysis may be conducted using 11-Unibalance software
Research Specific Risks	After considering all questions and participant involvement in this survey, it has been determined that there are no identified risks for this research study. There is no personal identifiable requested or used in this study. The level of questions asked within the survey pose no risk to the participants.
Benefits *(to subject and society)*	There are no benefits to the participants in this research study. The research study is expect to contribute to establishing requirements for systems of systems and complex systems, and further extend the body of knowledge in systems engineering requirements.
Data Analysis and Justification of Sample Size	The sample size of 24 was proposed to the Principal Investigator and EMSE Department Chair. The sample size was accepted as greater than the minimum standard of 15 participants for expert judgment experimentation. A minimum of 24 subjects with at least 25 years of acquisition experience will be surveyed for the purpose of this study.
Confidentiality and Privacy *(Include plan for data storage, deindentification, and destruction)*	Once the emailed survey responses are received, the names will be decoupled from the individual survey responses. What is meant here is that the Principal Contact has each participant's email, which in nearly all cases contains their fullname@company.com, so upon publishing data, the Principal Contact will not include any names (i.e. from their email address or any personally identifiable information) within the data set. There will be no linkages of the survey responses to the individual participants that saved outside of the personal computer of the Principal Contact's personal computer for data analysis and this data will be password protected and only used for this research study.
Use of results/findings *(plan for dissemination of information)*	The results of this research will be submitted within an article to the Institue of Electrical and Electronic Engineers (IEEE) and International Council on Systems Engineering (INCOSE) Systems Engineering Journal (scholarly peer reviewed journals). After the published article is completed, the Principal contact will then document the research study within a dissertation. There will be no published information on the participant's or linages to the survey data.

INVESTIGATIVE TEAM SIGNATURES: My signature indicates that I will respect and protect the rights and welfare of individuals enrolled in this research project. I will also carry out my responsibilities as Principal Investigator as is outlined in Federal-wide Assurance of Protection for Human Subjects, for which GWU is registered with OHRP/DHHS, and as detailed in GWU HRPP policies & procedures. I will be guided by the principles contained in the Belmont Report and The Code of Federal Regulations governing research with human subjects (45 CFR 46). I have queried all members of the research team to determine if they have an economic interest in this study as defined by GWU policies. ***These signatures must be originals and are required for submission.***

Principal Investigator (Print/Type) Thomas Mazzuchi	Signature	Date
Sub-Investigator (Print/Type)		
Sub-Investigator (Print/Type)		
Student Investigator/Research Coordinator (Print/Type) Richard M. Stuckey		

DEPARTMENT CHAIR/DEAN SIGNATURE: My signature indicates that this project has been reviewed by the appropriate departmental parties, who have judged that 1) there is a scholarly and a scientific justification for the protocol, that the study is feasible, and that the proposed methods are scientifically valid, 2) that the department has made the space and time commitment necessary to carry out the project, 3) that the financial implications of the research have been considered and

deemed acceptable to the department and 4) that all ethical principles have been appropriately addressed.		
Medical, Alan G. Wasserman, MD or Gary Simon, MD, PhD **Non-Medical**, Name of Dept. Chair	Signature	
Department Affiliation/Campus Location		
Phone	Fax	Email

Please submit to OHR, 2100 Pennsylvania Ave. NW Suite 300-A or ohrirb@gwu.edu with all materials identified in the IRB Submission Checklist

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

Office of Human Research

Memorandum

To: Dr. Mazzuchi and Richard

From: The George Washington University Office of Human Research

Date: 04/16/15

Study #: 041525

Study Title: Survey of Acquisition and Operations Experts for Ranking of Requirements Attributes

RE: Exempt Registration

The request for an exemption determination for the above-referenced study has been completed. The study was determined to be research that is exempt from IRB review under DHHS regulatory category 2. The project as described in the application may proceed without further oversight by the OHR.

The exemption determination applies only to the project described in your Exempt Request Form. Any changes that may alter in any way the risks to participants, type of information to be accessed, addition of new populations, or change in PI may not be instituted without submission of an Exempt Modification memo and further review by the OHR prior to implementation of the changes.

Questions or concerns regarding the exemption determination made for the study should be directed to the OHR staff at ohrirb@gwu.edu.

(bcl)

Appendix B

Survey

on

Requirements for Systems, Unconstrained Systems, and Complex Systems

Survey Purpose

“The purpose of this survey is to question subject matter experts to determine if” there is a variance in importance of requirement attributes for systems, unconstrained systems, and complex systems (Georgiadis, 2011). Attributes chosen for this study were developed by the authors to support well written requirements.

“Your participation in this survey is greatly appreciated, and will be critical in the expanding of knowledge” in how to properly write requirements for systems, unconstrained systems, and complex systems (Georgiadis, 2011).

This survey will take approximately 1 hour to complete all four sections.

Once competed, please save all work and email this file to
rich.stuckey@gwmail.gwu.edu

Section 1: Demographics

Instructions:

Please fill out your years of experience, education level, and title.

A: Total Experience

How many total years of professional experience?

B: Detailed Experience

The combined years of detailed experience should equal total experience years.

How many years of program management experience?

How many years of systems engineering or requirements analysis experience?

How many years of operations experience?

How many years of logistics experience?

How many years of academic experience?

How many years of any other related experience you think is important?

Type of experience?

How many years?

Type of experience?

How many years?

C: Education Level:

What is your highest education level? (Use the drop down box below 'choose an item')

Choose an item.

D: Title

What is your title (examples: SES, General, Admiral, Vice President, Executive Director, Chief Engineer, Chief, Senior Fellow)?

E: Briefs and Papers:

In your professional career estimate the number of briefs you have created and given to a major public audience, and the number of articles you have written and published in a public journal or magazine.

Number of briefs:

Number of articles:

F: Requirements Experience

On a scale of 1 to 6 what is the estimate of your knowledge in the area of requirements? (Use the drop down menu below)

Choose an item.

G: Comments - please provide any comments you might have

Recommend you save your inputs prior to moving to Section 2

Section 2: Systems

Instructions:

1. Read the definition of systems and requirements below.
2. Review the systems requirement attributes and their definitions on the next page.

You will then see 36 pairs of attributes to compare. Select the attribute for each pairing that you think is more important. There is a dropdown box to select the more important attribute for each combination.

*"**Systems Definition:*** An interdependent group of people, objectives, and procedures constituted to achieve defined objectives or some operational role by performing specified functions. A complete system includes all of the associated equipment, facilities, material, computer programs, firmware, technical documentation, services, and personnel required for operations and support to the degree necessary for self-sufficient use in its intended environment" (IEEE, 1998).

Requirement Definition

(A) "A condition or capability needed by a user to solve a problem or achieve an objective.

(B) A condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed document.

(C) A document representation of a condition or capability as in definition (A) or (B)" (IEEE, 1998).

Systems Requirement Attributes and Definitions

Attribute	Definition
Correct	**Correct** if and only if every requirement stated therein represents something required of the system to be built.
Unambiguous	**Unambiguous** if and only if every requirement stated therein has only one interpretation and includes only one requirement (unique).
Complete	**Complete** if it possesses these qualities: 6) Everything it is supposed to do is included. 7) Definitions of the responses of software to all situations are included. 8) All pages are numbered. 9) No sections are marked "To be determined." 10) Is necessary.
Verifiable	**Verifiable** if and only if every requirement stated therein is verifiable.
Consistent	**Consistent** if and only if (1) no requirement stated therein is in conflict with other preceding documents, and (2) no subset of requirements stated therein conflict.
Understandable by Customer	**Understandable by customer** if there exists a complete unambiguous mapping between the formal and informal representations.
Achievable	**Achievable** – the designer should have the expertise to assess the achievability of the requirements to include subcontractors, manufacturing and customers/users within the constraints of the cost and schedule lifecycle.
Design Independent	**Design independent** if it does not imply a specific architecture or algorithm.
Concise	**Concise** if given two requirements for the same system, each exhibiting identical levels of all previous mentioned attributes, the shorter is better.

(Davis, 1993; INCOSE, 2011; ISO/IEC/IEEE, 2011)

Note: There are requirement formatting attributes that are not included in this study and you are not requested to compare these attributes. Formatting attributes and their definitions are below for your reference.

Attribute	Definition
Modifiable	**Modifiable** if its structure and style are such that any necessary changes to the requirement can be made easily, completely, and consistently.
Traced	**Traced** if the origin of each of its requirements is clear.
Traceable	**Traceable** if it is written in a manner that facilitates the referencing of each individual requirement stated therein.
Annotated	**Annotated** if there is guidance to the development organization such as relative necessity (ranked) and relative stability.
Organized	**Organized** if the requirements contained therein are easy to locate.

(Davis, 1993; INCOSE, 2011; ISO/IEC/IEEE, 2011)

Compare the following pairs of factors. In the last column there is a drop down menu (choose an item) to select which factor you think is more important for each pairing.

Factor	Factor	Select More Important Factor
Correct	Unambiguous	Choose an item.
Correct	Complete	Choose an item.
Correct	Verifiable	Choose an item.
Correct	Consistent	Choose an item.
Correct	Understandable by Customer	Choose an item.
Correct	Achievable	Choose an item.
Correct	Design Independent	Choose an item.
Correct	Concise	Choose an item.
Unambiguous	Complete	Choose an item.
Unambiguous	Verifiable	Choose an item.
Unambiguous	Consistent	Choose an item.
Unambiguous	Understandable by Customer	Choose an item.
Unambiguous	Achievable	Choose an item.
Unambiguous	Design Independent	Choose an item.
Unambiguous	Concise	Choose an item.
Complete	Verifiable	Choose an item.
Complete	Consistent	Choose an item.
Complete	Understandable by Customer	Choose an item.
Complete	Achievable	Choose an item.
Complete	Design Independent	Choose an item.
Complete	Concise	Choose an item.
Verifiable	Consistent	Choose an item.
Verifiable	Understandable by Customer	Choose an item.
Verifiable	Achievable	Choose an item.
Verifiable	Design Independent	Choose an item.
Verifiable	Concise	Choose an item.
Consistent	Understandable by Customer	Choose an item.
Consistent	Achievable	Choose an item.
Consistent	Design Independent	Choose an item.
Consistent	Concise	Choose an item.
Understandable by Customer	Achievable	Choose an item.
Understandable by Customer	Design Independent	Choose an item.
Understandable by Customer	Concise	Choose an item.
Achievable	Design Independent	Choose an item.
Achievable	Concise	Choose an item.
Design Independent	Concise	Choose an item.

Provide any comments you might have on systems requirement attributes and definitions.

Recommend you save your selections prior to moving to Section 3

Section 3: Unconstrained Systems

Instructions:

1. Read the definition of unconstrained systems and requirements below.
2. Review the unconstrained system requirement attributes and their definitions on the next page.
3. You will then see 36 pairs of attributes to compare. Select the attribute for each pairing that you think is more important. There is a dropdown box to select the more important attribute for each combination.

Unconstrained Systems Definition: A collection of component systems, simple or complex, that are managed, operated, developed, funded, maintained, and sustained independently of their overarching principal system that creates a new capability.

Requirement Definition

(A) "A condition or capability needed by a user to solve a problem or achieve objective.

(B) A condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed document.

(C) A document representation of a condition or capability as in definition (A) or (B)" (IEEE, 1998).

Unconstrained Systems Requirement Attributes and Definitions

Attribute	Definition
Correct	**Correct** if and only if every requirement stated therein represents something required of the system to be built.
Unambiguous	**Unambiguous** if and only if every requirement stated therein has only one interpretation and includes only one requirement (unique).
Complete	**Complete** if it possesses these qualities: • Everything it is supposed to do is included. • Definitions of the responses of software to all situations are included. • All pages are numbered. • No sections are marked "To be determined." • Is necessary.
Verifiable	**Verifiable** if and only if every requirement stated therein is verifiable.
Consistent	**Consistent** if and only if (1) no requirement stated therein is in conflict with other preceding documents, and (2) no subset of requirements stated therein conflict.
Understandable by Customer	**Understandable by customer** if there exists a complete unambiguous mapping between the formal and informal representations.
Achievable	**Achievable** – the designer should have the expertise to assess the achievability of the requirements to include subcontractors, manufacturing and customers/users within the constraints of the cost and schedule lifecycle.
Design Independent	**Design independent** if it does not imply a specific architecture or algorithm.
Concise	**Concise** if given two requirements for the same system, each exhibiting identical levels of all previous mentioned attributes, the shorter is better.

(Davis, 1993; INCOSE, 2011; ISO/IEC/IEEE, 2011)

Note: There are requirement formatting attributes that are not included in this study and you are not requested to compare these attributes. Formatting attributes and their definitions are below for your reference.

Attribute	Definition
Modifiable	**Modifiable** if its structure and style are such that any necessary changes to the requirement can be made easily, completely, and consistently.
Traced	**Traced** if the origin of each of its requirements is clear.
Traceable	**Traceable** if it is written in a manner that facilitates the referencing of each individual requirement stated therein.
Annotated	**Annotated** if there is guidance to the development organization such as relative necessity (ranked) and relative stability.
Organized	**Organized** if the requirements contained therein are easy to locate.

(Davis, 1993; INCOSE, 2011; ISO/IEC/IEEE, 2011)

Compare the following pairs of factors. In the last column there is a drop down menu (choose an item) to select which factor you think is more important for each pairing.

Factor	Factor	Select More Important Factor
Correct	Unambiguous	Choose an item.
Correct	Complete	Choose an item.
Correct	Verifiable	Choose an item.
Correct	Consistent	Choose an item.
Correct	Understandable by Customer	Choose an item.
Correct	Achievable	Choose an item.
Correct	Design Independent	Choose an item.
Correct	Concise	Choose an item.
Unambiguous	Complete	Choose an item.
Unambiguous	Verifiable	Choose an item.
Unambiguous	Consistent	Choose an item.
Unambiguous	Understandable by Customer	Choose an item.
Unambiguous	Achievable	Choose an item.
Unambiguous	Design Independent	Choose an item.
Unambiguous	Concise	Choose an item.
Complete	Verifiable	Choose an item.
Complete	Consistent	Choose an item.
Complete	Understandable by Customer	Choose an item.
Complete	Achievable	Choose an item.
Complete	Design Independent	Choose an item.
Complete	Concise	Choose an item.
Verifiable	Consistent	Choose an item.
Verifiable	Understandable by Customer	Choose an item.
Verifiable	Achievable	Choose an item.
Verifiable	Design Independent	Choose an item.
Verifiable	Concise	Choose an item.
Consistent	Understandable by Customer	Choose an item.
Consistent	Achievable	Choose an item.
Consistent	Design Independent	Choose an item.
Consistent	Concise	Choose an item.
Understandable by Customer	Achievable	Choose an item.
Understandable by Customer	Design Independent	Choose an item.
Understandable by Customer	Concise	Choose an item.
Achievable	Design Independent	Choose an item.
Achievable	Concise	Choose an item.
Design Independent	Concise	Choose an item.

Provide any comments you might have on unconstrained systems requirement attributes and definitions.

Recommend you save your selections prior to moving to Section 4

Section 4: Complex Systems

Instructions:

1. Read the definition of complex systems and requirements below.
2. Review the complex systems requirement attributes and their definitions on the next page.
3. Then you will see 21 pairs of attributes to compare. Select the attribute for each pairing that you think is more important. There is a dropdown box to select the more important attribute for each combination.

Complex Systems: A collection of large, multifaceted, and interrelated component systems that are dependent on the entirety of the principal system for management, operations, development, funding, maintenance, and sustainment. Complex systems are non-deterministic, adaptive, holistic, and have non-linear interfaces between attributes.

Requirement Definition
(A) "A condition or capability needed by a user to solve a problem or achieve objective.
(B) A condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed document.
(C) A document representation of a condition or capability as in definition (A) or (B)" (IEEE, 1998).

Complex Systems Requirement Attributes and Definitions

Attribute	Definition
Holistic	**Holistic** considers the following: • Security & surety; scalability & openness; and legacy systems • Timing of schedules and budgets • Reliability, availability, and maintainability • Business and competition strategies • "Role of the observer, the nature of systems requirements, and the influence of the system environment" (Katina & Keating 2014, 47)
Social	**Social** considers the following: • Local, state, national, tribal, international stakeholders • Demographics & culture of consumers; culture of developing organization (Nescolarde-Selva & Uso-Domenech 2012 & 2013) • Sub-contractors, production, manufacturing, logistics, maintenance stakeholders • Human resources for program and systems integration (Jain et al. 2008) • "Social network consisting of the human components and the relationships that hold among them" (Bartolomei et al. 2011, 43) • Customer and social expectations and customer interfaces (Konrad & Gall 2008) • Uncertainty of stakeholders (Liang et al. 2010) • Use of "Web 2.0 tools and technologies" (e.g. wikis, folksonomie, and ontologies) (Liang et al. 2010, 27) • Knowledge workers ability to quickly change work connections (Hawryszkiewycz 2009)
Political	**Political** considers the following: • Local, state, national, tribal, international political circumstances and interests • Congressional circumstances and interests to include public law and funding • Company, partner, and subcontractor political circumstances and interests • Intellectual property rights, proprietary information, and patents
Adaptable	**Adaptability** considers the following: • Shifts from static to being adaptive in their nature (Svetinovic 2012) • "System's behavior changes in time in response to external stimulus" (Ames et al. 2011, 24) • Components adapt to "changes in the others, as well as changes in personnel, funding, and application" (Glass et al. 2011, 7)
Technical	**Technical** considers the following: • Technical readiness and maturity levels • Risk & safety • Modeling and simulation • Spectrum & frequency • Technical innovations (Glass et al. 2011) • "Physical, nonhuman components of the system to include hardware, software, and information" (Bartolomei et al. 2011, 43; Nescolarde-Selva & Uso-Domenech 2012 & 2013)
Interdependent	**Interdependencies** consider the following: • System and system components schedules of developing components and legacy components • Product and production lifecycles • Management of organizational relationships • Funding integration from system component sources • "The degree of complication of a system or system component, determined by such factors as the number of intricacy of interfaces, number and intricacy of conditional branches, the degree of nesting and types of data structure" (Jain et al. 2008, 211) • The integration of "data transfers across multiple zones of systems & network integration" (Hooper 2009)

Attribute	Definition
	• "Ability to organize connections and integration between system units and ability to support changed connections" (Hawryszkiewycz 2009, 343) • Connections between internal and external people, projects, and functions (Glass et al. 2011)
Environmental	**Environmental** considers the following: • Physical environment (e.g. wildlife, clean water protection) • Running a distributed environment by distributed teams and stakeholders (Liang et al., 2010) • Support "integration of platforms for modeling, simulation, analysis, education, training, and collaboration" (Glass et al. 2011, 12)

Compare the following pairs of factors. In the last column there is a drop down menu (choose an item) to select which factor you think is more important for each pairing.

Factor	Factor	Select More Important Factor
Holistic	Social	Choose an item.
Holistic	Political	Choose an item.
Holistic	Adaptable	Choose an item.
Holistic	Technical	Choose an item.
Holistic	Interdependent	Choose an item.
Holistic	Environmental	Choose an item.
Social	Political	Choose an item.
Social	Adaptable	Choose an item.
Social	Technical	Choose an item.
Social	Interdependent	Choose an item.
Social	Environmental	Choose an item.
Political	Adaptable	Choose an item.
Political	Technical	Choose an item.
Political	Interdependent	Choose an item.
Political	Environmental	Choose an item.
Adaptable	Technical	Choose an item.
Adaptable	Interdependent	Choose an item.
Adaptable	Environmental	Choose an item.
Technical	Interdependent	Choose an item.
Technical	Environmental	Choose an item.
Interdependent	Environmental	Choose an item.

Provide any comments you might have on complex systems requirement attributes and definitions.

Recommend you save your selections prior to any final reviews

This completes the survey. Please recheck this survey to ensure you have completed all sections and inputs. Save all inputs and email this file to:

rich.stuckey@gwmail.gwu.edu

Thank you for your help.

Appendix C

C-1 Unconstrained & Systems Order Sequence Randomization: Experts 1 - 40

Order	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
1st	1	0	1	1	1	0	0	0	1	1
2nd	0	1	0	0	0	1	1	1	0	0

Order	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20
1st	1	1	1	0	0	0	1	0	1	1
2nd	0	0	0	1	1	1	0	1	0	0

Order	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30
1st	1	0	0	1	1	0	0	1	0	1
2nd	0	1	1	0	0	1	1	0	1	0

Order	E31	E32	E33	E34	E35	E36	E37	E38	E39	E40
1st	1	0	1	0	1	0	1	1	0	0
2nd	0	1	0	1	0	1	0	0	1	1

0 Unconstrained
1 Complex

C-2 System Sequence Randomization: Experts 1 - 10

		Base	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
Correct	Unambiguous	1	13	29	34	17	2	5	31	4	17	15
Correct	Complete	2	16	4	6	24	15	17	12	27	32	5
Correct	Verifiable	3	8	32	1	23	25	9	11	19	35	23
Correct	Consistent	4	33	17	17	12	16	1	4	13	33	28
Correct	Understandable by Customer	5	1	28	23	14	11	2	2	11	36	13
Correct	Achievable	6	18	21	11	34	31	7	24	9	14	30
Correct	Design Independent	7	5	9	19	10	33	23	8	32	22	2
Correct	Concise	8	28	22	28	19	19	35	18	25	3	26
Unambiguous	Complete	9	6	31	24	33	32	30	30	33	1	20
Unambiguous	Verifiable	10	4	8	20	5	29	36	13	6	2	33
Unambiguous	Consistent	11	24	10	13	22	23	34	33	36	29	24
Unambiguous	Understandable by Customer	12	19	23	36	32	20	19	21	17	18	27
Unambiguous	Achievable	13	34	20	32	15	28	11	9	1	12	21
Unambiguous	Design Independent	14	20	6	8	31	12	21	28	22	4	6
Unambiguous	Concise	15	17	13	27	20	17	8	26	26	16	25
Complete	Verifiable	16	30	3	2	18	14	12	16	23	30	17
Complete	Consistent	17	12	36	33	29	8	6	35	29	7	9
Complete	Understandable by Customer	18	15	1	31	13	18	28	5	2	19	1
Complete	Achievable	19	9	26	16	35	27	27	27	20	15	19
Complete	Design Independent	20	25	33	22	1	6	25	20	12	21	10
Complete	Concise	21	22	19	10	27	34	31	22	14	31	32
Verifiable	Consistent	22	7	35	18	16	21	24	32	21	26	34
Verifiable	Understandable by Customer	23	14	11	26	2	30	4	17	31	8	4
Verifiable	Achievable	24	23	24	12	25	26	3	15	5	20	3
Verifiable	Design Independent	25	26	5	3	11	4	18	6	30	23	35
Verifiable	Concise	26	31	14	35	21	7	22	25	15	13	7
Consistent	Understandable by Customer	27	21	30	30	9	24	26	36	28	10	31
Consistent	Achievable	28	35	2	5	6	35	15	10	3	28	22
Consistent	Design Independent	29	2	16	15	28	13	20	29	10	9	11
Consistent	Concise	30	29	34	7	4	36	33	14	34	34	36
Understandable by Customer	Achievable	31	32	12	29	8	3	14	1	7	27	18
Understandable by Customer	Design Independent	32	10	7	4	36	5	29	23	18	25	29
Understandable by Customer	Concise	33	36	18	21	3	10	10	3	8	24	12
Achievable	Design Independent	34	27	27	14	26	22	13	34	35	5	14
Achievable	Concise	35	3	25	25	7	1	32	7	16	6	8
Design Independent	Concise	36	11	15	9	30	9	16	19	24	11	16

C-3 Systems Sequence Randomization: Experts 11 - 20

		Base	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20
Correct	Unambiguous	1	12	9	18	24	23	19	31	15	21	36
Correct	Complete	2	4	33	11	28	4	30	17	35	1	4
Correct	Verifiable	3	34	3	12	2	36	9	30	32	27	12
Correct	Consistent	4	22	27	6	29	3	5	24	6	9	5
Correct	Understandable by Customer	5	23	34	36	33	35	26	35	28	23	32
Correct	Achievable	6	10	16	24	6	21	17	11	22	17	33
Correct	Design Independent	7	30	13	16	1	24	14	3	31	11	29
Correct	Concise	8	15	17	14	34	5	12	32	34	5	26
Unambiguous	Complete	9	25	25	15	35	19	36	21	27	35	13
Unambiguous	Verifiable	10	18	11	20	36	28	25	22	24	14	28
Unambiguous	Consistent	11	35	20	32	31	13	21	26	30	13	23
Unambiguous	Understandable by Customer	12	26	22	29	20	12	32	23	20	10	20
Unambiguous	Achievable	13	14	19	8	7	34	29	29	33	2	25
Unambiguous	Design Independent	14	29	10	28	30	7	7	15	7	19	1
Unambiguous	Concise	15	24	18	7	12	25	16	25	26	24	17
Complete	Verifiable	16	31	5	33	5	16	15	36	3	28	31
Complete	Consistent	17	5	23	22	9	2	22	5	13	29	34
Complete	Understandable by Customer	18	20	24	35	10	6	2	12	11	22	30
Complete	Achievable	19	27	1	27	27	27	23	4	29	3	35
Complete	Design Independent	20	9	28	17	26	18	1	2	5	25	3
Complete	Concise	21	8	14	25	8	17	10	13	19	20	9
Verifiable	Consistent	22	36	26	10	18	32	3	8	17	34	22
Verifiable	Understandable by Customer	23	33	7	23	11	29	28	33	12	30	7
Verifiable	Achievable	24	2	32	34	4	1	35	10	18	36	2
Verifiable	Design Independent	25	17	21	30	25	11	4	7	21	12	14
Verifiable	Concise	26	6	31	13	15	22	11	20	36	4	8
Consistent	Understandable by Customer	27	16	8	9	23	15	18	28	8	18	24
Consistent	Achievable	28	3	30	26	16	33	34	16	1	32	27
Consistent	Design Independent	29	21	35	3	32	14	33	18	2	15	19
Consistent	Concise	30	32	15	5	13	10	24	1	4	33	10
Understandable by Customer	Achievable	31	7	6	19	3	30	13	9	23	16	11
Understandable by Customer	Design Independent	32	1	12	4	21	8	31	19	9	8	16
Understandable by Customer	Concise	33	11	4	2	22	9	6	14	10	6	21
Achievable	Design Independent	34	28	29	1	17	26	8	34	16	26	15
Achievable	Concise	35	13	2	31	14	31	20	27	25	31	18
Design Independent	Concise	36	19	36	21	19	20	27	6	14	7	6

C-4 Systems Sequence Randomization: Experts 21 - 30

		Base	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30
Correct	Unambiguous	1	25	7	10	29	14	16	26	25	33	26
Correct	Complete	2	16	16	2	34	6	7	34	36	23	5
Correct	Verifiable	3	13	4	13	19	9	4	24	28	7	8
Correct	Consistent	4	35	1	26	12	12	27	5	19	29	9
Correct	Understandable by Customer	5	15	19	35	33	7	22	10	9	30	4
Correct	Achievable	6	6	25	18	4	15	28	1	14	4	12
Correct	Design Independent	7	29	14	31	32	11	2	6	17	19	20
Correct	Concise	8	28	18	12	5	34	34	12	5	27	24
Unambiguous	Complete	9	32	22	8	2	25	32	22	29	10	17
Unambiguous	Verifiable	10	26	10	23	7	21	33	15	4	13	2
Unambiguous	Consistent	11	34	30	28	17	19	1	30	24	34	10
Unambiguous	Understandable by Customer	12	36	8	20	36	3	11	19	31	20	33
Unambiguous	Achievable	13	22	34	9	24	1	17	4	20	22	18
Unambiguous	Design Independent	14	30	11	6	22	24	3	2	30	11	23
Unambiguous	Concise	15	21	17	19	15	32	13	9	11	25	7
Complete	Verifiable	16	18	23	24	25	13	20	7	23	2	29
Complete	Consistent	17	7	15	4	26	5	24	25	16	5	25
Complete	Understandable by Customer	18	24	6	22	16	35	23	31	3	36	28
Complete	Achievable	19	23	32	34	6	23	8	33	27	18	11
Complete	Design Independent	20	4	3	21	20	18	26	36	35	9	6
Complete	Concise	21	9	33	32	28	31	25	28	1	6	16
Verifiable	Consistent	22	27	21	3	21	29	10	20	13	15	22
Verifiable	Understandable by Customer	23	20	26	27	14	27	31	29	26	8	13
Verifiable	Achievable	24	11	27	14	8	33	29	27	15	21	31
Verifiable	Design Independent	25	14	36	29	31	4	15	13	8	3	19
Verifiable	Concise	26	31	13	17	27	30	30	35	32	14	32
Consistent	Understandable by Customer	27	8	12	11	13	10	5	3	6	26	30
Consistent	Achievable	28	3	24	36	35	26	21	11	18	35	15
Consistent	Design Independent	29	17	28	1	23	17	36	14	33	12	3
Consistent	Concise	30	2	2	5	3	36	18	16	7	28	34
Understandable by Customer	Achievable	31	12	20	7	11	16	6	32	10	32	14
Understandable by Customer	Design Independent	32	5	9	25	30	22	14	23	21	16	21
Understandable by Customer	Concise	33	1	35	15	10	20	9	8	2	17	27
Achievable	Design Independent	34	10	31	33	9	28	19	21	34	1	36
Achievable	Concise	35	33	29	16	18	8	35	17	22	31	1
Design Independent	Concise	36	19	5	30	1	2	12	18	12	24	35

C-5 Systems Sequence Randomization: Experts 31 - 40

		Base	E31	E32	E33	E34	E35	E36	E37	E38	E39	E40
Correct	Unambiguous	1	14	4	12	12	20	13	16	15	12	24
Correct	Complete	2	11	18	35	4	2	8	36	14	30	5
Correct	Verifiable	3	9	30	34	27	7	14	4	21	20	14
Correct	Consistent	4	4	20	14	35	19	6	20	19	24	7
Correct	Understandable by Customer	5	31	1	18	15	6	28	28	2	1	23
Correct	Achievable	6	20	33	15	6	32	29	10	26	21	16
Correct	Design Independent	7	10	21	4	34	16	22	3	34	18	1
Correct	Concise	8	27	28	1	24	33	12	23	10	8	29
Unambiguous	Complete	9	28	19	25	5	29	2	17	6	9	10
Unambiguous	Verifiable	10	19	11	17	9	4	26	33	30	5	22
Unambiguous	Consistent	11	17	6	5	14	34	9	30	11	11	13
Unambiguous	Understandable by Customer	12	30	22	2	11	1	27	22	29	33	33
Unambiguous	Achievable	13	16	2	36	28	21	21	6	13	3	26
Unambiguous	Design Independent	14	36	9	3	2	12	32	8	23	2	8
Unambiguous	Concise	15	1	15	23	17	5	25	9	32	27	31
Complete	Verifiable	16	8	26	19	8	24	3	24	4	16	12
Complete	Consistent	17	18	10	21	22	8	4	25	9	32	9
Complete	Understandable by Customer	18	15	27	33	36	23	36	12	3	13	28
Complete	Achievable	19	13	32	28	7	9	7	7	7	6	18
Complete	Design Independent	20	22	12	9	19	10	18	14	36	22	27
Complete	Concise	21	26	8	29	31	35	31	15	8	15	3
Verifiable	Consistent	22	25	24	20	33	25	10	29	12	29	2
Verifiable	Understandable by Customer	23	5	31	32	32	15	20	5	25	35	6
Verifiable	Achievable	24	6	34	22	1	11	17	35	17	34	30
Verifiable	Design Independent	25	7	13	13	13	17	34	21	22	25	25
Verifiable	Concise	26	24	29	27	23	30	15	27	28	4	19
Consistent	Understandable by Customer	27	33	14	10	25	18	11	11	5	36	35
Consistent	Achievable	28	29	35	26	16	28	30	13	31	14	20
Consistent	Design Independent	29	12	16	16	3	13	24	2	27	31	36
Consistent	Concise	30	2	5	6	26	22	16	26	18	19	34
Understandable by Customer	Achievable	31	23	7	31	10	3	5	31	24	17	21
Understandable by Customer	Design Independent	32	21	23	8	21	14	33	34	35	10	32
Understandable by Customer	Concise	33	32	25	24	18	27	1	1	20	23	15
Achievable	Design Independent	34	34	3	7	30	26	23	19	1	7	11
Achievable	Concise	35	35	36	30	20	31	19	18	33	28	17
Design Independent	Concise	36	3	17	11	29	36	35	32	16	26	4

C-6 Unconstrained Systems Sequence Randomization: Experts 1 - 10

		Base	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
Correct	Unambiguous	1	14	6	7	7	10	2	13	23	15	18
Correct	Complete	2	9	28	13	27	6	35	7	28	25	29
Correct	Verifiable	3	18	15	3	5	24	28	33	17	6	1
Correct	Consistent	4	35	14	29	28	14	27	4	18	30	34
Correct	Understandable by Customer	5	28	23	21	16	30	11	9	21	17	13
Correct	Achievable	6	27	30	32	11	11	19	10	7	12	16
Correct	Design Independent	7	1	33	12	29	27	21	1	2	24	24
Correct	Concise	8	22	10	35	18	33	22	20	6	21	9
Unambiguous	Complete	9	10	22	34	19	13	24	25	11	2	5
Unambiguous	Verifiable	10	17	25	8	24	31	3	29	14	26	36
Unambiguous	Consistent	11	4	5	26	12	26	7	26	29	7	6
Unambiguous	Understandable by Customer	12	5	2	17	13	36	25	6	19	22	7
Unambiguous	Achievable	13	7	13	11	4	23	12	17	36	29	26
Unambiguous	Design Independent	14	23	18	30	34	20	30	27	26	10	21
Unambiguous	Concise	15	30	29	1	6	28	34	22	8	34	4
Complete	Verifiable	16	26	1	5	15	29	13	19	30	28	17
Complete	Consistent	17	33	27	24	33	18	18	30	31	35	25
Complete	Understandable by Customer	18	13	8	14	14	16	20	24	35	20	14
Complete	Achievable	19	11	11	16	20	21	33	14	9	33	33
Complete	Design Independent	20	32	19	9	26	8	5	28	5	27	20
Complete	Concise	21	31	9	33	36	17	36	16	10	11	10
Verifiable	Consistent	22	16	31	10	9	12	15	35	3	3	22
Verifiable	Understandable by Customer	23	20	34	6	32	15	29	5	20	36	31
Verifiable	Achievable	24	34	26	20	1	34	14	11	15	14	12
Verifiable	Design Independent	25	6	17	2	10	7	16	8	34	13	23
Verifiable	Concise	26	19	32	27	35	22	1	18	24	8	27
Consistent	Understandable by Customer	27	2	24	31	21	1	9	15	22	32	3
Consistent	Achievable	28	12	12	25	25	32	8	31	32	16	2
Consistent	Design Independent	29	8	35	23	23	4	10	21	13	31	11
Consistent	Concise	30	29	16	18	31	2	26	32	27	4	35
Understandable by Customer	Achievable	31	25	4	4	2	25	23	3	4	19	30
Understandable by Customer	Design Independent	32	15	21	36	8	35	17	36	12	5	32
Understandable by Customer	Concise	33	21	20	22	3	9	31	2	33	1	15
Achievable	Design Independent	34	24	36	15	17	19	6	23	1	23	8
Achievable	Concise	35	36	3	28	22	3	32	12	25	18	19
Design Independent	Concise	36	3	7	19	30	5	4	34	16	9	28

C-7 Unconstrained Systems Sequence Randomization: Experts 10 - 19

		Base	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20
Correct	Unambiguous	1	35	34	31	36	32	19	29	22	11	20
Correct	Complete	2	18	18	22	15	15	29	32	20	21	12
Correct	Verifiable	3	26	32	27	27	12	34	14	8	25	9
Correct	Consistent	4	19	15	3	21	7	28	9	1	8	34
Correct	Understandable by Customer	5	27	20	32	3	13	27	20	26	13	33
Correct	Achievable	6	7	13	23	24	36	22	16	13	30	28
Correct	Design Independent	7	36	17	7	22	3	18	1	32	32	35
Correct	Concise	8	23	23	17	6	19	5	21	11	7	21
Unambiguous	Complete	9	22	16	28	5	5	20	7	33	1	26
Unambiguous	Verifiable	10	32	25	16	16	9	2	23	24	10	1
Unambiguous	Consistent	11	28	30	6	12	27	3	8	17	4	24
Unambiguous	Understandable by Customer	12	6	4	25	2	6	24	12	27	5	3
Unambiguous	Achievable	13	15	8	33	30	21	7	11	30	31	6
Unambiguous	Design Independent	14	21	5	10	17	4	1	24	12	22	25
Unambiguous	Concise	15	5	3	26	10	22	13	4	21	15	2
Complete	Verifiable	16	4	9	35	33	16	21	2	36	26	8
Complete	Consistent	17	20	1	2	29	20	8	10	18	18	29
Complete	Understandable by Customer	18	14	29	11	4	8	31	19	19	35	14
Complete	Achievable	19	31	26	4	1	17	10	31	10	24	10
Complete	Design Independent	20	1	28	5	28	34	15	22	9	17	23
Complete	Concise	21	2	36	30	8	14	11	5	29	28	27
Verifiable	Consistent	22	9	10	29	13	11	4	15	5	6	16
Verifiable	Understandable by Customer	23	10	12	36	34	25	16	33	35	12	19
Verifiable	Achievable	24	30	33	34	11	29	17	28	31	20	5
Verifiable	Design Independent	25	24	24	19	35	33	25	25	2	3	22
Verifiable	Concise	26	3	31	15	19	23	35	36	4	14	30
Consistent	Understandable by Customer	27	17	35	13	20	18	33	35	23	9	13
Consistent	Achievable	28	33	22	20	25	35	9	34	14	33	17
Consistent	Design Independent	29	29	21	18	31	1	36	18	16	36	11
Consistent	Concise	30	11	7	21	9	24	12	6	34	27	31
Understandable by Customer	Achievable	31	12	6	24	18	28	23	27	3	16	7
Understandable by Customer	Design Independent	32	16	27	14	23	26	26	30	7	29	4
Understandable by Customer	Concise	33	8	14	12	7	10	32	26	15	2	15
Achievable	Design Independent	34	34	11	8	14	31	14	13	6	34	18
Achievable	Concise	35	25	2	1	32	30	30	17	25	19	32
Design Independent	Concise	36	13	19	9	26	2	6	3	28	23	36

C-8 Unconstrained Systems Sequence Randomization: Experts 21 - 30

		Base	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30
Correct	Unambiguous	1	7	2	32	28	25	16	7	11	35	33
Correct	Complete	2	25	1	26	27	31	36	4	26	17	4
Correct	Verifiable	3	31	17	29	30	2	15	26	5	26	35
Correct	Consistent	4	29	7	5	12	15	26	3	15	8	18
Correct	Understandable by Customer	5	6	34	28	10	21	9	34	24	16	25
Correct	Achievable	6	27	19	6	24	19	31	35	7	33	11
Correct	Design Independent	7	16	4	22	5	20	24	12	19	9	19
Correct	Concise	8	3	11	3	29	3	20	28	28	27	9
Unambiguous	Complete	9	32	9	25	31	34	22	15	3	7	24
Unambiguous	Verifiable	10	12	22	11	4	27	33	20	32	20	8
Unambiguous	Consistent	11	9	24	27	2	36	6	1	20	12	6
Unambiguous	Understandable by Customer	12	8	15	15	16	10	2	16	30	2	17
Unambiguous	Achievable	13	1	20	30	19	7	30	2	1	29	21
Unambiguous	Design Independent	14	13	31	36	36	14	18	13	34	1	29
Unambiguous	Concise	15	14	14	7	17	9	32	24	18	3	34
Complete	Verifiable	16	35	35	23	11	1	7	18	12	22	32
Complete	Consistent	17	21	36	8	21	13	29	17	31	5	27
Complete	Understandable by Customer	18	28	5	10	8	32	4	33	27	21	23
Complete	Achievable	19	17	27	18	34	33	13	32	10	11	26
Complete	Design Independent	20	23	25	12	20	26	3	11	22	32	31
Complete	Concise	21	10	21	19	25	6	34	8	13	23	14
Verifiable	Consistent	22	4	30	2	33	18	17	36	2	15	5
Verifiable	Understandable by Customer	23	30	18	35	6	8	25	19	17	28	28
Verifiable	Achievable	24	11	32	9	13	23	1	21	35	6	30
Verifiable	Design Independent	25	5	26	16	22	24	11	9	6	19	2
Verifiable	Concise	26	26	28	21	14	11	5	29	16	10	1
Consistent	Understandable by Customer	27	34	13	24	26	12	14	27	4	18	22
Consistent	Achievable	28	20	3	20	32	22	21	25	33	34	15
Consistent	Design Independent	29	24	33	34	18	28	23	22	9	13	7
Consistent	Concise	30	36	29	14	23	5	27	23	29	4	13
Understandable by Customer	Achievable	31	2	16	1	7	35	10	31	8	25	12
Understandable by Customer	Design Independent	32	19	6	17	3	4	19	14	21	14	16
Understandable by Customer	Concise	33	18	12	4	1	17	28	30	14	30	10
Achievable	Design Independent	34	15	10	31	35	30	35	6	25	36	20
Achievable	Concise	35	22	8	13	9	16	12	10	36	31	3
Design Independent	Concise	36	33	23	33	15	29	8	5	23	24	36

C-9 Unconstrained Systems Sequence Randomization: Experts 31 - 40

		Base	E31	E32	E33	E34	E35	E36	E37	E38	E39	E40
Correct	Unambiguous	1	1	5	32	23	5	8	26	7	2	24
Correct	Complete	2	20	31	17	24	18	26	21	34	33	27
Correct	Verifiable	3	19	1	3	35	24	32	16	32	16	3
Correct	Consistent	4	7	13	22	4	35	33	23	17	25	2
Correct	Understandable by Customer	5	34	16	30	12	6	36	25	22	17	13
Correct	Achievable	6	10	12	23	14	7	2	8	26	36	8
Correct	Design Independent	7	21	15	11	3	33	35	2	11	9	5
Correct	Concise	8	31	35	26	29	31	12	22	2	14	1
Unambiguous	Complete	9	36	34	19	13	28	28	1	10	32	12
Unambiguous	Verifiable	10	23	14	14	31	17	22	30	36	21	6
Unambiguous	Consistent	11	2	19	6	36	8	30	15	24	28	10
Unambiguous	Understandable by Customer	12	14	4	20	26	26	17	9	27	12	25
Unambiguous	Achievable	13	15	26	5	32	36	24	7	4	22	33
Unambiguous	Design Independent	14	11	24	18	10	2	21	31	21	34	22
Unambiguous	Concise	15	35	17	10	1	20	7	12	23	7	7
Complete	Verifiable	16	9	11	16	9	3	9	28	29	26	32
Complete	Consistent	17	32	23	34	2	32	25	20	1	13	15
Complete	Understandable by Customer	18	26	7	8	21	21	31	36	20	1	34
Complete	Achievable	19	12	32	15	22	27	27	29	18	8	19
Complete	Design Independent	20	4	30	4	27	19	5	10	5	29	26
Complete	Concise	21	8	8	33	5	22	6	34	28	18	17
Verifiable	Consistent	22	6	27	21	16	12	14	35	6	30	36
Verifiable	Understandable by Customer	23	25	21	35	34	15	13	27	13	27	28
Verifiable	Achievable	24	5	28	31	30	16	1	33	31	24	16
Verifiable	Design Independent	25	24	9	28	11	4	15	4	14	15	20
Verifiable	Concise	26	18	22	24	28	14	11	11	19	31	31
Consistent	Understandable by Customer	27	27	10	29	6	11	34	5	25	6	35
Consistent	Achievable	28	13	29	2	17	13	20	6	33	10	21
Consistent	Design Independent	29	17	36	36	15	25	18	18	3	35	29
Consistent	Concise	30	29	6	27	7	30	4	19	9	20	14
Understandable by Customer	Achievable	31	22	20	1	33	9	3	3	16	11	30
Understandable by Customer	Design Independent	32	33	3	12	20	10	16	24	35	4	9
Understandable by Customer	Concise	33	3	2	25	19	34	10	13	12	23	18
Achievable	Design Independent	34	28	33	7	8	1	23	14	15	3	4
Achievable	Concise	35	16	18	13	18	23	29	32	30	19	11
Design Independent	Concise	36	30	25	9	25	29	19	17	8	5	23

C-10 Complex Systems Sequence Randomization: Experts 1 - 10

		Base	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
Holistic	Social	1	16	4	3	15	14	10	8	17	8	8
Holistic	Political	2	10	18	11	19	20	19	9	2	5	3
Holistic	Adaptable	3	11	16	15	14	15	7	4	14	3	6
Holistic	Technical	4	6	20	6	17	17	9	2	4	11	13
Holistic	Interdependent	5	9	19	14	4	4	15	1	15	20	21
Holistic	Environmental	6	20	12	20	16	21	4	6	16	4	14
Social	Political	7	13	13	4	1	5	12	18	3	14	5
Social	Adaptable	8	21	17	18	12	10	18	20	10	2	18
Social	Technical	9	19	3	5	7	7	17	12	7	19	12
Social	Interdependent	10	2	21	21	5	11	5	19	6	13	2
Social	Environmental	11	7	15	7	21	9	21	10	13	12	17
Political	Adaptable	12	18	6	2	18	2	13	17	21	1	20
Political	Technical	13	14	9	13	10	6	8	15	18	10	19
Political	Interdependent	14	4	2	1	13	8	14	13	19	18	9
Political	Environmental	15	17	1	8	9	13	1	14	8	6	1
Adaptable	Technical	16	8	10	16	20	18	6	7	9	17	15
Adaptable	Interdependent	17	15	5	19	8	16	2	11	12	15	16
Adaptable	Environmental	18	3	11	12	6	3	11	21	20	7	11
Technical	Interdependent	19	12	14	10	2	1	16	3	11	21	10
Technical	Environmental	20	5	8	9	3	12	20	5	1	9	7
Interdependent	Environmental	21	1	7	17	11	19	3	16	5	16	4

C-11 Complex Systems Sequence Randomization: Experts 11 - 20

		Base	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20
Holistic	Social	1	4	6	17	5	6	6	3	13	21	14
Holistic	Political	2	18	1	1	15	20	7	17	9	9	10
Holistic	Adaptable	3	7	7	16	16	15	1	2	15	19	13
Holistic	Technical	4	11	14	19	7	18	4	14	16	5	7
Holistic	Interdependent	5	1	2	13	8	17	9	10	3	16	15
Holistic	Environmental	6	16	21	5	12	4	17	16	10	7	19
Social	Political	7	9	4	11	1	19	10	6	6	3	12
Social	Adaptable	8	19	12	10	3	5	18	20	2	13	4
Social	Technical	9	14	10	3	9	1	21	7	20	8	6
Social	Interdependent	10	5	5	20	21	9	2	12	5	17	17
Social	Environmental	11	10	17	9	19	11	5	9	7	6	20
Political	Adaptable	12	13	8	6	2	8	20	11	11	12	16
Political	Technical	13	6	20	4	14	12	11	18	4	20	1
Political	Interdependent	14	17	15	21	13	13	14	5	21	15	11
Political	Environmental	15	12	11	14	6	3	13	13	1	18	21
Adaptable	Technical	16	3	16	8	17	2	19	19	17	11	18
Adaptable	Interdependent	17	2	13	15	18	21	15	4	18	4	9
Adaptable	Environmental	18	8	18	18	4	10	3	8	8	2	5
Technical	Interdependent	19	15	9	7	11	16	16	21	14	10	3
Technical	Environmental	20	20	19	12	20	7	12	1	12	1	2
Interdependent	Environmental	21	21	3	2	10	14	8	15	19	14	8

C-12 Complex Systems Sequence Randomization: Experts 21 - 30

		Base	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30
Holistic	Social	1	10	6	20	21	21	21	12	13	5	12
Holistic	Political	2	8	11	6	3	7	3	9	10	8	13
Holistic	Adaptable	3	14	1	5	6	12	9	19	20	18	16
Holistic	Technical	4	17	19	17	14	13	7	11	2	13	14
Holistic	Interdependent	5	11	14	2	12	19	18	18	5	4	17
Holistic	Environmental	6	13	18	8	15	6	11	5	9	11	8
Social	Political	7	5	5	16	20	17	12	6	19	3	11
Social	Adaptable	8	19	7	18	19	11	15	3	17	2	4
Social	Technical	9	9	13	11	8	3	14	1	7	21	20
Social	Interdependent	10	12	10	7	5	4	5	15	11	7	9
Social	Environmental	11	7	20	13	10	1	1	8	15	14	10
Political	Adaptable	12	16	12	10	18	18	4	17	21	6	15
Political	Technical	13	15	2	1	7	2	19	20	6	1	2
Political	Interdependent	14	18	4	12	11	20	13	13	14	10	6
Political	Environmental	15	4	3	21	4	16	8	2	8	16	3
Adaptable	Technical	16	1	16	15	16	10	10	4	12	17	18
Adaptable	Interdependent	17	2	15	14	17	9	2	7	4	19	19
Adaptable	Environmental	18	21	21	4	2	14	20	14	16	12	7
Technical	Interdependent	19	20	8	3	9	5	16	21	3	9	21
Technical	Environmental	20	3	17	9	13	15	17	10	18	15	1
Interdependent	Environmental	21	6	9	19	1	8	6	16	1	20	5

C-13 Complex Systems Sequence Randomization: Experts 31 - 40

		Base	E31	E32	E33	E34	E35	E36	E37	E38	E39	E40
Holistic	Social	1	6	8	7	3	2	11	8	12	20	15
Holistic	Political	2	21	14	2	15	4	2	5	3	9	18
Holistic	Adaptable	3	13	21	18	10	14	13	15	16	11	4
Holistic	Technical	4	17	6	1	1	9	19	16	1	16	3
Holistic	Interdependent	5	20	12	20	8	19	18	20	18	3	9
Holistic	Environmental	6	1	11	13	6	15	12	4	5	19	17
Social	Political	7	3	9	12	4	20	17	3	8	15	12
Social	Adaptable	8	10	2	10	16	8	10	11	4	18	11
Social	Technical	9	5	20	14	13	7	4	7	7	10	13
Social	Interdependent	10	7	17	9	14	1	15	18	13	1	16
Social	Environmental	11	16	4	17	17	12	21	9	14	14	19
Political	Adaptable	12	14	7	4	9	11	7	17	20	8	10
Political	Technical	13	4	15	19	7	6	3	6	11	12	7
Political	Interdependent	14	12	1	11	12	3	9	12	6	17	14
Political	Environmental	15	15	16	21	2	13	6	14	2	21	2
Adaptable	Technical	16	8	19	5	11	16	1	21	10	7	1
Adaptable	Interdependent	17	11	5	3	19	10	20	10	15	6	5
Adaptable	Environmental	18	9	13	15	18	18	14	19	21	2	6
Technical	Interdependent	19	2	10	8	21	5	5	1	19	4	20
Technical	Environmental	20	19	3	6	5	17	8	2	9	13	8
Interdependent	Environmental	21	18	18	16	20	21	16	13	17	5	21

Appendix D

Expert #1 Data [Industry]

Systems: Triads: 2 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	>	<	>	>	>	>	>
2	<		>	<	>	<	>	>	<
3	<	<		<	<	<	<	<	<
4	>	>	>		>	>	>	>	>
5	<	<	>	<		>	>	>	<
6	<	>	>	<	<		>	<	<
7	<	<	>	<	<	<		<	<
8	<	<	>	<	<	>	>		<
9	<	>	>	<	>	>	>	>	

Unconstrained Systems / FoS: Triads: 18 P Value: 0.1794

	1	2	3	4	5	6	7	8	9
1		<	>	>	>	>	>	<	>
2	>		>	>	<	>	<	>	>
3	<	<		>	>	<	<	<	<
4	<	<	<		>	>	>	<	>
5	<	>	<	<		>	<	>	>
6	<	<	>	<	<		>	<	>
7	<	>	>	<	>	<		>	>
8	>	<	>	>	<	>	<		>
9	<	<	>	<	<	<	<	<	

Complex Systems: Triads: 5 P Value: 0.0690

	1	2	3	4	5	6	7
1		<	<	>	<	<	<
2	>		>	<	>	>	>
3	>	<		<	<	<	>
4	<	>	>		>	<	>
5	>	<	>	<		<	>
6	>	<	>	>	>		>
7	>	<	<	<	<	<	

Expert #2 Data [Industry]

Systems: Triads: 8 P Value: 0.0031

	1	2	3	4	5	6	7	8	9
1		>	<	<	>	<	<	>	>
2	<		>	<	>	>	<	>	<
3	>	<		<	<	>	<	>	>
4	>	>	>		>	>	<	>	>
5	<	<	>	<		>	<	>	>
6	>	<	<	<	<		<	>	>
7	>	>	>	>	>	>		>	>
8	<	<	<	<	<	<	<		>
9	<	>	<	<	<	<	<	<	

Unconstrained Systems / FoS: Triads: 0 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		<	<	<	<	<	<	>	>
2	>		>	<	>	>	<	>	>
3	>	<		<	<	>	<	>	>
4	>	>	>		>	>	<	>	>
5	>	<	>	<		>	<	>	>
6	>	<	<	<	<		<	>	>
7	>	>	>	>	>	>		>	>
8	<	<	<	<	<	<	<		<
9	<	<	<	<	<	<	<	>	

Complex Systems: Triads: 3 P Value: 0.0170

	1	2	3	4	5	6	7
1		<	>	<	>	<	>
2	>		>	<	<	<	>
3	<	<		<	<	<	>
4	>	>	>		>	<	>
5	<	>	>	<		<	<
6	>	>	>	>	>		>
7	<	<	<	<	>	<	

Expert #3 Data [Industry]

Systems: Triads: 1 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		<	>	>	>	>	>	>	>
2	>		>	>	>	>	<	>	>
3	<	<		<	>	>	<	>	>
4	<	<	>		>	>	<	>	>
5	<	<	<	<		<	<	>	>
6	<	<	<	<	>		<	>	>
7	<	>	>	>	>	>		>	>
8	<	<	<	<	<	<	<		<
9	<	<	<	<	<	<	<	>	

Unconstrained Systems / FoS: Triads: 2 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	>	>	>	>	<	<	>
2	<		>	>	>	>	<	>	>
3	<	<		<	<	<	<	<	>
4	<	<	>		>	>	<	>	>
5	<	<	>	<		<	<	<	>
6	<	<	>	<	>		<	<	>
7	>	>	>	>	>	>		>	>
8	>	<	>	<	>	>	<		>
9	<	<	<	<	<	<	<	<	

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		>	>	>	<	>	>
2	<		>	>	<	<	<
3	<	<		>	<	<	<
4	<	<	<		<	<	<
5	>	>	>	>		>	>
6	<	>	>	>	<		>
7	<	>	>	>	<	<	

Expert #4 Data [Industry]

Systems: Triads: 4 P Value: 0.0004

	1	2	3	4	5	6	7	8	9
1		>	>	>	>	>	>	>	>
2	<		>	<	>	<	<	>	<
3	<	<		<	>	>	<	>	>
4	<	>	>		>	<	<	>	>
5	<	<	<	<		<	<	<	<
6	<	>	<	>	>		<	>	>
7	<	>	>	>	>	>		>	>
8	<	<	<	<	>	<	<		>
9	<	>	<	<	>	<	<	<	

Unconstrained Systems / FoS: Triads: 8 P Value: 0.0031

	1	2	3	4	5	6	7	8	9
1		>	>	>	>	>	<	<	>
2	<		>	>	>	>	<	>	>
3	<	<		<	<	<	<	<	>
4	<	<	>		>	>	<	>	>
5	<	<	>	<		<	<	<	>
6	<	<	>	<	>		<	<	>
7	>	>	>	>	>	>		>	>
8	>	<	>	<	>	>	<		>
9	<	<	<	<	<	<	<	<	

Complex Systems: Triads: 1 P Value: 0.0020

	1	2	3	4	5	6	7
1		>	>	<	>	>	>
2	<		<	<	<	<	<
3	<	>		<	<	<	<
4	>	>	>		<	>	>
5	<	>	>	>		>	>
6	<	>	>	<	<		>
7	<	>	>	<	<	<	

Expert #5 Data [Industry]

Systems: Triads: 2 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	>	<	<	>	<	>	>
2	<		>	>	>	>	<	>	>
3	<	<		<	<	<	<	>	>
4	>	<	>		>	>	<	>	>
5	>	<	>	<		>	<	>	>
6	<	<	>	<	<		<	>	>
7	>	>	>	>	>	>		>	>
8	<	<	<	<	<	<	<		>
9	<	<	<	<	<	<	<	<	

Unconstrained Systems / FoS: Triads: 5 P Value: 0.0007

	1	2	3	4	5	6	7	8	9
1		>	>	<	<	>	<	>	>
2	<		<	>	>	>	<	>	>
3	<	>		<	<	<	<	>	>
4	>	<	>		>	>	<	>	>
5	>	<	>	<		>	<	>	>
6	<	<	>	<	<		<	>	>
7	>	>	>	>	>	>		>	>
8	<	<	<	<	<	<	<		>
9	<	<	<	<	<	<	<	<	

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		>	>	>	>	>	>
2	<		>	<	<	<	>
3	<	<		<	<	<	>
4	<	>	>		>	>	>
5	<	>	>	<		<	>
6	<	>	>	<	>		>
7	<	<	<	<	<	<	

Expert #6 Data [Industry]

Systems: Triads: 5 P Value: 0.0007

	1	2	3	4	5	6	7	8	9
1		>	>	>	>	>	>	>	>
2	<		>	<	<	>	<	<	>
3	<	<		<	>	>	<	<	>
4	<	>	>		>	>	>	<	>
5	<	>	<	<		>	>	>	>
6	<	<	<	<	<		<	<	>
7	<	>	>	<	<	>		>	>
8	<	>	>	>	<	>	<		>
9	<	<	<	<	<	<	<	<	

Unconstrained Systems / FoS: Triads: 2 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	>	>	>	>	>	>	>
2	<		<	<	<	>	>	<	>
3	<	>		<	>	>	<	<	>
4	<	>	>		>	>	>	<	>
5	<	>	<	<		>	>	<	>
6	<	<	<	<	<		<	<	>
7	<	<	>	<	<	>		<	>
8	<	>	>	>	>	>	>		>
9	<	<	<	<	<	<	<	<	

Complex Systems: Triads: 2 P Value: 0.0060

	1	2	3	4	5	6	7
1		>	>	>	>	<	>
2	<		>	>	<	<	>
3	<	<		>	>	<	>
4	<	<	<		<	<	<
5	<	>	<	>		<	<
6	>	>	>	>	>		>
7	<	<	<	>	>	<	

Expert #8 Data [Industry]

Systems: Triads: 1 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	>	<	>	>	<	>	>
2	<		<	<	>	<	<	<	<
3	<	>		>	>	>	<	>	>
4	>	>	<		>	>	<	>	>
5	<	<	<	<		<	<	<	<
6	<	>	<	<	>		<	>	>
7	>	>	>	>	>	>		>	>
8	<	>	<	<	>	<	<		<
9	<	>	<	<	>	<	<	>	

Unconstrained Systems / FoS: Triads: 1 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	>	<	>	>	<	>	>
2	<		<	<	>	<	<	>	<
3	<	>		<	>	>	<	>	>
4	>	>	>		>	>	>	>	>
5	<	<	<	<		<	<	<	<
6	<	>	<	<	>		<	>	>
7	>	>	>	<	>	>		>	>
8	<	<	<	<	>	<	<		>
9	<	>	<	<	>	<	<	<	

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		>	>	<	<	<	<
2	<		<	<	<	<	<
3	<	>		<	<	<	<
4	>	>	>		<	<	>
5	>	>	>	>		<	>
6	>	>	>	>	>		>
7	>	>	>	<	<	<	

Expert #9 Data [Industry]

Systems: Triads: 3 P Value: 0.0003

	1	2	3	4	5	6	7	8	9
1		<	>	>	>	>	>	>	>
2	>		>	>	>	>	>	>	>
3	<	<		>	>	<	<	<	>
4	<	<	<		<	<	<	<	<
5	<	<	<	>		<	<	>	>
6	<	<	>	>	>		<	>	>
7	<	<	>	>	>	>		<	>
8	<	<	>	>	<	<	>		>
9	<	<	<	>	<	<	<	<	

Unconstrained Systems / FoS: Triads: 6 P Value: 0.0008

	1	2	3	4	5	6	7	8	9
1		>	>	>	>	>	>	>	>
2	<		<	>	>	>	<	>	>
3	<	>		>	>	>	>	>	>
4	<	<	<		<	<	<	<	<
5	<	<	<	>		<	<	<	>
6	<	<	<	>	>		<	>	<
7	<	>	<	>	>	>		<	=
8	<	<	<	>	>	<	>		>
9	<	<	<	>	<	>	=	<	

Complex Systems: Triads: 2 P Value: 0.0060

	1	2	3	4	5	6	7
1		<	<	>	<	<	>
2	>		<	<	<	<	>
3	>	>		>	<	>	>
4	<	>	<		<	>	>
5	>	>	>	>		>	>
6	>	>	<	<	<		>
7	<	<	<	<	<	<	

Expert #10 Data [Industry]

Systems: Triads: 6 P Value: 0.0008

	1	2	3	4	5	6	7	8	9
1		<	>	>	>	<	>	>	>
2	>		<	<	>	<	<	>	>
3	<	>		<	>	<	<	>	<
4	<	>	>		>	<	>	>	>
5	<	<	<	<		<	<	>	<
6	>	>	>	>	>		>	>	>
7	<	>	>	<	>	<		>	>
8	<	<	<	<	<	<	<		=
9	<	<	>	<	>	<	<	=	

Unconstrained Systems / FoS: Triads: 2 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		<	<	<	>	<	<	>	>
2	>		<	<	>	<	<	>	>
3	>	>		>	>	<	<	>	>
4	>	>	<		>	>	<	>	>
5	<	<	<	<		<	<	>	<
6	>	>	>	<	>		>	>	>
7	>	>	>	>	>	<		>	>
8	<	<	<	<	<	<	<		<
9	<	<	<	<	>	<	<	>	

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		>	>	>	<	<	>
2	<		<	<	<	<	<
3	<	>		<	<	<	<
4	<	>	>		<	<	>
5	>	>	>	>		>	>
6	>	>	>	>	<		>
7	<	>	>	<	<	<	

Expert #11 Data [Industry]

Systems: Triads: 1 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	>	>	>	>	>	>	>
2	<		<	<	<	<	<	=	<
3	<	>		<	>	>	<	>	>
4	<	>	>		>	>	<	>	>
5	<	>	<	<		>	<	>	>
6	<	>	<	<	<		<	<	<
7	<	>	>	>	>	>		>	>
8	<	=	<	<	<	>	<		<
9	<	>	<	<	<	>	<	>	

Unconstrained Systems / FoS: Triads: 1 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	>	<	>	>	<	>	>
2	<		<	<	<	>	<	<	<
3	<	>		<	<	>	<	>	>
4	>	>	>		>	>	<	>	>
5	<	>	>	<		>	<	>	<
6	<	<	<	<	<		<	<	<
7	>	>	>	>	>	>		>	>
8	<	>	<	<	<	>	<		<
9	<	>	<	<	>	>	<	>	

Complex Systems: Triads: 2 P Value: 0.0060

	1	2	3	4	5	6	7
1		<	>	<	<	<	<
2	>		<	<	<	>	<
3	<	>		<	<	>	<
4	>	>	>		<	>	>
5	>	>	>	>		>	>
6	>	<	<	<	<		<
7	>	>	>	<	<	>	

Expert #12 Data [Government]

Systems: Triads: 3 P Value: 0.0003

	1	2	3	4	5	6	7	8	9
1		>	<	>	<	>	<	>	>
2	<		>	<	<	<	<	>	>
3	>	<		>	<	>	<	>	>
4	<	>	<		<	<	<	>	>
5	>	>	>	>		>	>	>	>
6	<	>	<	>	<		<	>	>
7	>	>	>	>	<	>		>	>
8	<	<	<	<	<	<	<		>
9	<	<	<	<	<	<	<	<	

Unconstrained Systems / FoS: Triads: 6 P Value: 0.0012

	1	2	3	4	5	6	7	8	9
1		>	>	>	<	<	<	<	>
2	<		>	<	<	<	<	<	<
3	<	<		>	<	<	<	<	<
4	<	>	<		>	<	<	<	<
5	>	>	>	<		<	<	<	>
6	>	>	>	>	>		>	<	>
7	>	>	>	>	>	<		<	<
8	>	>	>	>	>	>	>		>
9	<	>	>	>	<	<	>	<	

Complex Systems: Triads: P Value:

	1	2	3	4	5	6	7
1							
2							
3							
4							
5							
6							
7							

Expert #13 Data [Government]

Systems: Triads: 9 P Value: 0.0050

	1	2	3	4	5	6	7	8	9
1		>	>	>	>	>	<	>	>
2	<		<	>	>	>	<	>	>
3	<	>		<	>	>	>	>	>
4	<	<	>		<	>	>	>	>
5	<	<	<	>		<	<	>	>
6	<	<	<	<	>		<	<	>
7	>	>	<	<	>	>		>	>
8	<	<	<	<	<	>	<		<
9	<	<	<	<	<	<	<	>	

Unconstrained Systems / FoS: Triads: 9 P Value: 0.0050

	1	2	3	4	5	6	7	8	9
1		>	>	>	>	>	<	>	>
2	<		<	>	>	>	<	>	>
3	<	>		<	>	>	>	>	>
4	<	<	>		<	>	>	>	>
5	<	<	<	>		<	<	>	>
6	<	<	<	<	>		<	<	>
7	>	>	<	<	>	>		>	>
8	<	<	<	<	<	>	<		<
9	<	<	<	<	<	<	<	>	

Complex Systems: Triads: 1 P Value: 0.0020

	1	2	3	4	5	6	7
1		>	>	>	<	<	<
2	<		>	<	<	<	<
3	<	<		<	<	<	<
4	<	>	>		<	<	>
5	>	>	>	>		>	>
6	>	>	>	>	<		>
7	>	>	>	<	<	<	

Expert #14 Data [Government]

Systems: Triads: 3 P Value: 0.0003

	1	2	3	4	5	6	7	8	9
1		<	>	>	>	<	>	>	>
2	>		>	>	>	<	>	>	>
3	<	<		>	>	<	>	>	>
4	<	<	<		<	<	>	>	>
5	<	<	<	>		<	<	<	>
6	>	>	>	>	>		>	>	>
7	<	<	<	<	>	<		>	>
8	<	<	<	<	>	<	<		<
9	<	<	<	<	<	<	<	>	

Unconstrained Systems / FoS: Triads: 0 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		<	>	>	>	<	>	>	>
2	>		>	>	>	>	>	>	>
3	<	<		>	>	<	>	>	>
4	<	<	<		<	<	<	>	>
5	<	<	<	>		<	<	>	>
6	>	<	>	>	>		>	>	>
7	<	<	<	>	>	<		>	>
8	<	<	<	<	<	<	<		>
9	<	<	<	<	<	<	<	<	

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		<	>	<	<	<	<
2	>		>	>	<	<	>
3	<	<		<	<	<	<
4	>	<	>		<	<	>
5	>	>	>	>		>	>
6	>	>	>	>	<		>
7	>	<	>	<	<	<	

Expert #15 Data [Government]

Systems: Triads: 16 P Value: 0.0918

	1	2	3	4	5	6	7	8	9
1		<	>	<	>	<	>	>	>
2	>		<	<	>	>	>	>	<
3	<	>		<	>	>	>	>	>
4	>	>	>		<	<	>	>	>
5	<	<	<	>		<	<	<	<
6	>	<	<	>	>		>	>	<
7	<	<	<	<	>	<		>	<
8	<	<	<	<	>	<	<		>
9	<	>	<	<	>	>	>	<	

Unconstrained Systems / FoS: Triads: 1 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		<	>	<	>	>	<	<	>
2	>		>	>	>	>	<	>	>
3	<	<		<	>	<	<	<	>
4	>	<	>		>	>	>	>	>
5	<	<	<	<		<	<	<	>
6	<	<	>	<	>		<	<	>
7	>	>	>	<	>	>		>	>
8	>	<	>	<	>	>	<		>
9	<	<	<	<	<	<	<	<	

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		>	>	>	>	>	>
2	<		<	<	<	<	>
3	<	>		<	<	<	>
4	<	>	>		>	>	>
5	<	>	>	<		<	>
6	<	>	>	<	>		>
7	<	<	<	<	<	<	

Expert #16 Data [Industry]

Systems: Triads: 2 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		<	<	<	<	<	<	<	<
2	>		>	<	>	>	<	>	>
3	>	<		<	<	<	<	>	>
4	>	>	>		>	>	<	>	>
5	>	<	>	<		<	<	>	>
6	>	<	>	<	>		<	<	>
7	>	>	>	>	>	>		>	>
8	>	<	<	<	<	>	<		>
9	>	<	<	<	<	<	<	<	

Unconstrained Systems / FoS: Triads: 0 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		<	<	<	<	<	<	<	<
2	>		>	<	>	>	>	>	>
3	>	<		<	<	<	<	<	>
4	>	>	>		>	>	>	>	>
5	>	<	>	<		<	<	>	>
6	>	<	>	<	>		<	>	>
7	>	<	>	<	>	>		>	>
8	>	<	>	<	<	<	<		>
9	>	<	<	<	<	<	<	<	

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		>	>	<	>	>	>
2	<		>	<	>	>	>
3	<	<		<	<	>	>
4	>	>	>		>	>	>
5	<	<	>	<		>	>
6	<	<	<	<	<		<
7	<	<	<	<	<	>	

Expert #17 Data [Government]

Systems: Triads: 4 P Value: 0.0004

	1	2	3	4	5	6	7	8	9
1		>	>	>	<	>	<	>	>
2	<		<	<	<	<	<	>	>
3	<	>		<	<	>	<	>	>
4	<	>	>		<	>	<	>	>
5	>	>	>	>		>	<	>	>
6	<	>	<	<	<		>	>	>
7	>	>	>	>	>	<		>	>
8	<	<	<	<	<	<	<		>
9	<	<	<	<	<	<	<	<	

Unconstrained Systems / FoS: Triads: 5 P Value: 0.0007

	1	2	3	4	5	6	7	8	9
1		>	>	>	>	<	>	<	>
2	<		<	<	<	<	<	<	>
3	<	>		<	>	<	<	<	>
4	<	>	>		>	<	<	<	>
5	<	>	<	<		<	<	>	>
6	>	>	>	>	>		<	>	>
7	<	>	>	>	>	>		>	>
8	>	>	>	>	<	<	<		>
9	<	<	<	<	<	<	<	<	

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		>	>	>	<	<	>
2	<		>	>	<	<	>
3	<	<		<	<	<	<
4	<	<	>		<	<	>
5	>	>	>	>		>	>
6	>	>	>	>	<		>
7	<	<	>	<	<	<	

Expert #18 Data [Government]

Systems: Triads: 15 P Value: 0.0636

	1	2	3	4	5	6	7	8	9
1		<	>	<	<	<	<	>	<
2	>		>	<	<	<	<	>	<
3	<	<		>	<	<	<	<	<
4	>	>	<		>	>	>	>	>
5	>	>	>	<		<	>	<	>
6	>	>	>	<	>		<	<	>
7	>	>	>	<	<	>		>	>
8	<	<	>	<	>	>	<		>
9	>	>	>	<	<	<	<	<	

Unconstrained Systems / FoS: Triads: n/a P Value: n/a

	1	2	3	4	5	6	7	8	9
1									
2									
3									
4									
5									
6									
7									
8									
9									

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		>	<	<	>	<	>
2	<		<	<	>	<	>
3	>	>		<	>	<	>
4	>	>	>		>	>	>
5	<	<	<	<		<	<
6	>	>	>	<	>		>
7	<	<	<	<	>	<	

Expert #19 Data [Government]

Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7	8	9
1		<	<	<	<	<	<	>	<
2	>		>	>	>	<	>	>	>
3	>	<		>	<	<	<	>	<
4	>	<	<		<	<	<	>	<
5	>	<	>	>		<	<	>	<
6	>	>	>	>	>		>	>	>
7	>	<	>	>	>	<		>	>
8	<	<	<	<	<	<	<		<
9	>	<	>	>	>	<	<	>	

Unconstrained Systems / FoS: Triads: 1 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		<	>	>	<	<	<	>	<
2	>		>	>	>	<	>	>	>
3	<	<		<	<	<	<	>	<
4	<	<	>		<	<	<	>	<
5	>	<	>	>		<	<	>	<
6	>	>	>	>	>		<	>	>
7	>	<	>	>	>	>		>	>
8	<	<	<	<	<	<	<		<
9	>	<	>	>	>	<	<	>	

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		>	>	<	>	>	>
2	<		>	<	<	<	<
3	<	<		<	<	<	<
4	>	>	>		>	>	>
5	<	>	>	<		>	>
6	<	>	>	<	<		>
7	<	>	>	<	<	<	

Expert #20 Data [Government]

Systems: Triads: 1 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	<	<	>	<	<	>	>
2	<		<	<	<	<	<	<	<
3	>	>		<	>	<	>	>	>
4	>	>	>		>	>	>	>	>
5	<	>	<	<		<	<	>	<
6	>	>	>	<	>		>	>	>
7	>	>	<	<	>	<		>	<
8	<	>	<	<	<	<	<		<
9	<	>	<	<	>	<	>	>	

Unconstrained Systems / FoS: Triads: 0 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	>	<	>	<	<	>	>
2	<		<	<	<	<	<	<	<
3	<	>		<	>	<	<	>	>
4	>	>	>		>	<	>	>	>
5	<	>	<	<		<	<	>	<
6	>	>	>	>	>		>	>	>
7	>	>	>	<	>	<		>	>
8	<	>	<	<	<	<	<		<
9	<	>	<	<	>	<	<	>	

Complex Systems: Triads: 1 P Value: 0.0020

	1	2	3	4	5	6	7
1		>	>	<	>	>	>
2	<		>	<	>	>	>
3	<	<		<	>	<	<
4	>	>	>		>	>	>
5	<	<	<	<		>	<
6	<	<	>	<	<		<
7	<	<	>	<	>	>	

Expert #22 Data [Government]

Systems: Triads: 5 P Value: 0.0007

	1	2	3	4	5	6	7	8	9
1		<	<	>	<	>	>	>	<
2	>		<	>	<	<	>	>	>
3	>	>		>	>	>	>	>	>
4	<	<	<		<	<	<	>	>
5	>	>	<	>		>	>	>	>
6	<	>	<	>	<		<	>	>
7	<	<	<	>	<	>		>	>
8	<	<	<	<	<	<	<		<
9	>	<	<	<	<	<	<	>	

Unconstrained Systems / FoS: Triads: 3 P Value: 0.0003

	1	2	3	4	5	6	7	8	9
1		<	<	>	<	>	>	>	<
2	>		<	>	<	<	>	>	>
3	>	>		>	>	>	>	>	>
4	<	<	<		<	<	<	>	>
5	>	>	<	>		>	>	>	>
6	<	>	<	>	<		<	>	>
7	<	<	<	>	<	>		>	>
8	<	<	<	<	<	<	<		<
9	>	<	<	<	<	<	<	>	

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		<	<	>	>	<	>
2	>		>	>	>	>	>
3	>	<		>	>	<	>
4	<	<	<		<	<	>
5	<	<	<	>		<	>
6	>	<	>	>	>		>
7	<	<	<	<	<	<	

Expert #23 Data [Government]

Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7	8	9
1		>	<	>	<	>	>	>	>
2	<		<	<	<	<	<	>	>
3	>	>		>	>	>	>	>	>
4	<	>	<		<	<	<	>	>
5	>	>	<	>		>	>	>	>
6	<	>	<	>	<		>	>	>
7	<	>	<	>	<	<		>	>
8	<	<	<	<	<	<	<		>
9	<	<	<	<	<	<	<	<	

Unconstrained Systems / FoS: Triads: 1 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	<	>	<	>	>	>	>
2	<		<	<	<	<	>	>	>
3	>	>		>	>	>	>	>	>
4	<	>	<		<	<	<	>	>
5	>	>	<	>		>	>	>	>
6	<	>	<	>	<		>	>	>
7	<	<	<	>	<	<		>	>
8	<	<	<	<	<	<	<		>
9	<	<	<	<	<	<	<	<	

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		>	>	>	<	<	>
2	<		>	>	<	<	>
3	<	<		>	<	<	>
4	<	<	<		<	<	>
5	>	>	>	>		>	>
6	>	>	>	>	<		>
7	<	<	<	<	<	<	

Expert #24 Data [Industry]

Systems: Triads: 5 P Value: 0.0007

	1	2	3	4	5	6	7	8	9
1		<	>	<	>	>	<	>	>
2	>		>	>	<	<	<	>	>
3	<	<		<	<	<	<	<	>
4	>	<	>		>	>	>	>	>
5	<	>	>	<		>	<	>	>
6	<	>	>	<	<		<	>	>
7	>	>	>	<	>	>		>	>
8	<	<	>	<	<	<	<		>
9	<	<	<	<	<	<	<	<	

Unconstrained Systems / FoS: Triads: 0 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	>	<	>	>	<	>	>
2	<		>	<	>	<	<	>	>
3	<	<		<	<	<	<	<	>
4	>	>	>		>	>	>	>	>
5	<	<	>	<		<	<	<	>
6	<	>	>	<	>		<	>	>
7	>	>	>	<	>	>		>	>
8	<	<	>	<	>	<	<		>
9	<	<	<	<	<	<	<	<	

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		>	>	>	<	>	>
2	<		<	<	<	<	>
3	<	>		<	<	<	>
4	<	>	>		<	>	>
5	>	>	>	>		>	>
6	<	>	>	<	<		>
7	<	<	<	<	<	<	

Expert #25 Data [Government]

Systems: Triads: 2 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		<	<	<	>	>	<	>	>
2	>		<	<	>	<	<	>	>
3	>	>		<	>	>	<	>	>
4	>	>	>		>	>	>	>	>
5	<	<	<	<		>	<	>	>
6	<	>	<	<	<		<	>	>
7	>	>	>	<	>	>		>	>
8	<	<	<	<	<	<	<		<
9	<	<	<	<	<	<	<	>	

Unconstrained Systems / FoS: Triads: 9 P Value: 0.0050

	1	2	3	4	5	6	7	8	9
1		>	>	>	<	<	>	<	>
2	<		<	<	<	<	<	<	<
3	<	>		>	>	<	>	<	<
4	<	>	<		<	<	<	<	>
5	>	>	<	>		<	>	<	>
6	>	>	>	>	>		>	<	>
7	<	>	<	>	<	<		<	>
8	>	>	>	>	>	>	>		<
9	<	>	>	<	<	<	<	>	

Complex Systems: Triads: 1 P Value: 0.0020

	1	2	3	4	5	6	7
1		>	>	>	>	<	>
2	<		>	<	<	<	>
3	<	<		<	<	<	<
4	<	>	>		>	>	>
5	<	>	>	<		<	>
6	>	>	>	<	>		>
7	<	<	>	<	<	<	

Expert #26 Data [Government]

Systems: Triads: 2 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		<	>	>	>	>	>	>	>
2	>		>	>	>	>	>	>	>
3	<	<		<	>	>	>	>	>
4	<	<	>		>	>	<	>	>
5	<	<	<	<		>	>	>	>
6	<	<	<	<	<		<	<	>
7	<	<	<	>	<	>		>	>
8	<	<	<	<	<	>	<		>
9	<	<	<	<	<	<	<	<	

Unconstrained Systems / FoS: Triads: 1 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		<	>	>	<	>	>	>	>
2	>		>	>	>	>	>	>	>
3	<	<		<	<	>	>	>	>
4	<	<	>		<	>	<	>	>
5	>	<	>	>		>	>	>	>
6	<	<	<	<	<		<	<	>
7	<	<	<	>	<	>		>	>
8	<	<	<	<	<	>	<		>
9	<	<	<	<	<	<	<	<	

Complex Systems: Triads: 1 P Value: 0.0020

	1	2	3	4	5	6	7
1		>	>	>	<	>	>
2	<		>	>	<	<	<
3	<	<		<	<	<	<
4	<	<	>		<	<	>
5	>	>	>	>		>	>
6	<	>	>	>	<		>
7	<	>	>	<	<	<	

Expert #27 Data [Industry]

Systems: Triads: 4 P Value: 0.0004

	1	2	3	4	5	6	7	8	9
1		>	>	>	>	>	<	>	>
2	<		>	<	>	<	<	>	>
3	<	<		<	<	>	<	>	>
4	<	>	>		<	>	<	>	>
5	<	<	>	>		<	<	>	>
6	<	>	<	<	>		<	>	>
7	>	>	>	>	>	>		>	>
8	<	<	<	<	<	<	<		<
9	<	<	<	<	<	<	<	>	

Unconstrained Systems / FoS: Triads: 3 P Value: 0.0003

	1	2	3	4	5	6	7	8	9
1		>	>	>	>	>	>	>	>
2	<		>	>	>	<	<	>	>
3	<	<		>	<	<	<	>	>
4	<	<	<		<	>	<	>	>
5	<	<	>	>		<	<	>	>
6	<	>	>	<	>		<	>	>
7	<	>	>	>	>	>		>	>
8	<	<	<	<	<	<	<		>
9	<	<	<	<	<	<	<	<	

Complex Systems: Triads: 1 P Value: 0.0020

	1	2	3	4	5	6	7
1		>	>	<	>	>	>
2	<		>	<	<	<	<
3	<	<		<	<	<	<
4	>	>	>		>	<	>
5	<	>	>	<		<	>
6	<	>	>	>	>		>
7	<	>	>	<	<	<	

Expert #28 Data [Industry]

Systems: Triads: 19 P Value: 0.2424

	1	2	3	4	5	6	7	8	9
1		<	>	<	<	<	>	>	<
2	>		>	<	<	<	>	>	<
3	<	<		>	<	>	>	<	<
4	>	>	<		<	<	>	>	>
5	>	>	>	>		>	>	<	>
6	>	>	<	>	<		>	<	>
7	<	<	<	<	<	<		<	>
8	<	<	>	<	>	>	>		<
9	>	>	>	<	<	<	<	>	

Unconstrained Systems / FoS: Triads: 18 P Value: 0.1794

	1	2	3	4	5	6	7	8	9
1		>	>	<	<	<	<	>	<
2	<		>	<	<	<	<	<	>
3	<	<		>	<	<	>	<	<
4	>	>	<		>	>	>	>	>
5	>	>	>	<		>	>	<	>
6	>	>	>	<	<		<	>	>
7	>	>	<	<	<	>		<	<
8	<	>	>	<	>	<	>		<
9	>	<	>	<	<	<	>	>	

Complex Systems: Triads: 10 P Value: 0.5530

	1	2	3	4	5	6	7
1		<	>	>	>	>	>
2	>		>	>	>	<	<
3	<	<		>	<	>	>
4	<	<	<		>	>	<
5	<	<	>	<		<	>
6	<	>	<	<	>		>
7	<	>	<	>	<	<	

Expert #31 Data [Government]

Systems: Triads: 1 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	>	<	>	>	>	>	>
2	<		>	<	>	>	<	>	>
3	<	<		<	<	<	<	<	>
4	>	>	>		>	>	>	>	>
5	<	<	>	<		<	<	>	>
6	<	<	>	<	>		<	>	>
7	<	>	>	<	>	>		>	>
8	<	<	>	<	<	<	<		>
9	<	<	<	<	<	<	<	<	

Unconstrained Systems / FoS: Triads: 5 P Value: 0.0007

	1	2	3	4	5	6	7	8	9
1		>	>	<	>	<	>	>	>
2	<		>	<	<	<	<	>	>
3	<	<		<	<	>	<	<	>
4	>	>	>		>	>	>	>	>
5	<	>	>	<		>	<	>	>
6	>	>	<	<	<		<	>	>
7	<	>	>	<	>	>		>	>
8	<	<	>	<	<	<	<		>
9	<	<	<	<	<	<	<	<	

Complex Systems: Triads: 0 P Value: 0.0000

	1	2	3	4	5	6	7
1		>	>	>	<	<	>
2	<		>	<	<	<	<
3	<	<		<	<	<	<
4	<	>	>		<	<	>
5	>	>	>	>		>	>
6	>	>	>	>	<		>
7	<	>	>	<	<	<	

Expert #33 Data [Government]

Systems: Triads: 1 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	>	<	>	>	>	>	>
2	<		<	<	>	>	>	>	>
3	<	>		>	>	>	>	>	>
4	>	>	<		>	>	>	>	>
5	<	<	<	<		>	>	>	>
6	<	<	<	<	<		>	>	>
7	<	<	<	<	<	<		>	>
8	<	<	<	<	<	<	<		>
9	<	<	<	<	<	<	<	<	

Unconstrained Systems / FoS: Triads: 1 P Value: 0.0001

	1	2	3	4	5	6	7	8	9
1		>	>	>	>	>	>	>	>
2	<		<	<	>	<	>	<	>
3	<	>		>	>	>	>	<	>
4	<	>	<		>	<	>	<	>
5	<	<	<	<		<	>	<	<
6	<	>	<	>	>		>	<	>
7	<	<	<	<	<	<		<	>
8	<	>	>	>	>	>	>		>
9	<	<	<	<	>	<	<	<	

Complex Systems: Triads: 1 P Value: 0.0020

	1	2	3	4	5	6	7
1		>	>	>	<	>	>
2	<		>	<	<	<	<
3	<	<		<	<	<	>
4	<	>	>		<	>	>
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