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Thomas James Meyers
Old Dominion University

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A RISK- AND FUZZY SET-BASED METHODOLOGY FOR ADVANCED CONCEPT TECHNOLOGY DEMONSTRATION MILITARY UTILITY ASSESSMENT DESIGN

by

Thomas James Meyers
B.S. April 1975, Jacksonville University
M.S. October 1989, U.S. Naval Postgraduate School

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Approved by:

Charles B. Keating (Director)

Resit Unal (Member)

C. Ariel Pinto (Member)

Bruce A. Conway (Member)

ABSTRACT

A RISK- AND FUZZY SET-BASED METHODOLOGY FOR ADVANCED CONCEPT TECHNOLOGY DEMONSTRATION MILITARY UTILITY ASSESSMENT DESIGN

Thomas James Meyers
Old Dominion University, 2007
Director: Dr. Charles B. Keating

The U.S. Department of Defense Advanced Concept Technology Demonstration (ACTD) and derivative, rapid acquisition programs offer timely solutions to critical military needs by assessing the utility of technologies mature enough to be fielded without application of traditional, defense system development processes. Military utility assessments (MUA) are ACTDs' most critical features, but the lack of a standard for identifying assessment criteria tailored to specific demonstrations risks poorly informed acquisition decisions and the military operations those decisions are intended to support.

The purpose of this research was to develop and deploy a methodology for identifying measures of effectiveness integral to advanced concept technology demonstration military utility assessment design. Within a context determined by attributes of complex systems, the research observed twin premises that ACTD assessment designs should accommodate: all risks possible when incorporating demonstration prototypes within superior and complex, joint military operations metasystems; and the ambiguities and other of what have been termed "fuzzy" manifestations of the cognition and language with which end-user, military operators craft and express perspectives required to identify measures of effectiveness fundamental to MUA designs. The effort pursued three research questions:

(1) How might joint military operations metasystem models guide the identification of ACTD measures of effectiveness?

(2) How might be developed and employed joint military metasystem models with which can be identified ACTD measures of effectiveness?

(3) How useful might ACTD managers and analysts find the MUA design methodology developed and deployed with this research?

The deployed methodology stimulated answers to these research questions by uniquely combining tailored versions of established risk assessment methods with a fuzzy method for resolving small group preferences. The risk assessment methods honored one research premise while enabling the identification and employment of a joint military operations metasystem model suited to MUA design needs of a simulated ACTD. The fuzzy preference method honored the second research premise as it, too, promoted metasystem model employment. The complete methodology was shown to hold favor with a large segment of a community expert in managing and assessing the utility of ACTDs emphasizing critical, joint military service needs.

I dedicate this work to my parents, my children, and my wife: to Mom and Dad for instilling in me the value of education and the perseverance to acquire it; to Jenny and Scotty – Daddy's Baby Doll and Buddy Boy – for being everything I could ever want; and to Yolanda…for all of that and somehow even more. I love you all.

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I shall always remain grateful to Ann Arnold, El Halley, Dennis Popiela, and Tom Fernan; without their incredibly generous and beyond-the-call-of-duty gifts of time and thought, this dissertation could not have materialized. For support granted me by other colleagues within the U.S. Joint Forces Command and The Johns Hopkins University Applied Physics Laboratory, I am also indebted.

Lastly, I wish to thank every one of the Old Dominion University's Department of Engineering Management and Systems Engineering faculty members with whom my program of study ever intersected. I thank them for a superb program and, surely more importantly, for a program execution ever-guided by their and their department's plainly genuine sense of student worth.

PREFACE

This dissertation advances a methodology developed with the hope that United States military service members will benefit from its application. The methodology's tested application domain of advanced concept technology demonstrations (ACTD) was chosen to represent other domains to which it may also be applied for the benefit of joint forces and missions: domains such as ACTD-derivative, joint capabilities technology demonstrations; rapid prototyping efforts of the Department of Defense(DoD); formal, DoD acquisition-related operational testing, and other domains prominently characterized by a need to employ subject matter experts for the identification and emplacement of measures of effectiveness able to drive meaningful assessments of the utility of systems and processes proposed for military use.

The research with which was developed and demonstrated this risk- and fuzzy set-based methodology for ACTD military utility assessment (MUA) design exploited theoretical and methodological perspectives of a problem drawn from practice, and only with those perspectives could the methodology be claimed to support practitioners. While some might argue the methodology's principal components of risk assessment, fuzzy set theory, and complex systems as peripheral to the realm of everyday, military operations, the researcher believes those components to undeniably and significantly contribute to assessments of utility of prototypes and methods proposed for the military. Given the opportunity to do so through the use of this document's practitioner guide and fundamental themes, the methodology derived from this research effort will well support current and future, U.S. military missions.

This dissertation comprises five chapters and ten appendices constructed and linked to offer readers a hopefully understandable and appealing blend of theoretical, methodological, and practical concerns regarding ACTD and similar, MUA designs. Chapter sections are likewise intended to clearly and comprehensively support chapter themes.

The introductory chapter identifies a research purpose and questions prompted by a MUA design standards deficiency noted by the DoD and external agencies as having plagued the ACTD program since its 1994 inception. The first chapter also offers a characterization of the ACTD program in terms of history and intent, together with the intent and other attributes of demonstration MUAs. Corresponding emphasis upon the complex nature of military operations that ACTDs are expected to markedly enhance establishes a context observed as the MUA design methodology was developed, deployed, and evaluated for its own utility.

The second chapter review of pertinent literature extrapolated ACTD program and MUA intents in identifying nine elements of the literature bearing on the MUA design standards problem. Relatively obvious elements like risk assessment, fuzzy set theory, and fuzzy approaches to risk assessment are explained, as are those less obvious – such as pairwise comparisons and small expert group characteristics – once the latter are logically drawn from the former. The Literature Review chapter represents a thorough and detailed effort to support the MUA design methodology explained in the following chapter.

"Research Methodology" is the heart of the dissertation document. This third chapter encompasses a rationale for and description of the MUA design methodology and its employment. It notably offers a description of the action research format used with this particular research effort and intended to be used with all applications of the design methodology. It also identifies and elaborates upon the five-phase design that governed this work, and it cites the approach emplaced to ensure a research effort faithful to tenets of reliability and validity.

The Results chapter illustrates the design methodology's deployment, beginning with deliberations of an action research group of one leader and three additional, military operations experts, and concluding with judgments of the proposed methodology's utility rendered by a 20-member expert group of managers and analysts that represented a sizable portion of all individuals ever to have pursued or supervised MUA designs for U.S. multi-service demonstrations. Results chapter data evince the methodology utility next addressed in "Conclusions."

The Conclusions chapter links methodology deployment results with the three research questions of the Introduction, argues for methodology status of the research's risk- and fuzzy set-based approach to MUA design, and cites theoretical, methodological, and practical contributions made by the research. It also serves a call for research targeting further mitigation of ACTD and ACTD-like, assessment design problems.

This dissertation's first nine appendices complement information resident in its five chapters, but the tenth crystallizes the principal intent of all work portrayed in the document. The "ACTD Assessment Guide for Practitioners" notes 25 steps that capture for demonstration managers and analysts the essence of the MUA design methodology proposed here. The Guide is not prescriptive, in keeping with the methodological level claimed for this research's assessment design approach; but it must be used smartly and rigorously. Though other research products may be rightfully evaluated as important, the Guide is the only one that can genuinely, immediately, and significantly benefit U.S. military service members.

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INTRODUCTION

The U.S. Department of Defense instituted its Advanced Concept Technology Demonstration (ACTD) program in 1994 to “help expedite the transition of maturing technologies from…developers to…[military] users” (Department of Defense [DoD], no date-a, Introduction to ACTDs: Introduction section, ¶ 3) challenged by rapidly changing and significant threats (DoD, no date-b; Payton 2002). Conducted largely free of longer-established but more prescriptive and time-consuming (U.S. General Accounting Office [GAO], 2002), defense acquisition procedures, these demonstrations offer opportunities to relatively quickly advance to military use critically needed (DoD, no date-a), technological systems proposed but not necessarily developed for the military. The ACTD program is noted to have met its intent in widely varying degrees (DoD, 1997, no date-a; “On the Fast Track,” 2005; Payton, 2002; South, 2003; U.S. Congressional Budget Office [CBO], 1998; GAO, 1999, 2002), with numerous demonstrations criticized for frailties of methods used to assess the military utility of proffered systems (GAO, 2002).

“The heart of an ACTD is the assessment of military utility by the warfighter” (DoD, no date-a, ACTD Guidelines: Formulation, Selection, and Initiation – Formulation and Submission section, ¶ 11), yet poorly designed or executed military utility assessments (MUA) have plagued many (GAO, 2002) of the nearly 150 demonstrations conducted 1995-2006 (DoD, 2006). Responsible DoD officials have conceded the need

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for standards promoting thorough and consistent assessments (GAO, 2002), but none have been formally promulgated by the department (A. G. Arnold, personal communication, January 18, 2005; W. F. Smith, personal communication, January 18, 2005). This lack of MUA design standards invites a plethora of risks to acquisition decisions (GAO, 2002) and the very military operations those decisions are intended to support (DoD, no date-a; GAO, 2002). The standards deficiency constitutes a serious problem that should be eliminated and, if smartly addressed, can be.

PROBLEM STATEMENT

Military utility assessments are the most critical features of advanced concept technology demonstrations, yet poorly designed or executed assessments have plagued numerous demonstrations and represent significant risks to system acquisition decisions and military operations the decisions are intended to support. The ACTD program suffers from a lack of standards promoting consistently thorough assessment designs tailored to individual demonstrations. Program officials concede the need for improved designs but have provided no mechanism with which ACTD managers and their staffs can rigorously identify the assessment criteria those designs should emplace.

THE ACTD PROGRAM

Findings and recommendations of the 1986 President's Blue Ribbon Commission on Defense Management, commonly called the Packard Commission, catalyzed the ACTD program (South, 2003). Eight years later, the Commission's call for a new, defense acquisition management concept (President's Blue Ribbon Commission on Defense Management, 1986) became what then-U.S. Secretary of Defense, Les Aspin termed an ACTD program to "address operational utility and operational cost effectiveness with minimal technical risk" (Aspin, 1994, as cited in South, 2003, p. 14). Those tenets of the program that spawned today's ubiquitous, Predator and Global Hawk unmanned aerial vehicle (GAO, 1999; "On the Fast Track," 2005) operations, for example, remain unchanged since 1994.

Advanced concept technology demonstrations are "extremely important precursor[s] to…[what might be] formal acquisition processes" (Bachkosky, 1997, p. 54) involving certain types of military systems. They offer military users "try-before-buy" (Payton, 2006, p. 11) opportunities to operate prototype systems, explore prototype capabilities derived from those systems, judge prototype system effectiveness and suitability, and so influence related acquisition decisions that may follow. "Specifically, ACTDs focus on the question, 'Is there a near-term solution, based on mature technology, that provides a useful and cost-effective response to…[a particularly notable] military need?'" (Perdue, 1997, p. 18). The ACTD process is not intended as "a substitute for the formal acquisition system required to introduce…weapons systems such as ships, tanks, …aircraft, ...or other[s]…[not involving]…substantial modification of operational concepts or procedures" (Perry, 1995, as cited in South, 2003, p. 16). It is, instead, a mechanism for blending "technology, …advanced concepts, tactics, techniques, and procedures" (Payton, 2002, p. 72) to satisfy "critical military needs" (DoD, no date-a, Introduction to ACTDs: Focus of ACTDs – User needs section).

Demonstrations allow military operators to gain understanding of demonstration prototype-derived capabilities postulated as significant. Users develop employment concepts, or concepts of operations (CONOPS) (Ghambir, 2001; Koumbis, 2006), for ACTD systems and, through trials of appropriate numbers, assess the military utility of capabilities those systems provide (DoD, no date-a, Introduction to ACTDs: Introduction section, ¶ 4) in concert with developed CONOPS. These processes lead to one of three demonstration outcomes (DoD, no date-a, Introduction to ACTDs: Introduction section, ¶ 5):

(1) Demonstration systems and associated capabilities may be found militarily effective, suitable, and required on a scale exceeding that of the demonstration. In such cases demonstration officials will recommend that additional and possibly refined systems be procured by formal acquisition means and that assessed prototypes remain in the military's possession to provide interim capabilities;

(2) Demonstration systems and associated capabilities may be found militarily effective and suitable but required only to an extent already satisfied by residual prototypes. Demonstration officials will recommend against additional acquisitions in those cases; or

(3) Assessors may adjudge demonstration systems insufficiently useful and recommend against acquisition or residual system pursuits.

Outcomes realized largely depend on military utility assessments peculiarly designed and executed for every ACTD.

ACTD MILITARY UTILITY ASSESSMENTS

The "primary purpose of an ACTD is to allow the user to evaluate the military utility of a [technology prototype-fostered] capability being considered in response to a critical military need, and to do so prior to a decision by DoD to acquire that capability" (DoD, no date-a, ACTD Guidelines: Transition – Test and Evaluation – Assessment of Military Utility section). Given that critical military needs may include counters to new threats, significant improvements in current mission performance, or wholly new approaches to warfare (DoD, no date-a, ACTD Guidelines: Management Plans – Objective section), military utility assessments aim to characterize demonstration systems in terms of two questions:

(1) What can it do? In other words, is it effective?

(2) Can it be operated and maintained by the user? In other words, is it suitable?

(Perdue, 1997; DoD, no date-a, ACTD Guidelines: Transition – Test and Evaluation – Assessment of Military Utility section). These questions must be answered using ACTDs' three most essential, analytical components of critical operational issues, measures of effectiveness, and measures of performance (DoD, no date-a, ACTD Guidelines: Transition – Test and Evaluation – Assessment of Military Utility section):

(a) Critical operational issues (COI). Incontrovertible, user-identified requirements for mission success or, equivalently, "show stoppers" (Sproles, 2002, p. 257) that "if not...addressed...[to assessors' satisfaction] will make...[ACTDs] unacceptable on functional grounds" (Sproles, 2001, p. 147);

(b) Measures of effectiveness (MOE). "High level indicators of operational effectiveness or suitability (DoD, no date-a, ACTD Guidelines: Management Plans – Concept and Technical Approach – Measures of Effectiveness [MoE] and Measures of Performance [MoP] section); "the engines of (test and evaluation)" (Sproles, 2002, p. 257); and standards directly derived by users from COIs, independent of systems under evaluation and against which should be assessed the performance (Sproles, 2000, 2001, 2002) of ACTD prototypes; and

(c) Measures of performance (MOP). "Technical characteristics that determine a particular aspect of effectiveness or suitability (DoD, no date-a, ACTD Guidelines: Management Plans – Concept and Technical Approach – Measures of Effectiveness [MoE] and Measures of Performance [MoP] section), evaluations of "internal" (Sproles, 2001, p. 146) functions, and the system performance values that are judged against MOEs (Sproles, 2000, 2001, 2002) in efforts to assess demonstration system effectiveness and suitability.

With COI identification a strict charge of military operators and MOPs mere evaluations of ACTD prototype attributes, it is left for utility assessments to apply MOEs providing "the maximum opportunity to demonstrate…[any prototype] utility…[and operational] synergy" (Arnold and Kujawa, 1999, p. 34) realized when employing demonstration systems within settings replicating military operations (GAO, 2002). Effectiveness measures normally represent formulations "heavily dependent on creative thought" (Sproles, 2002, p. 257) of subject matter experts, but a MOE development process that respects key features of complex military systems, or military systems of systems, might more reliably channel expert creativity toward attributes of consistency, thoroughness, and realism officially endorsed for utility assessments (GAO, 2002).

THE JOINT MILITARY OPERATIONS METASYSTEM

Advanced Concept Technology Demonstration program guidelines cite three classes of demonstrations. Class I ACTDs typically address information systems pursued to meet very specific needs that can be met with system quantities roughly those used for demonstrations. Class II ACTDs involve weapon or sensor systems, such as the Predator and Global Hawk, similar to many procured through formal means (DoD, no date-a, ACTD Guidelines: Transition – Classes of ACTDs section) but novel in terms of capabilities provided. Class III ACTDs are termed "systems of systems" (DoD, no date-a, ACTD Guidelines: Transition – Classes of ACTDs section, ¶ 3) demonstrations because they comprise combinations of: already-fielded, or legacy, systems; systems not yet fielded but being acquired; and systems drawn from the technology base, such as those that could be categorized as Class I or II if assessed alone. The system of systems nature of Class III ACTDs effectively mandates that their assessments accommodate system and process integration issues associated with the demonstrations' own components, but this concern can be generalized to endorse MUAs accommodating integration issues attendant to all ACTDs as they are evaluated in settings replicating the complex and hierarchically superior systems of systems, the metasystems (Keating et al., 2003; Keating, Sousa-Poza, & Mun, 2004, Keating, Sousa-Poza, & Kovacic, 2005) of joint, or multi-U.S. military service, operations (DoD, no date-a, ACTD Guidelines: Formulation, Selection, and Initiation – Objective section, ¶ 2) with which demonstration prototypes or their derivatives can be ultimately incorporated (DoD, no date-a).

"There is no clear, common, definition of 'systems of systems'" (DoD, 1999, p. 44). "The term…means different things to different people" (DoD, 1999, p. 43), but recent literature (Carlock & Fenton, 2001; Chen & Clothier, 2003; DoD, 1999; Eisner, Marciniak, & McMillan, 1991; Keating et al., 2003; Keating et al., 2004; Luman, 1998; Maier, 1999; Sage & Cuppan, 2001) evinces a confluence of complex system concepts relevant to ACTD assessment design and described with this study's most important terms in Appendix A:

- Integrating complex systems - "many of which…[may not be] well integrated themselves" (DoD, 1999, p. 43) - to effectively serve joint military operations is a daunting task (Sage & Cuppan, 2001) of equally challenging implications for the measurement of integration success;
- Assessments of joint military operations metasystems must "accurately (reflect) joint operations" (DoD, 1999, p. 44), including CONOPS (Carlock & Fenton, 2001);
- Joint military operations are executed by what may be considered sociotechnical, military metasystems of prominent social (such as individual and organizational attitudes or relationships among distinct commands) and technical (such as command structures, equipment, or knowledge required for military missions) components. Advanced concept technology demonstrations mark attempts to consequentially redesign military operations metasystems, with redesign the central theme of a sociotechnical systems theory espousing balances of social and technical components (Keating, Jacobs, Sousa-Poza, & Pyne, 2001);
- Joint military operations metasystems are continuously evolving and heterogeneous sets of legacy and new systems, with every system defined by its own operational, economic, political, technical, or other attributes (Carlock & Fenton, 2001; Chen & Clothier, 2003; Keating et al., 2003; Maier, 1999; Sage & Cuppan, 2001) and interacting with others in complex and myriad ways (Keating et al., 2003);
- Assessment designs must consider truly optimal, metasystem configurations as fallacies precluded by metasystems' ever-evolving nature and environmental factors such as threat. Design processes should emphasize satisfactory configurations to be

identified by assessed systems' intended users (Keating et al., 2003; Kwok, Ma, Vogel, & Zhou, no date);

- Assessment designs must concede and accommodate high degrees of ambiguity and uncertainty regarding metasystems addressed (Keating et al., 2003);
- Assessment designs should pursue what Keating, Sousa-Poza, and Kovacic (2005) have termed phased system changes that respect anticipated effects of ACTDs upon the military operations metasystems with which they could be incorporated.

The foregoing list and earlier text illuminate two ACTD MUA design principles that most motivated this research:

- To design military utility assessments able to adequately measure effectiveness and suitability of demonstration prototypes, the ACTD program tenet regarding minimal technical risk must be expanded to one emphasizing "all types of risk" (Tchankova, 2002, p. 294) – such as organizational or operational as well as technical – possible when incorporating prototypes with joint military operations metasystems; and
- As with all ACTD assessment activities, MUA design processes should respect end-user perspectives in identifying risks of incorporating ACTD prototypes with joint military operations metasystems. Assessment design schemes should therefore employ analytical methods suited to the ambiguities and other of what have been termed "fuzzy" (Zadeh, 1965, p. 338) manifestations of the cognition and language (Büyüközkan & Feyzioğlu, 2003; Karwowski & Mital, 1986) with which end-users would craft and express their perspectives.

These two principles prompted a research effort that merged methods of risk assessment and fuzzy set theory to yield a fuzzy approach to risk assessment and a methodology for identifying the measures of effectiveness integral to advanced concept technology demonstration military utility assessment design.

RESEARCH PURPOSE AND QUESTIONS

The purpose of this research was to develop and deploy a methodology for identifying measures of effectiveness integral to advanced concept technology demonstration military utility assessment design. The purpose implied two objectives: developing a literature-based methodology with which can be identified measures of effectiveness integral to ACTD MUA design; and deploying that methodology to gauge its worth to ACTD MUA design. Those two objectives prompted three questions that steered the research effort:

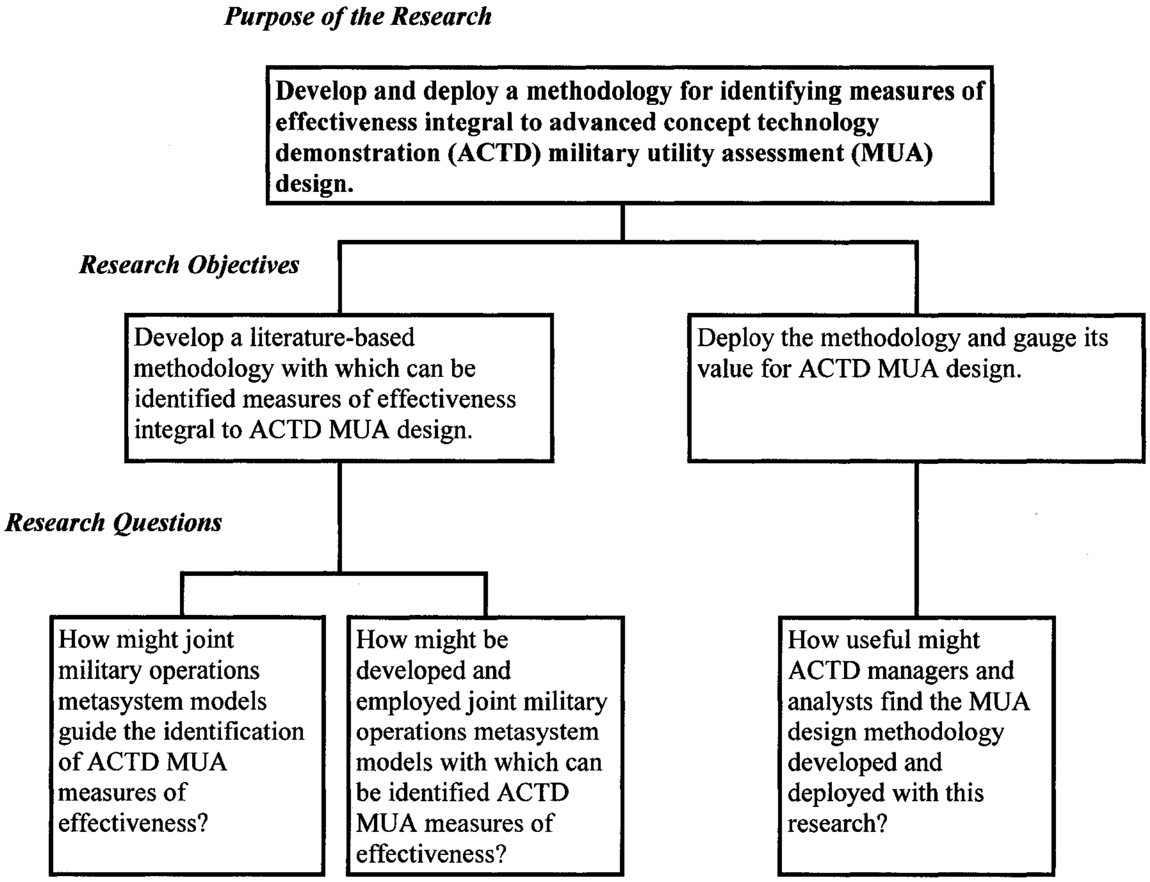
(1) How might joint military operations metasystem models guide the identification of ACTD MUA measures of effectiveness?

(2) How might be developed and employed joint military operations metasystem models with which can be identified ACTD MUA measures of effectiveness?

(3) How useful might ACTD managers and analysts find the MUA design methodology developed and deployed with this research?

Once developed, the methodology was deployed to synthesize from joint military operations literature and expert group perspectives a joint military operations metasystem model suited to a simulated ACTD. Given that model and additional deliberations of the operations expert group, the methodology next identified a group preference of prioritized risks associated with fielding the simulated ACTD and from which could be derived measures of effectiveness needed to assess the demonstration's military utility. The methodology and its deployment results were lastly reviewed by a distinct expert group of ACTD managers and analysts who evaluated the methodology's potential contribution to ACTD MUA design. Figure 1 represents the framework of inquiry that guided this dissertation's research.

Figure 1. Framework of Inquiry



SIGNIFICANCE OF THE STUDY

This research contributed to the theory, methodology, and practice associated with joint military operations metasystem transformations driven by new technology and process insertion. In doing that, it also suggested a set of theoretical, methodological, and practical considerations regarding assessments of similar transformations applied to other types of metasystems.

The study explored boundaries among theories regarding research in the fields of complex systems, risk, and fuzzy sets. It revealed undeniable links among those domains and forced consideration of synergies to be gained by exploiting them. It recognized the utility of fuzzy set theory in describing epistemic risk so prominent in complex system settings, and its emphasis upon risk, in particular, identified considerations pertinent to the recognition of failure modes of complex systems.

The work demonstrated a valid, risk- and fuzzy set-based methodology for ACTD military assessment design, and in doing so provided a flexible yet common scheme for assessments quite unlike the ad hoc approaches previously used. The methodology itself promoted a merger of risk assessment and fuzzy set theory that reflected theoretical findings regarding the inextricability of fuzzy approaches to particular risk settings, and the methodology's deployment under an action research format endorsed the efficacy of that qualitative scheme for assessment design efforts.

The research lastly and perhaps most significantly contributed to practice. The MUA design methodology produced offers ACTD program executives, managers, and analysts a standard they concede as lacking and necessary. A corollary product of the research, a practitioner's guide, can rigorously enable the identification and emplacement of measures of effectiveness fundamental to ACTD MUA designs or designs needed for assessments of ACTD-like enterprises. Indeed, the methodology and its derivative techniques suggest means with which complex system transformations of many kinds – especially those planned by small numbers of subject matter experts constrained by limited, evaluation resources – can be anticipated.

LIMITATIONS AND DELIMITATIONS OF THE STUDY

The research described here was delimited in several ways and for several reasons. Limitations of research processes and results were partly attributable to the delimitations imposed.

Delimitations constrained the research scope and primarily comprised restrictions upon methodology deployment. The methodology was applied to only a single, simulated, joint operations ACTD derived from a single, actual, joint operations ACTD. This restriction was emplaced because it honored the distinctiveness of individual demonstrations while still satisfying research questions. The methodology was applied by a small group of joint military operations experts of backgrounds less diverse than that normally espoused in the literature, a conscious research concession to the homogeneity of the U.S. military officer corps and the arguably often limited availability of more heterogeneous groups to ACTD managers and analysts. Lastly, the operations expert group pursued just one cycle of an action research process conventionally iterative but restricted in this research to suitably exercise the proposed methodology without unduly taxing valuable resources personified by volunteer members of the expert group.

Most research limitations of greatest significance directly reflected or derived from delimitations established. The methodology's single application to a single (simulated) ACTD kept the research scope manageable but simultaneously opened to challenge the generalization of research findings. So, too, could be criticized the study's use of a small and purposively selected group of military operations experts drawn, however carefully, from an expert pool many times larger. The single iteration of an action research-based MUA design scheme could prompt concerns regarding the completeness of the proposed methodology's deployment results, though such concerns might be blunted by arguments emphasizing the proof-of-concept nature of the deployment over comprehensiveness of the results. Likewise, plausible criticisms of the study's use of purposively selected, joint operations ACTD managers and analysts would have to overcome the reality that the expert sample used constituted a statistically significant portion – perhaps as high as 50% – of a very small population of joint operations ACTD experts largely known and available to the researcher.

A possible limitation independent of delimitations imposed could derive from researcher assumptions regarding factors most consequential to MUA design. Should the nine factors identified in the literature and employed for methodology development constitute other than a necessary and sufficient set, the design methodology itself could suffer challenge.

SUMMARY

The U.S. Department of Defense Advanced Concept Technology Demonstration program is intended to provide rapid and low-risk solutions to critical military operations problems, yet it offers no rigorous methodology for designing military utility assessments of demonstration systems. This research sought to correct that deficiency by developing and deploying a joint military operations metasystem-oriented methodology to identify measures of effectiveness required of ACTD MUA designs. The research was steered by three questions:

(1) How might joint military operations metasystem models guide the identification of ACTD MUA measures of effectiveness?;

(2) How might be developed and employed joint military operations metasystem models with which can be identified ACTD MUA measures of effectiveness?; and

(3) How useful might ACTD managers and analysts find the MUA design methodology developed and deployed with this research?

Joint military operations metasystem characteristics pertinent to advanced concept technology demonstrations were identified and in turn promoted the identification of two principles of ACTD MUA design: that assessments address all types of risk – such as organizational or operational as well as technical risk – possible when incorporating demonstration prototypes with superior and complex, joint military operations systems; and that MUA design processes employ analytical schemes suited to fuzzy manifestations of human cognition and language that will be encountered during design phases. These two principles and the three research questions drove a thorough literature review.

LITERATURE REVIEW

This dissertation research rested on two premises: that ACTD military utility assessments should account for principal risks associated with deploying demonstration systems and associated CONOPS within standing, military operations metasystems of relevance; and that the identification of principal risks to metasystem operations must accommodate the ambiguities and other "fuzzy" (Zadeh, 1965, p. 338) characteristics of human cognition and language (Büyüközkan & Feyzioğlu, 2003; Karwowski & Mital, 1986) inseparable from the subject matter expert (SME) judgments needed to identify and evaluate metasystem risks. A literature review determined that these premises could foster an original and significant contribution to the extant body of relevant research.

The literature is witness to an abundance of risk assessment study and practice. It attests to an equal abundance of study and practice regarding fuzzy set theory. The rich and ever-growing offerings of both fields of literature provided this study the thread to stitch together a logical methodology for ACTD MUA design. A smaller but equally instructive body of material addressing mergers of risk assessment and fuzzy set theory – fuzzy approaches to risk assessment – further endorsed this work's premises and served as a first step in channeling the research toward literature deficiencies as evident as the abundance of risk or fuzzy set treatments. Additional steps certified that this study would remove some of those deficiencies.

The literature suffers from inattention to the utility of risk assessment and fuzzy set theory, singly or together, within contexts true to joint military operations. Military operations evaluations seem seldom to have been made using methods, techniques, or tools of either field. Published literature regarding ACTD MUA design even more rarely addresses what this research presumed to be markedly supportive aspects of risk assessment, fuzzy set theory, and complex system-based approaches to design. That paucity of pertinent literature illuminated the need for a risk- and fuzzy set-based methodology for advanced concept technology demonstration military utility assessment design.

RELEVANCE OF RISK ASSESSMENT

"ACTDs are intended primarily to explore operational...[effectiveness and suitability] issues of mature technologies; high technical risk is normally not acceptable" (DoD, no date-a, ACTD Guidelines: Management Plans - Concept and Technical Approach - Technical Risk Assessment section). Demonstration planning must nevertheless account for technical risks together with others such as the acceptability of schemes – the CONOPS – envisioned for employment of demonstration prototypes. All "risks must be identified and accepted by the primary stakeholders in the ACTD prior to its initiation" (DoD, no date-a, ACTD Guidelines: Formulation, Selection and Initiation - Formulation and Submission section, ¶ 10). This emphasis upon risk permeates the ACTD program as it does all U.S. defense system acquisition processes (DoD, 2003a, 2003b, 2003c). It supports a notion that military utility assessment designs could or even should be risk-based.

"*Risk-based decisionmaking and risk-based approaches in decisionmaking* are terms frequently used to indicate that some systematic process that deals with uncertainties is being used to formulate...options and assess their various impacts and ramifications" (Haimes, 2004, p. 3). While often applied for purposes of policy development, risk-based decision processes need not be so restricted. "Risk analysis is always part of a decision context" (Aven & Kørte, 2002) and has been at least twice applied to determine the scope of operational testing and evaluation (Thompson & Montagne, 1998) required for military systems being procured with traditional acquisition mechanisms. The efficacy of a risk-based approach to ACTD MUA design becomes even more apparent with review of risk-related definitions and risk assessment conventions.

FUNDAMENTALS OF RISK ASSESSMENT

Risk is perhaps most often defined as a function of likelihood and consequence (Bedford & Cooke, 2001; DoD, 2003c; Haimes, 1998, 2004; Kaplan & Garrick, 1981; Kaplan, Haimes, & Garrick, 2001; Kosmowski, 2000; Kujawski, 2002; Thompson & Montagne, 1998). Within Department of Defense publications frequently used by ACTD managers, risk is defined as "a measure of the potential inability to achieve overall program objectives" (DoD, 2003c, p. 7), a definition those same managers could plausibly be expected to interpret as a demonstration's potential inability to perform well against MUA measures of effectiveness. Two additional and important definitions presented within the context of the ACTD program include:

- Risk events are events that, should they occur, might limit capabilities otherwise achievable with ACTD prototypes and which therefore warrant assessment in terms of the two major risk components of likelihood and consequence (DoD, 2003c); and
- Risk assessment is the process of first identifying risk events (Tchankova, 2002; Williams, 1995) and then analyzing them for their criticality to military utility (DoD, 2003c). The process is intended to answer three questions: (a) What can go wrong?;

(b) What is the likelihood that it will?; and (c) What would be the consequences if it does? (Haimes, 1991, 2004; Kaplan & Garrick, 1981).

Like the development of a demonstration's MOEs, the identification and analysis of risk events is a process the DoD intends be accomplished in concert with experts in military operations and related endeavors (DoD, 2003c).

RELEVANCE OF FUZZY SET THEORY

Zadeh's (1965) seminal exposition has spawned more than four decades of additional research regarding fuzzy set theory and derivative theories and applications such as fuzzy numbers, linguistic variables, and evidence and possibility theory (Bae, Grandhi, & Canfield, 2004; Bender and Simonovic, 2000; Dubois, Prade, & Smets, 2001; Fedrizzi, 1987; Kangari & Riggs, 1989; Terano, Asai, & Sugeno, 1992; Zadeh, 1996). Fuzzy set theory has been applied to fields as diverse as business project selection and management, large-scale systems engineering and analysis, computer-aided design, meteorology, medical diagnoses, decision-making for security trading and many other purposes, human reliability, and robotic control of common systems as large as trains and aircraft and as small as toaster ovens and video camcorders (Bender and Simonovic, 2000; Dutta, 1993; Karwowski & Mital, 1986; Klir & Folger, 1988; Kuchta, 2001; Machacha & Bhattacharya, 2000; Mon, Cheng, & Lu, 1995; Perincherry, Kikuchi, & Hamamatsu, 1994; Terano et al., 1992; Wang & Chang, 1980). Research closely resembling that conducted with this effort has explored generalized risk engineering and assessment (Cai, 1996; Kangari & Riggs, 1989; Karwowski & Mital, 1986), software operational risk assessments (Xu, Khoshgoftaar, & Allen, 2003), and military exercise reconstruction (Parsons, 1989). With its now widely-acknowledged utility for resolving ambiguities and imprecision in human thought and language (Gue, 2002; Kangari & Riggs, 1989; Liao, Celmins, & Hammell, 2002; Lin & Chen, 2004), fuzzy set theory bears significantly on processes central to ACTD military utility assessment design.

Zadeh (1965) and countless following practitioners have purported fuzzy set theory's usefulness in defining and manipulating typically human evaluations such as "approximately 5 kg," "short experience," and "hot" weather (Parsons, 1989; Tah, Thorpe, & McCaffer, 1993; Weiss, 2001), evaluations imprecise not for the aleatory uncertainty precipitated by random variables of classic probability but for the epistemic uncertainty (Bae et al., 2004; Bedford & Cooke, 2001; Quelch & Cameron, 1994; Williams, 1995) derived from "the absence of sharply defined criteria of class membership" (Zadeh, 1965, p. 339). A logical extension of these claims would have the discipline support the understanding of "military utility" or other descriptors such as "unacceptable" consequence, "frequent" likelihood, and "high risk" that could be intuitively and easily used by experts (Huang, Chen, & Wang, 2001; Karwowski & Mital, 1986) assessing ACTD risks. Since MUA designers can be expected to construct assessments that will draw upon deterministic (for example, certain prototype component costs or threat system parameters) as well as probabilistic (such as historical weather data pertinent to prototype missions) data, it is plausible to view fuzzy methods as necessary to a suite of methods that assessment designs should offer assessors to evaluate the mixes of deterministic, probabilistic, and fuzzy data (Cai, 1996; Zaras, 2003) those assessors will routinely encounter. That such mixes will routinely comprise sizable proportions of subject matter expertise and other fuzzy data (Quelch & Cameron, 1994) manifests in four traits of new commercial product development (Lin & Chen, 2004) readily translatable to terms appropriate for ACTD military utility assessments:

(1) much of the information available to MUA designers is uncertain or incomplete;

(2) the prototype threat and operational environments are marked by uncertainty and rapid changes in technologies and missions;

(3) criteria for military utility are not always quantifiable or comparable, and may directly conflict or interact;

(4) multiple groups of interested parties, each with a different perspective, should be accommodated in MUA design processes and therefore render them like so many of the multicriteria and multi-attribute decision processes to which fuzzy set theory has been applied for decades (Bender & Simonovic, 2000; Büyüközkan & Feyzioğlu, 2003; Enea & Piazza, 2004; Ghyym, 1999; Ibrahim, 1991: Li & Yen, 1995; Lin & Chen, 2004; Roubens & Vincke, 1987; Whalen, 1987; Zaras, 2003; Zimmerman, 1996).

A description of fuzzy set theory fundamentals further buttresses the theory's place in MUA design.

FUNDAMENTALS OF FUZZY SET THEORY

Traditional theory regarding what are termed "crisp" sets holds that members of some universal set strictly are or are not wholly contained within any subset of the universal set (Zimmerman, 1996). For example, each of the three elements of the crisp set A of counting numbers, $\{1, 2, 3\}$, a subset of the universal set U of counting numbers, $\{1, 2, 3, 4, 5, \ldots\}$, are wholly contained within set A; the universal set's remaining counting numbers of 4, 5, 6, ... are not elements of set A. Such a thoroughly unambiguous approach using distinct set boundaries cannot support mathematics appropriate for analyzing fuzzy concepts so prevalent in human cognition and language; but fuzzy set theory does seem able to do so (Li & Yen, 1995).

Fuzzy set theory allows set elements partial – and hence, fuzzy – membership in a set. Formally,

DEFINITION 1. A fuzzy set $\tilde{A}$ of elements, x, on a given universe U is a set of ordered pairs such that

$$\tilde{A} = \{ (x, \mu_{\tilde{A}}(x)) \mid x \in U \}, \text{ where}$$

$$\mu_{\tilde{A}}(x) \in [0, 1]$$

is the membership function of x or grade of membership of x in the fuzzy set, $\tilde{A}$.

For example, a fuzzy set defining old-aged persons in discrete terms of decades of life between 10 and 80 could be represented as (Klir & Folger, 1988)

$$\widetilde{old} = \{ (10, 0.0), (20, 0.1), (30, 0.3), (40, 0.4), (50, 0.6), (60, 0.7), (70, 0.8), (80, 1) \},$$

while a similar but continuous set might be expressed as (Büyüközkan & Feyzioğlu, 2003)

$$\widetilde{old} = \begin{cases} 0, & x \leq 10 \\ \dfrac{x-10}{70}, & 10 < x < 80 \\ 1, & x \geq 80. \end{cases}$$

Note that unlike the somewhat analogous, density functions of classic probability, the membership values of elements of fuzzy sets need not sum to unity, and this total relaxation of a tenet of probability theory promotes fuzzy set theory as the better vehicle for mathematically representing the vagaries of risk assessments in situations devoid of data sufficient for application of the former (Quelch & Cameron, 1994). Note, too, however, that identification of membership functions has been long held as problematic.

"The issue of membership function generation is vital to…[every] fuzzy set theory…application [that] depends on the membership function used" (Liao et al., 2002, p. 242). Such functions can be estimated from data when it is available, but must often be assumed a priori by theorists and practitioners (Medaglia, Fang, Nuttle, & Wilson, 2002). There is neither universal agreement on characteristics required of membership functions (Medaglia et al., 2002) nor even uniformity in interpreting the meaning of membership grades (Dubois & Prade, 1997). Much research has been and continues to be dedicated to resolving the membership function dilemma, but the dilemma apparently remains (Ayyub, 2001; Cornelissen, van den Berg, Koops, & Kaymak, 2002; Liao et al., 2002; McCauley-Bell & Badiru, 1996a; Mendoza & Prabhu, 2003; Norwich & Turksen, 1984; Turksen, 1991).

Equally integral to fuzzy set theory but far less problematic than membership functions are the corollary concepts of α-cuts and cut-sets, $\tilde{A}^{\alpha}$, "especially useful for…arithmetic operations on fuzzy numbers" (Büyüközkan & Feyzioğlu, 2003, p. 43). The cut-set, $\tilde{A}^{\alpha}$, of a fuzzy set, $\tilde{A}$, may be formally expressed as (Büyüközkan & Feyzioğlu, 2003)

DEFINITION 2.
$$\tilde{A}^{\alpha} = \{\, x \in U \mid \mu_{\tilde{A}}(x) \geq \alpha \,\}$$
$$\text{for } \alpha \in [0, 1] \text{ and } \mu_{\tilde{A}}(x) \in [0, 1],$$

with an α-cut simply the minimum membership value on the interval [0, 1] that every member of the cut-set, $\tilde{A}^{\alpha}$, of $\tilde{A}$ must hold.

Definitions 1 and 2 are as fundamental to the MUA design principles of this research as they are to fuzzy set theory, itself. They make apparent a link between fuzzy operations and epistemic risk that in turn promotes fuzzy approaches to risk assessment.

FUZZY APPROACHES TO RISK ASSESSMENT

The literature abounds with treatments of risk assessment and fuzzy set theory. A body of material far smaller than that dedicated to either field concerns mergers of the two: fuzzy approaches to risk assessment. Such approaches served both to presage and refine the scope of this work.

Carroll (1983) may have been among the first to endorse the use of fuzzy methods expressly for risk analyses, particularly for the analyses of complex problems strongly characterized by uncertainty. Karwowski and Mital (1986) shortly afterward echoed the aspect of uncertainty by noting "risk (as) a fuzzy concept in that there does not exist a unique risk that a hazardous event will occur in a given period of time" (p. 106). Others have also endorsed the suitability of fuzzy methods for many risk assessment constructs traditionally employed only with probability techniques the fuzzy set theorists considered insidiously too exact (Quelch & Cameron, 1994; de Ru & Eloff, 1996; Tah et al. 1993; Yager, 2002; Zimmerman, 1983).

Fuzzy approaches to classic risk assessment-related methods and techniques such as: critical path method (Kaufmann & Gupta, 1988); program evaluation and review (Mon et al., 1995); fault tree analysis (Terano et al., 1992); event tree analysis (Cho, Choi, & Kim, 2002; Huang et al., 2001); failure mode, effects, and criticality analysis (Bowles & Peláez, 1995); and quantitative risk analysis (Quelch & Cameron, 1994) have been explored during the past two decades. Fuzzy risk assessment methods have also been deployed that share no links with probabilistic convention.

Fuzzy set theory has been suggested as a means to address some of this nation's most public topics related to risk. Five years after Pennsylvania's Three Mile Island incident, Yeh (1984) proposed that fuzzy set theory – precisely, fuzzy ranking schemes – be used to assess nuclear power plant fire risks. Cornelissen et al. (2002) demonstrated a fuzzy approach to assessing risks inherent in agricultural production systems upon which the United States so greatly depends. Karwowski and Mital (1986) identified numerous industrial safety engineering applications of fuzzy concepts, McCauley-Bell and Badiru (1996a, 1996b) applied the same to the slightly more refined topic of occupational injuries in workplaces, and Merilan (1996) portrayed fuzzy set theory as a potent, risk assessment tool for epidemiologists. Demonstrated, too, have been business applications of importance to the nation's economic health.

Serguieva and Hunter (2004) suggested fuzzy set theory as a means to appraise business investment risks. That proposal complemented and was in large part made plausible by preceding research regarding the multi-industry applicability of fuzzy methods to countless problems rooted in epistemic uncertainties of information or information flow (Kaufmann & Gupta, 1988; Klir & Folger, 1988; Zimmerman, 1996), conceptual design evaluation (Smith & Verma, 2004; Verma, Smith, & Fabrycky, 1999), major system design firm performance prediction (Sun, 2000), major system design performance prediction (Büyüközkan and Feyzioğlu, 2003; Chen, 2001; Ibrahim, 1991), project selection (Enea & Piazza, 2004), major system operations risks (Xu et al., 2003), supplier evaluations (Tsai, 1999), the risks of selling certain consumer goods (Lin &

Chen, 2004; Liu, 1996), and general project risks of many sorts (Grabot, Blanc, & Binda, 1996; Gue, 2002; Jones, 2001; Kangari & Riggs, 1989; Kuchta, 2001; Liberatore, 2002; Machacha & Bhattacharya, 2000; Tamimi, 1989; Wells, 1997; Zaras, 2003).

These cited and other mergers of risk assessment and fuzzy set theory channeled this research effort, with other elements of the literature providing further refinement. The balance of relevant literature addressed ACTD MUA design methodologies, approaches to complex system analysis and transformation, risk-based and fuzzy approaches to military operations assessments, small expert group and group decision characteristics, and fuzzy risk prioritization schemes.

ADDITIONAL RELEVANT LITERATURE

The literature displays a paucity of research and convention directly applicable to development of an ACTD MUA design methodology. To construct a methodology of value, therefore, fundamentally-pertinent topics of risk assessment, fuzzy set theory, and fuzzy approaches to risk assessment must be largely supplemented by literature related only indirectly to critical aspects of ACTD assessment: literature, for example, that illuminates complex system analysis and transformation attributes bearing on assessment design; literature respecting military operations; and literature addressing key elements of small group decision processes integral to MUA design, such as group composition, group size, proclivity for agreement among group members, and means by which decisions of any level of accord may be rendered in the face of ambiguity or uncertainty typically associated with decision criteria.

ACTD MUA Design Methodologies

Little official, government literature directly addresses the question of how to design an advanced concept technology demonstration military utility assessment, and directives that do exist focus on assessment conduct rather than design. Unofficial proposals for MUA design compensate somewhat for the paucity of Defense Department guidelines, but these unofficial suggestions collectively provide more for concept- than for methodology-level needs.

The Department of Defense unequivocally mandates that typically limited, ACTD resources be directed toward determining "how effectively (a) capability under evaluation performs (an) intended mission and how suitable [that capability] is...for use in military operations" (DoD, no date-a, ACTD Guidelines: Management Plans – Concept and Technical Approach – Measures of Effectiveness [MoE] and Measures of Performance [MoP] section). Department guidance additionally stipulates those determinations to be made with respect to measures of effectiveness identified during demonstration planning stages by intended users assisted by military utility assessment agents (DoD, no date-a, ACTD Guidelines: Management Plans – Concept and Technical Approach – Measures of Effectiveness [MoE] and Measures of Performance [MoP] section). These few official dictates are complemented by military- and nonmilitary-related literature sourced beyond the confines of the Department of Defense.

Arnold and Kujawa (1999) emphasize systems of systems aspects of ACTD MUA design in offering a methodology for identifying effectiveness measures derived by military users and assessment analysts from the highest-level definitions of success in missions that individual ACTDs aim to support. Arnold (no date) and others refine that approach by suggesting that joint ACTD MOEs be directly derived with subject matter expertise from critical operational issues (Arnold, 1998; Elliott, Madden, & Dean, 1997; Luman, 1998; Luman & Scotti, 1996; Singleton, Luman, & Rapport, 1998; Sproles 2000, 2001, 2002; The Johns Hopkins University Applied Physics Laboratory [JHU/APL], 2000; JHU/APL, 2004; U.S. Atlantic Command [USACOM], 1998) in turn drawn from the Universal Joint Task List (DoD, 2002) of mission tasks assigned U.S. joint military forces (Arnold, no date; Singleton et al., 1998). Additional military and nonmilitary works (Arnold, 1998; Bahill & Briggs, 2001; Carlock & Fenton, 2001; Enea & Piazza, 2004; Ghyym, 1999; Haimes, 2004; JHU/APL, 2000, 2004; Lin & Chen, 2004; Longstaff & Haimes, 2002; Luman, 1998; Sproles, 2001; USACOM, 1998; Verma, Smith, & Fabrycky, 1999) indirectly reinforce the importance to MOE identification of CONOPS and system of system perspectives, particularly when attempts to upgrade complex sociotechnical metasystems entail the use and related risks of what are termed commercial-off-the-shelf (COTS) technologies (Bahill & Briggs, 2001; Chung & Cooper, 2003; Luman, 1998; JHU/APL, 2000) so prominent in the ACTD program. Significantly, none of these offerings specify or even imply other than Sproles' (2002) earlier-cited, "creative thought" (p. 257) method for identifying effectiveness measures; but Thompson and Montagne (1998) do provide the specificity upon which this research quite strongly depends.

Thompson and Montagne (1998) perhaps alone have challenged a serious literature deficiency by illustrating a "risk assessment process…(to) plan operational tests" (p. 42) in accordance with DoD (2000) prescriptions for formalized, operational testing. Those authors' method for designing operational tests and evaluations of military command and control systems might serve as an example for designing deliberately less formal (GAO, 2002), ACTD assessments. Their employment of user-developed, risk assessments as first steps toward MOE identification might be repeated by ACTD MUA managers and designers. Just as important to repeat might be three more aspects of the Thompson and Montagne formula:

(1) a "user community...intimately familiar with...[demonstration] system requirements and...therefore the best group to assess the mission impact of a failure to meet each requirement" (p. 44);

(2) a "level of (assessment)...sufficient to provide high confidence among the entire (user) community that...(assessment) results properly (reflect)...operational effectiveness and suitability" (p. 46) of the assessed capability, without wasting resources that might be otherwise wasted with differently-designed assessment plans; and

(3) a level of user involvement strongly supporting the identification of risks across all domains relevant to military operations metasystems of interest.

This third aspect also figures prominently in complex system analyses and transformation approaches quite pertinent to the development of a methodology for ACTD MUA design.

Approaches to Complex System Analysis and Transformation

The literature supports a presumption that joint military operations should be analyzed and transformed as complex metasystems with all metasystem characteristics typically attendant. While only a tiny fraction of relevant literature (Arnold and Kujawa, 1999; Luman, 1998; Luman & Scotti, 1996) directly supports that notion's application to ACTDs, a larger body of military- and nonmilitary-related work does indirectly secure the validity of holistic, complex system-based approaches to analysis and transformation that ACTDs can impose on sociotechnical, joint operations systems of systems.

Holistic, complex system analyses depend on holistic, complex system modeling that places a primacy on characteristics distinguishing complex systems from simple ones. These characteristics include sociotechnical constructs postulated by numerous researchers (Clegg, 2000; Einarsson & Rausand, 1998; Elzen, Enserink, & Smit, 1996; Gregoriades, Sutcliffe, & Shin, 2003; Haimes, 2004; Keating et al., 2001; Keating et al., 2005; Kosmowski, 2000; Kosmowski & Kwiesielewicz, 2002; Longstaff & Haimes, 2002; Sage & Cuppan, 2001; Williams, 1999), a principle holding that different perspectives will generally foster different models of any complex system (Enea & Piazza, 2004; Haimes, 2004; Keating et al., 2003; Newbern & Nolte, 1999; Pennock & Haimes, 2002), and what many (Beckerman, 2000; Calvano & John, 2003; Chen and Clothier, 2003; Keating et al., 2004; Williams, 1999) have described as dynamic behavior and "system properties that 'emerge' from the synthesis of interactions between components, at each level of interconnection within" (Beckerman, 2000, p. 98) any complex system. The importance of such characteristics influences the transformation as well as the analysis of complex systems.

Complex system transformation – an activity that perfectly describes the intent of any ACTD – most often occurs in environments of attributes familiar to ACTD MUA managers and designers:

- Multiple stakeholders related to all component systems…with varying interests;
- High levels of technical complexity;
- Large scale, broad scope and long term activity;

- Change and evolution management (required for many) activities;
- Various constituent systems featuring independent lifecycles and lines of responsibility;
- (Complex system assembly) often (made) at short notice to meet unprecedented operational needs; [and]
- The requirement for (complex system) adaptability…[and] flexibility. (Chen & Clothier, 2003, pp. 173-174)

These environmental factors "both constrain and enable" (Keating et al., 2004, p. 4) the transformation of complex systems, so complex system transformation efforts should account for them (Beckerman, 2000; Keating et al., 2004; Keating et al., 2005) together with the closely-related characteristics of complex systems (Clegg, 2000; Elzen et al., 1996; Gregoriades et al., 2003; Keating et al., 2004; Keating et al., 2005; Rouse, 2005). Plausible accounting tools seem to be risk-based and fuzzy approaches to military operations and relevant aspects of the environments in which those operations occur.

Risk-based and Fuzzy Approaches to Military Operations Assessments

The literature makes evident no risk assessment or fuzzy set theory-based MUA design schemes per se, although the operational test and evaluation design proposal of Thompson and Montagne (1998) quite nearly does offer the former. Military operations and operations support processes other than those of ACTDs have more often been the objects of risk-based approaches to assessment.

Risk-based approaches to military operations assessments have perhaps been most visibly pursued by Haimes (2004) and others (Haimes, Kaplan, & Lambert, 2002; Lambert, Haimes, Li, Schoof, & Tulsiani, 2001; Lamm & Haimes, 2002; Leung, Lambert, & Mosenthal, 2004; Longstaff & Haimes, 2002; Riese, 2001; Riese, Brown, & Haimes, 2006) who have advanced the concept of a hierarchical, holographic model, or HHM, aligned with holistic approaches to complex system analysis because of its holistic (Haimes, 1989, 1991) representations of those same systems and associated risks. "The term, hierarchical refers to the desire to understand what can go wrong at many different levels of...[a] system hierarchy" (Haimes, 2004, p. 90), with that emphasis on hierarchy seemingly quite appropriate for addressing strongly hierarchical, military operations metasystems. The term, holographic "is suggested by holography....The difference between holography and conventional photography, which captures only two-dimensional planar representations of scenes, is analogous to the differences...between conventional mathematical modeling techniques...and the HHM schema" (p. 89) that affords multiple views of a hierarchical system's multiple components. The HHM methodology has been frequently applied to military operations and operations support systems in efforts to determine and assess associated risks.

Haimes (2004) has applied hierarchical holographic modeling to military operations like those for which ACTDs can be appropriately staged, with applications ranging from operations support processes such as military system procurement, through what are termed military operations other than war (MOOTW), to homeland defense operations. Lambert et al. (2001) have used HHM to model and assess risks associated with additional, military procurement systems; Haimes, Kaplan, and Lambert (2002) have used the methodology to model and assess risks of additional MOOTW; and Ozinci, Singleton, Stobbart, and Zulick (2002) and Leung, Lambert, and Mosenthal (2004) have applied it to yet more homeland defense issues for which each group determined a set of defense priorities for critical highway infrastructure nodes thought vulnerable to terrorist attacks. Lamm and Haimes (2002) and Longstaff and Haimes (2002) have also applied HHM to risk-related pursuits regarding the need for military information assurance so critical to contemporary, joint operations.

The literature reveals a number of fuzzy set theory-based approaches to military operations assessments far smaller than that evident for risk-based methods. Parsons' (1989) suggestion of theory utility for military exercise reconstruction and analysis may be the best example and few, if any, others might be so directly linked.

Zimmerman (1983) was among the first to extol the virtues of fuzzy set theory vis-à-vis operations research and in so doing can be argued to have first promoted its applicability to the assessment of military operations. In recognizing the importance of multi-attribute system concept designs – with their routinely imprecise requirements and priorities – inextricably linked to the holistic system modeling already described, the work of Verma, Smith, and Fabrycky (1999) represents a large body of research (Bellman & Zadeh, 1970; Bollujo, 1996; Büyüközkan & Feyzioğlu, 2003; Enea & Piazza, 2004; Fedrizzi, 1990; Gaines, 1987; Lin & Chen, 2004; Liu, 1996; Machacha & Bhattacharya, 2000; Perrincherry, Kikuchi, & Hamamatsu, 1994; Smith & Verma, 2004; Terano, 1992; Whalen, 1987; Zahariev, 1990) that indirectly supports fuzzy set theory's place in military operations assessments.

Small Expert Group and Group Decision Characteristics

The literature is replete with treatments of large and small expert group decision functions, especially risk assessment (Aven & Kørte, 2002; Ayyub, 2001; Blin, 1974; Blin & Whinston, 1973; Clemen & Winkler, 1999; Cornelissen et al., 2002; Ghyym, 1999; Haimes, 2004; Kunreuther & Slovic, 1996; Lin & Chen, 2004; Saaty, 1980, 1987; Slovic, Finucane, Peters, & MacGregor, 2004; Wang, Sii, Yang, Pillay, Yu, Liu, et al., 2004; Weiss, 2001). Given "the limited resources available" (DoD, no date-a, ACTD Guidelines: Management Plans – Concept and Technical Approach – Measures of Effectiveness [MoE] and Measures of Performance [MoP] section) to ACTD managers, one can argue the importance of small group risk assessments to ACTD MUA design as well as the literature-acknowledged pertinence to such assessments of group composition, group size, and degree of participant agreement regarding decisions often made under the very uncertainty driving the need for expert perspectives.

Ayyub (2001) advocates expert panels that possess "a balance and broad spectrum of viewpoints, expertise, technical points of view, and organizational representation" (p. 242). Clemen and Winkler (1999), too, endorse "heterogeneity among experts (as) highly desirable" (p. 199), as do Cornelissen et al. (2002), though the latter do not wholly dismiss a place for expert group homogeneity. Other researchers (Bezdek, Spillman, & Spillman, 1978; Enea & Piazza; Ghymm, 1999; Spillman, Bezdek, & Spillman, 1979) implicitly emphasize heterogeneity of expert groups with their explicit emphasis upon the multi-attribute or multicriteria decision processes of groups of experts characterized by differing viewpoints, expertise, organizational allegiances, and the like.

The proper size for particular, small expert groups assigned particular – perhaps risk assessment – functions "should be determined on a case-by-case basis....(but also) be large enough to achieve a needed diversity of opinion, credibility, and result reliability" (Ayyub, 2001, p. 241). The sizing might also be bounded by parameters found in the literature.

Chen's (2001) approach to evaluating the rate of aggregative risk in software development employed two experts. Ghyym (1999) employed a three-expert risk assessment panel, while Chytka (2003) followed by citing an admonition "that combining the assessments of three experts yields the most advantage to (certain types of group decision processes)…(with)…little to no empirical evidence that adding additional experts improves…effectiveness" (p. 17). Clemen and Winkler (1999) exceeded the number three slightly by noting analyses suggesting "three to five experts" (p. 199) to be optimal in many cases. Small group risk expert assessment panels of sizes 4 (Lin & Chen, 2004; Wang et al., 2004), 10 (Weiss, 2001), and 7 through 20 (Haimes, 2004) have also been demonstrated.

Past and current research emphasizes the need for means to measure the level of agreement among members of small groups of experts attempting to render consolidated, group decisions of all sorts, including decisions regarding risk. Many authors (Bezdek et al., 1978; Blin, 1974; Blin & Whinston, 1973; Clemen & Winkler, 1999; Fedrizzi, 1990; Saaty, 1980, 1987; Spillman, Spillman, & Bezdek, 1980; Weiss, 2001; Xu, 2004) indicate the desirability of measures of small group accord, particularly when group decisions are subject to ambiguity, uncertainty, or even ignorance of information. Means posited and practiced to measure degrees of agreement behind small group judgments rendered under uncertainty have proved valuable accompaniments to proposed or practiced means for first achieving the small group risk prioritizations such measures of accord might describe.

Fuzzy Risk Prioritization Methods

Small group risk assessments demand prioritization schemes by which "individual preferences on a given set [can be reduced] to a single collective preference" (Fernandez & Olmedo, 2004, p. 430), and "the combining process (as part of the overall expert judgment process) should depend on the details of each individual situation" (Clemen & Winkler, 1999, p. 199). While many may rarely if ever have been applied to military operations or similar assessments, the literature does evince group prioritization schemes aligned with this study's motivating precept that ACTD MUA measures of effectiveness be derived from holistic risk assessments accommodating "fuzzy" (Zadeh, 1965, p. 338) manifestations of assessors' cognition and language (Büyüközkan & Feyzioğlu, 2003; Karwowski & Mital, 1986). Most demonstrate characteristics that can be used to classify them as either ordinal scale-type, comparative techniques or cardinal scale-type, direct ranking techniques, and many of both classifications can be difficult to employ and produce inconsistent results (Kim & Park, 1990). Cardinal scale-based comparisons, in particular, are vulnerable to claims that they can force expert evaluators to exceed the 7 ± 2 absolute, unidimensional judgments long considered by many as a limit of human capacity (Ghyym, 1999: Karwowski & Mital, 1986; Miller, 1956; Mustafa & Al-Bahar, 1991; Saaty, 1980; Wang et al., 2004).

"Blin and Whinston (1973) and Blin (1974) first considered the possibility of using fuzzy sets to model the process of group decision making. They constructed a fuzzy [binary preference] relation over the set of alternatives under consideration by a group" (Spillman et al., 1980, p. 292) that drew from Zadeh's (1965, 1971) definition of such relations as fuzzy collections of ordered pairs associated by membership functions describing group confidence in collective, pairwise rankings. Fuzzy, pairwise ranking has since been often and favorably applied (Basile, 1987; Bezdek et al., 1978; Büyüközkan and Feyzioğlu, 2003; Chen & Klein, 1997; Fernandez & Olmedo, 2004; Roubens & Vincke, 1987; Spillman et al., 1979; Xu & Da, 2003) within decision contexts demanding comparisons of moderately large numbers of alternatives or when decision criteria are imprecisely determined (Graham & Rhomberg, 1996; Zahariev, 1990). The worth of so "natural" (Harker, 1987b, p. 837) a comparison method and its parent class of ordinal scale-based techniques has been acknowledged by the U.S. Department of Defense (2003c) and additionally promoted with fuzzy treatments (Enea & Piazza, 2004; Fedrizzi, 1990; Lee & Ahn, 1991; McCauley-Bell & Badiru, 1996a, 1996b; Mustafa & Al-Bahar, 1991; Wang, Wang, & Hu, 2005) of Saaty's (1980) widely-used, pairwise comparison-based analytic hierarchy process, or AHP, itself expressly endorsed (DoD, 2003c) for use in military risk assessments.

Cardinal scale-type, direct fuzzy ranking methods – including those utilized for risk assessments – are commonly found in literature offering resolutions of expert group preferences "when the number of alternatives to be compared is relatively small and the criteria are well determined" (Zahariev, 1990, p. 186). Smith and Verma (2004), for example, use a fuzzy, "weighted wedge" (p. 342) approach to individually grade the compliance with rigorously-specified requirements of small numbers of competing, system engineering project conceptual designs. Bowles & Peláez (1995) demonstrate fuzzy set theory's utility for determining risk priority numbers used with the automotive industry's risk assessment conventions that emphasize limited numbers of risk categories and well-defined criteria. Bender and Simonovic (2000) exercise what they term a fuzzy compromise approach that uses “the concept of the displaced ideal….to determine a direct ranking (strong ordering) of [small numbers of] alternatives” (p. 36) with respect to limited sets of criteria characterized as objectively as possible. A sizeable portion of cardinal scale-based, fuzzy multcriteria and multi-attribute approaches to risk assessment exhibits pairings of small numbers of decision alternatives with well determined, decision criteria (Ghyym, 1999; Ibrahim, 1991; Karwowski & Mital, 1986; Lin & Chen, 2004; Machacha & Bhattacharya, 2000).

SUMMARY

This dissertation effort rested on two premises: that ACTD military utility assessments should account for principal risks associated with deploying demonstration systems and associated operations concepts within joint military operations metasystems of which they could become a permanent part; and that the identification of those risks should accommodate ambiguities of cognition and language used by the experts assessing demonstrations’ military utility within relevant metasystems. A literature review that emphasized nine topics determined those premises to point toward an original and significant contribution to the extant body of related research:

- Risk assessment
- Fuzzy set theory
- Fuzzy approaches to risk assessment
- ACTD MUA design methodologies
- Approaches to complex system analysis and transformation
- Risk-based approaches to military operations assessment
- Fuzzy approaches to military operations assessments
- Small expert group and group decision characteristics
- Fuzzy risk prioritization methods

Ample risk assessment- and fuzzy set theory-related literature made evident those topics' relevance to ACTD MUA design methodology development. A smaller but still instructive body of work regarding fuzzy approaches to risk assessment demonstrated the value to be gained from an MUA design methodology that merged key elements of the fields of risk assessment and fuzzy set theory. Complementary components of the literature identified a niche into which a risk- and fuzzy set-based methodology for ACTD MUA design could fit.

The literature review confirmed the legitimacy of this dissertation's problem statement. Few offerings directly address the question of how to design advanced concept technology demonstration military utility assessments and, therefore, any proposal for a design methodology must largely depend on a synthesis of study and practice bearing on the problem only indirectly. Holistic approaches to complex system analysis and transformation were viewed as indispensable elements of that synthesis, as were more particular pursuits that applied either risk- or fuzzy set theory-based approaches to military operations assessments. Equally pertinent and even more particular were concerns for expert group decision processes required of ACTD MUA planning. By noting reasonably direct correspondence between representative research efforts and the literature review's nine topics of emphasis, Table 1 portrays the review's findings of literature supporting this study's two premises as well as deficiencies in research and practice the study is intended remove.

Table 1. Literature Related to the Study

	Risk assessment	Fuzzy set theory	Fuzzy approaches to risk assessment	ACTD MUA design methodologies	Approaches to complex system analysis and transformation	Risk-based approaches to military operations assessment	Fuzzy approaches to military operations assessment	Small expert group and group decision characteristics	Fuzzy risk prioritization methods
Arnold (no date)				●	●				
Arnold & Kujawa (1999)				●	●				
Aven & Kørte (2002)	●							●	
Ayyub (2001)	●	●	●					●	
Beckerman (2000)					●				
Bedford & Cooke (2001)	●					●			
Bender & Simonovic (2000)		●						●	●
Bezdek et al. (1978)			●					●	●
Blin (1974)		●						●	●
Blin & Whinston (1973)		●						●	●
Bowles & Peláez (1995)		●							●
Büyüközkan & Feyzioğlu (2003)	●	●	●					●	●
Carlock & Fenton (2001)				●	●				
Chen (2001)	●	●	●					●	
Chen & Clothier (2003)					●				
Chytka (2003)	●							●	
Clemen & Winkler (1999)	●					●		●	
Enea & Piazza (2004)	●	●	●		●			●	●

Table 1. Continued

	Risk assessment	Fuzzy set theory	Fuzzy approaches to risk assessment	ACTD MUA design methodologies	Approaches to complex system analysis and transformation	Risk-based approaches to military operations assessment	Fuzzy approaches to military operations assessment	Small expert group and group decision characteristics	Fuzzy risk prioritization methods
Fedrizzi (1987, 1990)		●						●	●
Fernandez & Olmedo (2004)		●						●	●
Ghyym (1999)	●	●		●				●	●
Haimes (1998, 2004)	●				●	●			
Ibrahim (1991)		●	●					●	●
JHU/APL (2000, 2004)				●	●				
Karwowski & Mital (1986)		●	●						●
Kaufmann & Gupta (1988)	●	●	●						
Keating et al. (2003, 2004, 2005)					●				
Klir & Folger (1988)	●	●	●						
Kunreuther & Slovic (1996)	●							●	
Lamm & Haimes (2002)	●				●	●			
Leung et al. (2004)	●				●	●			
Lin & Chen (2004)	●	●	●		●				●
Longstaff & Haimes (2002)	●				●	●			
McCauley-Bell & Badiru (1996a, 1996b)	●	●	●						●
Miller (1956)								●	
Parsons (1989)		●					●		

Table 1. Continued

	Risk assessment	Fuzzy set theory	Fuzzy approaches to risk assessment	ACTD MUA design methodologies	Approaches to complex system analysis and transformation	Risk-based approaches to military operations assessment	Fuzzy approaches to military operations assessment	Small expert group and group decision characteristics	Fuzzy risk prioritization methods
Quelch & Cameron (1994)	●	●	●						
Saaty (1980, 1987)					●			●	
Sage & Cuppan (2001)					●				
Singleton et al. (1998)				●	●				
Smith & Verma (2004)	●	●	●						●
Sproles (2000, 2001, 2002)				●	●				
Tamimi (1989)	●	●	●						
Thompson & Montagne (1998)	●			●		●			
U.S. DoD (2003c, no date)	●					●		●	●
Verma et al. (1999)	●	●	●						
Xu et al. (2003)	●	●	●						
Zadeh (1965, 1971, 1996)		●							●
Zahariev (1990)		●							●
Zimmerman (1983, 1996)	●	●	●				●		
Meyers (2007)	●	●	●	●	●	●	●	●	●

RESEARCH METHODOLOGY

The literature review confirmed the theoretical, methodological, and practical contributions to be made with an ACTD MUA design methodology respecting risks associated with demonstration deployments and ambiguities of cognition and language associated with expert perspectives of those risks. The development and deployment of such a design methodology would itself be subject to methodological strictures emplaced to buttress arguments for its worth. Its status as a legitimate methodology would also have to be argued.

A SYSTEM OF SYSTEMS ENGINEERING-BASED METHODOLOGY

Keating et al. (2003) endorse Checkland's (1999, as cited, p. 41) suggestion "that methodology is a guide more specific than philosophy (theory), but more general than a tool, method, or technique." Keating et al. (2004) continue that "a systems-based methodology must provide a framework that can be elaborated to effectively guide action" (p. 5), and they identify nine attributes of a system of systems-based methodology suited to the engineering that occurs when ACTDs test transformations of joint military operations metasystems. Table 2 lists the nine attributes, all of which this dissertation's proposed methodology can be seen to hold.

This study's ACTD MUA design methodology was developed to serve theoretical, methodological, and practical considerations regarding assessments of joint military operations metasystem transformations. It was also intended to be transportable to other types of assessments pursued within contexts set by similar metasystems – like assessments now also required for ACTD-derivative, joint capability technology demonstrations (JCTD) – or even distinct ones, provided that any assessment designs guided by the methodology are dependent on the judgments of subject matter expert groups of purpose and composition like those defining this dissertation's application. Small expert group characteristics of purpose and composition are particularly significant requirements that link the methodology's practical artifacts to its driving principles grounded in theory regarding risk assessment, fuzzy sets, and complex systems.

Table 2. Attributes of a System of Systems-based Methodology

Attribute	Attribute Description
Transportability	Capable of application across a spectrum of complex systems engineering problems and contexts.
Theoretical and Philosophical Grounding	Linkage of the methodology to a theoretical body of knowledge as well as philosophical underpinnings that form the basis of the methodology and its application.
Guide to Action	The methodology must provide sufficient detail to frame appropriate actions and guide direction of efforts to implement the methodology.
Significance	The methodology must exhibit the "holistic" capacity to address multiple problem system domains, minimally including contextual, human, organizational, managerial, policy, technical, and political aspects of a system of systems problem.
Consistency	Capable of providing replicability of approach and results interpretation based on deployment of the methodology in similar contexts.
Adaptability	Capable of flexing and modifying the approach configuration, execution, or expectations based on changing conditions or circumstances – remaining within the framework of the guidance provided by the methodology, but adapting as required to facilitate systemic inquiry.
Neutrality	The methodology attempts to minimize and account for external influences in application and interpretation. Provides sufficient transparency in approach, interpretation, and execution such that biases, assumptions, and limitations (may be) made explicit and challenged within the methodology application.
Multiple Utility	Supports a variety of applications with respect to complex systems of systems, including new system design, existing system transformation, and assessment of existing complex system of systems initiatives.
Rigor	Capable of withstanding scrutiny with respect to: (1) identified linkage …(to) a body of theory and knowledge; (2) sufficient depth to demonstrate sufficient grounding within the systems engineering discipline; and (3) capable of providing transparent results that are replicable with respect to results achieved.

(Keating et al., 2004, p. 6)

The significance of holism that Keating et al. (2004) assign to system of systems-based methodologies was a key determinant of the methodology developed for this dissertation, and that holism markedly supported development of a process providing the guide to action, consistency, adaptability, neutrality, and multiple utility described in Table 2. Those five attributes, together with the methodology's final attribute of rigor, will be evinced with coming, more detailed descriptions of this study's approach to ACTD MUA design.

PROBLEM SELECTION CRITERIA

Fernandez and Olmedo (2004) echo Zadeh (1971), Blin and Whinston (1973), Blin (1974), and others in acknowledging the importance of agents with which can be determined group, or social, decisions. They also recognize the difficulty of group decision agent design and endorse the use of fuzzy set theory in the design of decision agents to be applied to problem settings of the following characteristics:

> (1) Each (group member) considers the same set of alternatives or potential actions;
>
> (2) The preference of each group member can accurately be represented by a ranking (with ties) of all alternatives from best to worst;
>
> (3) All group members have the same importance for deriving final agreement; and
>
> (4) The group members accept a final ranking derived from an aggregation of their opinions with fairness and equity. (Fernandez & Olmedo, 2004, p. 430)

These characteristics perfectly describe key elements of the ACTD MUA design methodology this research tested against a simulated, Class III demonstration derived from an actual case of ACTD program history. They are also perfectly aligned with

Department of Defense intent that identification and analysis of risk events bearing on military system acquisitions be accomplished in concert with military operations experts and those of other pertinent fields (DoD, 2003c). The Department's acquisition-related intent bears on its ACTD program and can met by that program with methods drawn from the fields of risk assessment and fuzzy set theory.

A RISK ASSESSMENT METHOD SUITED TO THE PROBLEM

"The key to successful risk analysis is the development of a model that clearly illustrates risk factors and their relationships without getting into unnecessary detail" (Ashley & Avots, 1984, p. 56). "The 'right' model seems to capture the essentials of the system. Too much detail obscures the essentials; too little misses them" (Anderson et al., 1999, p. 59). Risk analyses should ideally avoid vulnerabilities such as: (a) dependence on models based on overly-simplistic assumptions, like those that assign independence or Normal variation to model entities or processes for which those characteristics cannot be verified (Beckerman, 2000; Tamimi, 1989); (b) analytical treatments conveying a sense of surety not justified by available data, as can occur when probabilistic methods are used to describe processes about which too little is known (Bier, Haimes, Lambert, Matalas, & Zimmerman, 1999); or (c) a level of reductionism greatly favoring identification of model components at the expense of studying interactions among them (Beckerman, 2000). One aspect of user-intensive, risk analysis that should always be prominent is the use of models understandable to participating users (Gue, 2002) but not so simple that they surrender utility (Tamimi, 1989). Risk assessments promoting MUA design should avoid unnecessary vulnerabilities and depend on justifiable and holistic, operations metasystem models elicited from and validated by military literature and experts;

assessment-peculiar elements of Haimes' (2004) well-practiced, Risk Filtering, Ranking, and Management (RFRM) method meet both criteria.

The RFRM comprises eight phases of risk-related review, the first three of which were important to the research of this dissertation. Phase I activities can identify military operations metasystem risk scenarios associated with ACTD prototypes by using a hierarchical holographic model (HHM) "developed to describe…[the metasystem's] 'as planned' or 'success' scenario[s]" (Haimes, 2004, p. 280). The filtering process of Phase II can reduce the number of Phase I-identified risks by emphasizing particular aspects of envisioned, ACTD prototype employment. Finally, the DoD-conventional (DoD, 2003c; Haimes, 2004), risk likelihood- and consequence-based filtering mechanism of Phase III can decrease what might be hundreds of Phase I-derived, ACTD risks (Haimes, 2004; Haimes et al., 2002) to a number of perhaps no more than 20 (Lamm & Haimes, 2002) practically required for the individual risk prioritization scheme this research pursued as a pivotal step in ACTD MUA design.

"The basic building block of the RFRM is the HHM" (Leung, Lambert, & Mosenthal, 2004). A HHM is able to demonstrate relationships among what could be termed an ACTD's overlapping functional, temporal, organizational, geographical, and like perspectives (or head topics) and subordinate domains (or subtopics) (Haimes, 1998, 2004; Haimes et al., 2002). Figure 2 offers an illustrative version of a HHM suited to designing ACTD assessments, with major, joint military operations metasystem components – Haimes' perspectives – of commands, critical operational issues, major missions, users, system functions, and threat decomposed into varying numbers of interdependent domains each simultaneously representing the success and, when normal operations are disrupted, the risk scenarios associated with ACTDs (Haimes, 2004; Kaplan et al., 2001). In practice, domains can be further subdivided into whatever number of subdomains needed to portray total risk to joint operations utility; the assumed interdependence of all domains and subdomains most enables identification of individual risks.

Figure 2. Representative HHM for ACTD Military Utility Assessments

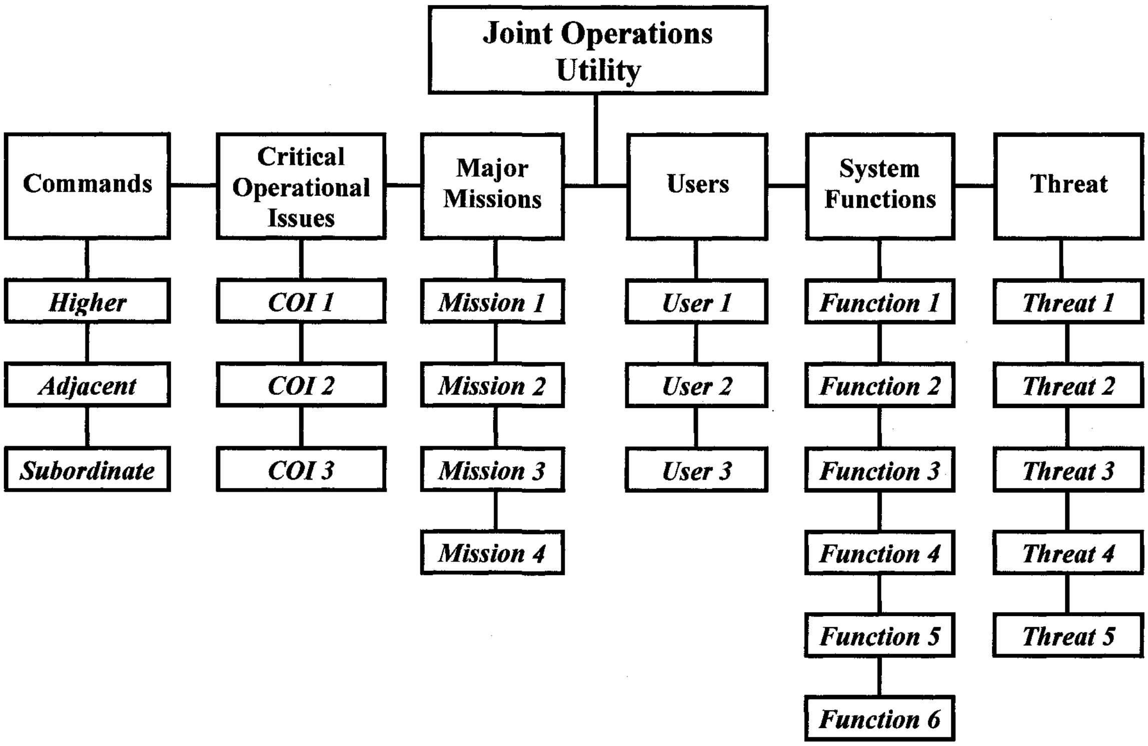
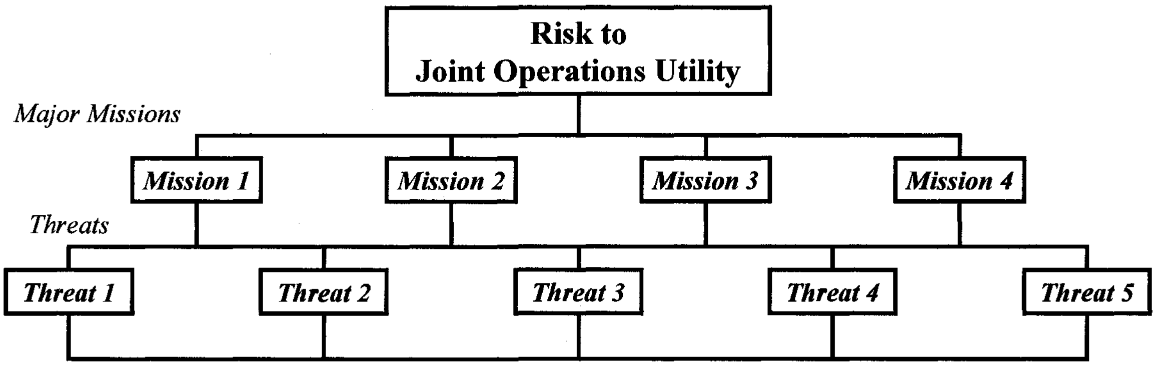


Figure 3 portrays the manner in which submodels of the Figure 2 example HHM afford identification of "an inclusive set of answers to 'what can go wrong?'' (Haimes et al., 2002, p. 386). It shows that, from the perspective of any of the four major missions the illustrated ACTD prototype might be expected to perform, there might be as many as five threats against which it could be employed or which could otherwise jeopardize its employment. Analysts, military operators, and other subject matter experts can use such relationships to prompt consideration regarding “what can go wrong?” Many risks will be identified in this way, though numerous other associations will merely illuminate highly unlikely or even infeasible scenarios. The qualitative elimination of unlikely or infeasible scenarios defines Phase II of the RFRM. The method’s Phase III can further refine the set of consequential risks to joint operations utility with its use of another qualitative procedure well known to ACTD managers.

Figure 3 ACTD Major Mission Submodel



Phase III of the RFRM features a matrix of independent dimensions of likelihood and consequence, graduated in accordance with long-standing, DoD evaluation measures generically depicted with Figure 4 (DoD, 2003c; Haimes, 2004; Jones, Lyford, Qazi, Solan, & Haimes, 2003). Should the balance of the number of risks identified through RFRM Phase II activities remain large, the matrix can be employed to determine whether those remaining risks should be classified as *high*, *moderate*, or *low*. These Phase III classifications allow experts to focus on lesser numbers of risks (perhaps only those classified as *high*) than will be identified through Phase II, numbers possibly more conducive to ensuing prioritizations with which can be developed ACTD MUA measures of effectiveness. With risk “a fuzzy concept….(of) quantities…inherently imprecise”

(Karwowski & Mital, 1986, p. 106), such risk prioritizations can employ a particular method of fuzzy set theory that respects the normal, experiential judgment processes (Slovic, Finucane, Peters, & MacGregor, 2004) used by subject matter experts rather than forcing those experts – as is the case with many risk prioritization methods – to render judgments in starkly analytical terms neither necessarily applicable nor with which the experts may be facile or unbiased (Karwowski & Mital, 1986).

Figure 4. DoD-Conventional Matrix of Risk Likelihood and Consequence

	LIKELIHOOD				
CONSEQUENCE	***Remote***	***Unlikely***	***Likely***	***Highly Likely***	***Frequent***
Unacceptable	Moderate	High	High	High	High
Minimally Acceptable	Low	Moderate	Moderate	High	High
Acceptable with Significant Utility Loss	Low	Low	Moderate	Moderate	High
Acceptable with Slight Utility Loss	Low	Low	Low	Moderate	Moderate
Little or None	Low	Low	Low	Low	Moderate

A FUZZY SET THEORY METHOD SUITED TO THE PROBLEM

The several risk filtering and ranking phases of Haimes' (2004) RFRM not already addressed in this chapter depend on often-challenged (and challenging) Bayesian techniques of evaluation (Aven & Kvaløy, 2002; Bier et al., 1999; Clemen & Winkler, 1999) as well as problematic weighting schemes (Bender & Simonovic, 2000; Büyüközkan & Feyzioğlu, 2003; Chen, 2001; Forman, 1987; Lee and Ahn, 1991; Xu,

2004) that can force subject matter experts to render judgments in starkly analytical terms neither necessarily applicable nor with which they may be facile or unbiased (Karwowski & Mital, 1986). Risk-related weighting schemes and resultant cardinal rankings additionally conflict with a strong DoD inclination toward ordinal evaluations of risk (DoD, 2003c), an organizational preference that must surely affect ACTD managers despite the availability of RFRM and many more risk ranking methods featuring criteria-weights, cardinal scales, distance and area metrics, or other arguably overly-analytical schemes, some even infused with fuzzy concepts (Bender & Simonovic, 2000; Bortolan & Degani, 1985; Chen & Klein, 1997; Lee & Ahn, 1991; Tseng & Klein, 1989). One sometimes weight-based scheme known to ACTD managers (DoD, 2003c) and often extended with fuzzy concepts is Saaty's (1980) AHP, notable not for its use of absolute measures or fuzzy extensions but for its dependence upon simple, pairwise comparisons minimally stressing (Harker, 1987b; Lee & Ahn, 1991; Mustafa & Al-Bahar, 1991; Vachnadze & Markozashvili, 1987) the number of 7 ± 2 absolute, unidimensional judgments popularly assigned as a limit of human capacity (Ghyym, 1999: Karwowski & Mital, 1986; Miller, 1956; Mustafa & Al-Bahar, 1991; Saaty, 1980; Wang et al., 2004). That these "pairwise comparisons are fundamental…[to] the AHP" (Saaty, 1987, p. 163) and that the AHP has found so many applications over the last quarter century (Harker, 1987a, 1987b; Lee & Ahn, 1991; Mustafa & Al-Bahar, 1991; Vachnadze & Markozashvili, 1987) is strong endorsement of the utility of a fuzzy set-based ranking method to which pairwise comparisons are equally central.

Less than a decade after Zadeh (1965) set forth his theory of fuzzy sets, Blin and Whinston (1973) and Blin (1974) proposed the notion of a fuzzy preference, a straightforward and fuzzy set-based method for relating small group preferences, and one that circumvents most problems of criteria weights, cardinal scales, membership functions, and like complications that could trouble ACTD managers or military operators. The essence of Blin and Whinston's approach has been revisited (Klir and Folger, 1988), expanded (Spillman, Bezdek, & Spillman, 1979; Spillman, Spillman, & Bezdek, 1980), and otherwise modified (Basile, 1990; Chen and Klein, 1997), but its original form and purpose of easily identifying and characterizing in terms of agreement level the preferences of small groups seems well-suited to a MUA design process typically involving small groups of experts who could develop MOEs based on their independent and relative assessments of demonstration system risks.

Individual choices may be categorized as binary, {Yes, No}, or {0, 1} in type, but "a cursory examination of the history of decisions should suffice to convince us of the fuzziness of group preferences" (Blin, 1974, p. 28). Group preferences may be modeled as fuzzy binary relations (Blin, 1974), or sets, in accordance with Zadeh's (1965, 1968, 1971) theories of fuzzy sets and relations (Blin and Whinston, 1973). Blin and Whinston's method for determining social, or group preferences, allows groups' "individual (members) to possess different aims and values while still assuming that the overall [group] purpose is to reach a common, acceptable decision" (Klir & Folger, 1988, p. 258), a presumption that can be plausibly made for military settings of many kinds, including ACTD MUA design. Multiplicity of opinion can be accommodated by defining a group, or social, preference, $\tilde{\boldsymbol{S}}$, as a fuzzy binary relation of membership function

$$\mu_{\tilde{S}}\,(x_i, x_j): \boldsymbol{U} \times \boldsymbol{U} \in [0, 1]$$

indicating the degree to which the group believes risk x_i exceeds risk x_j. Such an expression of group preference may be defined in many ways, with one of the most direct possibly free of significant, membership function-related controversy and thus appealing to ACTD participants:

DEFINITION 3. $$\mu_{\tilde{S}}(x_i, x_j) = \frac{N(x_i, x_j)}{n},$$

the simple fraction of the number, $N(x_i, x_j)$, of n-total experts considering x_i riskier than x_j. With such a membership function in place, final and nonfuzzy, group prioritizations of any number of risks may be determined by recognizing $\tilde{\boldsymbol{S}}$ as the union of crisp relations of its own cut-sets, $\tilde{\boldsymbol{S}}^{\alpha}$, with α-cut values essentially representing strengths of group agreements on particular prioritizations, or orderings.

The sequential procedure for identifying final, collective, group preferences and associated values of agreement level involves:

- identifying elements of the set, $\boldsymbol{O}$, of all possible, crisp preference orderings;
- selecting from all possible orderings, the subsets, $\boldsymbol{O}^{\alpha}$, of elements compatible with the paired elements of the cut-set of highest-valued α-cut; and
- continuing the process through cut-sets of increasingly smaller α-cut values until only a single, crisp preference ordering remains (Klir & Folger, 1988).

An example drawn from Klir and Folger (1988) illustrates how Blin and Whinston's (1973) method could be used to determine the most acceptable, overall group rankings of ACTD prototype risks requiring the greatest, MUA design emphasis:

> Suppose that $n = 8$ military experts, $\mathbf{E}_i$, $i = 1, 2, \ldots 8$, have together applied Phases I-III of the RFRM to identify an ACTD's four most critical risks, *a*, *b*, *c*, and *d*. Suppose still that this group hopes to prioritize – with

some reasonable degree of agreement – those four most critical risks in an effort to follow with a MUA construct of accordingly tailored MOEs. Now assume that the eight experts have independently ranked the four risks, in order from most to least risky, as:

$$\mathbf{E}_1 = (a, b, c, d)$$

$$\mathbf{E}_2 = \mathbf{E}_5 = (d, c, b, a)$$

$$\mathbf{E}_3 = \mathbf{E}_7 = (b, a, c, d)$$

$$\mathbf{E}_4 = \mathbf{E}_8 = (a, d, b, c)$$

$$\mathbf{E}_6 = (d, a, b, c).$$

Applying Definition 3 to the individual rankings of $\mathbf{E}_1$ through $\mathbf{E}_8$ yields what is termed a *reciprocal* (Spillman et al., 1979; Spillman et al, 1980), fuzzy, group preference relation, $\tilde{S}$, that may be expressed in matrix form as

$$\tilde{S} = \begin{array}{c|cccc|} & a & b & c & d \\ \hline a & 0 & 0.5 & 0.75 & 0.625 \\ b & 0.5 & 0 & 0.75 & 0.375 \\ c & 0.25 & 0.25 & 0 & 0.375 \\ d & 0.375 & 0.625 & 0.625 & 0 \\ \hline \end{array}.$$

The significant cut-sets of this fuzzy relation are those associated with α-cuts that match matrix values. Thus

$\tilde{S}^{1} = \emptyset$

$\tilde{S}^{0.75} = \{ (a, c), (b, c) \}$

$\tilde{S}^{0.625} = \{ (a, c), (b, c), (a, d), (d, b), (d, c) \}$

$\tilde{S}^{0.5} = \{ (a, c), (b, c), (a, d), (d, b), (d, c), (b, a), (a, b) \}$

$\tilde{S}^{0.375} = \{ (a, c), (b, c), (a, d), (d, b), (d, c), (b, a), (a, b), (d, a),$

$\ldots(b, d), (c, d) \}$

$\tilde{S}^{0.25}$ = { (a, c), (b, c), (a, d), (d, b), (d, c), (b, a), (a, b), (d, a),
...(b, d), (c, d), (c, a), (c, b) }.

To determine the unique, crisp ordering that will constitute the group choice, the set of all (in this example, 4! = 24) possible risk orderings can be reviewed in descending, α-cut value sequence to identify those compatible with the pairings of corresponding cut-sets:

O^1 = Trivial solution (all 24 possible orderings are compatible with $\tilde{S}^1 = \emptyset$)

$O^{0.75}$ = { (d, a, b, c), (a, b, c, d), (a, d, b, c), (a, b, d, c), (d, b, a, c),
...(b, a, c, d), (b, d, a, c), (b, a, d, c) }

$O^{0.625}$ = { (a, d, b, c) }

The ultimately determined, group-preferred ordering is { (a, d, b, c) }, which carries with it an agreement value of 0.625 and only coincidentally matches the individual preferences of experts $\mathbf{E}_4$ and $\mathbf{E}_8$.

This example not only demonstrates the Blin and Whinston (1973) and Blin (1974) method mechanics but also the method's characteristics that would most prominently affect its use in ACTD military utility assessment design. These are:

(1) **Simplicity.** Military operators would understand the method's foundational mechanics and so be likely to accept them.

(2) **Promotion of risk orderings independently identified by every evaluator.** Though DoD-endorsed (DoD, 2003c) and long-popular decision making methods like the AHP and RAND Corporation's Delphi (Ayyub, 2001) method allow groups' levels of agreement to be visible to group members, and even though enhancements of Blin and Whinston's own method (Spillman et al, 1979; Spillman et al, 1980)

promote open consensus building, there may be little reason to believe that open approaches to small group decisions can produce sets of paired risk comparisons more valid (Bone, Hey, and Suckling, 1999) than can the Blin and Whinston approach. Moreover, the shared sense of mission that can be plausibly ascribed to military operators, here evaluators, might alone preclude any need to debate the relative strengths of collaborative and independent processes.

(3) **De facto need to keep small the number of risks to be ranked.** The number of pairwise comparisons required for a collection of *n* risks is $(\frac{1}{2})(n)(n - 1)$. For example, the 20 risks previously described as a hoped-for upper limit of the number identified through a RFRM Phase III process would incur 190 pairwise comparisons, a total possibly taxing to even the most dutiful of military evaluators. Incomplete or inconsistent pairings could also occur with so large a number of comparisons, and methods like those of Harker (1987a, 1987b) or Saaty (1980, 1987) might have to be invoked in response. While at least one algorithm has been demonstrated to require only *n* comparisons of *n* risks (Chen & Klein, 1997), its otherwise quite complex features might prove intolerable to military users.

Additionally, the number of possible preference orderings for *n* risks is $n!$, a dauntingly large number for even small values of *n*. Though computer-based sorting should render this factor of little computational concern, such large numbers of permutations might nevertheless concern MUA designers.

The Blin and Whinston method can serve as a straightforward, risk prioritization tool complementing the equally straightforward, risk identification capability afforded by RFRM Phases I-III. The collective expert ranking offered by the application of both methods may promote the development of measures of effectiveness and derivative assessment designs de facto already validated by the military user community that would employ them. As a whole, then, this risk- and fuzzy set-based methodology developed for ACTD MUA design merited the tests of application and review.

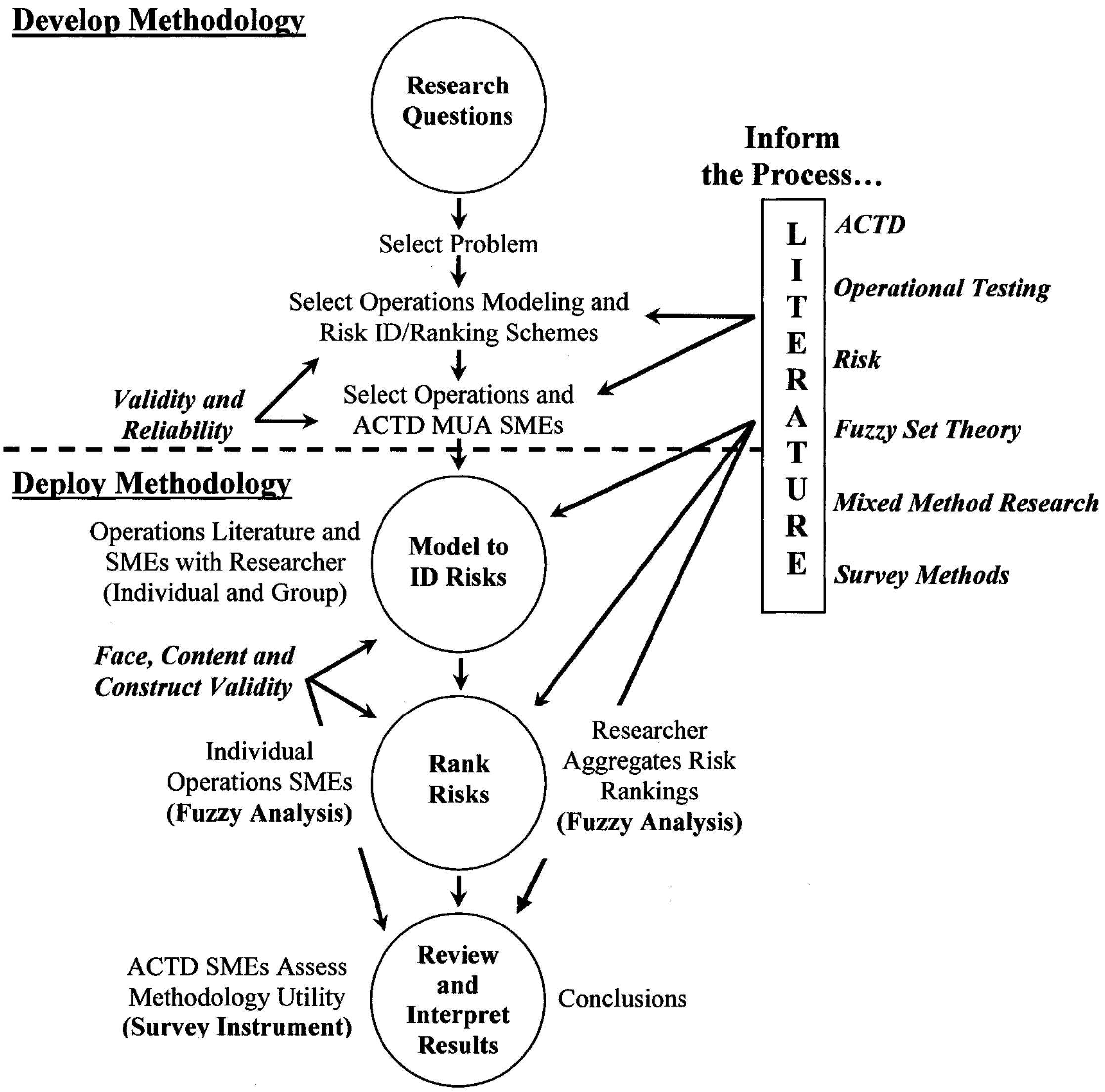
RESEARCH DESIGN

The research of this dissertation relied upon a simulated, Class III, system of systems ACTD of technology, organization, and military operations function components like those that MUAs are prescribed to address. The simulation was derived from an actual Class III demonstration in order to enhance research validity. A five-phase deployment scheme of key attributes depicted by Figure 5 afforded thorough exercise and review of the ACTD MUA design methodology developed for this research:

> **Phase 1. Joint warfare operations expert and researcher-assisted development of a military operations metasystem model suited to a joint service ACTD.** This first phase of research involved the researcher as study leader and three joint warfare operations specialists purposively selected for their familiarity with organizations and operational functions relevant to the simulated ACTD; the group size of three and purposive selection for membership reflected findings of the literature review as well as ACTD norms. Participants over time collectively reviewed, refined, and confirmed the appropriateness of a joint military operations metasystem HHM initially prototyped by the researcher using sources like the Universal Joint Task List (DoD, 2002) used to identify critical operational issues for actual ACTDs (Singleton et al., 1998). The HHM

development observed practice long employed and endorsed by numerous researchers (Florentine et al., 2003; Haimes, 2004; Haimes et al., 2002; Horowitz & Haimes, 2003; Jones et al., 2003; Lambert et al., 2001; Lamm & Haimes, 2002; Leung et al., 2004; Pennock & Haimes, 2002).

Figure 5. Research Design



Phase 2. Collective, military operations expert assessment of risks identified with the ACTD-relevant, military operations metasystem model. The same group of experts used to develop the simulated, ACTD-relevant HHM next collectively identified and analyzed the most significant risks represented by the model. This assessment utilized procedures conventional for the RFRM Phases II-III (Haimes, 2004; Haimes et al., 2002; Haimes et al., 2004; Horowitz & Haimes, 2003; Jones et al., 2003; Lambert et al., 2001; Leung et al., 2004; Pennock & Haimes, 2002) augmented by elements of expert perspective elicitation procedures proposed by Brandon (1998) and others.

Phase 3. Individual expert prioritizations of the group-identified risks of greatest significance. This process of independent rankings required final contributions from all joint military operations expert group members except the researcher, who supported individual ranking processes in face-to-face fashion for acceptable completeness and consistency.

Phase 4. Researcher aggregation of individual, risk rankings. The researcher exclusively executed this wholly mechanical process.

Phase 5. Individual expert reviews of methodology utility. This final phase of research synthesized judgments of a group of 20 purposively selected individuals collectively expert in ACTD management and MUA design. It employed a lone, single-stage, cross-sectional, primarily Likert scale-type survey instrument generally reflecting those demonstrated by Monroe (1997), Yeh (1998), Morgan (1999), and Chytka (2003) and topically related to survey structures used for related research in: (a) decision making (Yeh, 1998), (b) design performance evaluation (Sun, 2000); (c) risk and uncertainty assessment, including risk ranking (Chytka, 2003; Hampton, 2001; Monroe, 1997; Morgan, 1999; Wells, 1997); (d) technology adoption impact (Conway, 2003); and (e) evaluation of commercial product customer preferences (Liu, 1996).

Table 3 associates with these five phases this dissertation's three research questions and data collection and analysis processes pursued under the study's "dominant-less dominant" (Creswell, 1994, p. 177), research design.

Table 3. Data Collection and Analysis

Research Phase 1

Research Question: How might joint military operations metasystem models guide the identification of ACTD MUA measures of effectiveness?

Collection Method	Reference	Analysis Method	Reference	Expected Products
▪ Written document review ▪ One-on-one interviews ▪ Group interviews	▪ Brandon (1998) ▪ Brannen (2004) ▪ Creswell (1994) ▪ Denzin & Lincoln (2005) ▪ Haimes (2004) ▪ Leedy & Ormrod (2001)	▪ Triangulation ▪ Tabulation	▪ Creswell (1994) ▪ Haimes (2004) ▪ Leedy & Ormrod (2001)	▪ A military operations metasystem model pertinent to the simulated ACTD. ▪ A military operations metasystem model implying ACTD risks.

Research Phases 2-4

Research Question: How might be developed and employed joint military operations metasystem models with which can be identified ACTD MUA measures of effectiveness?

Collection Method	Reference	Analysis Method	Reference	Expected Products
▪ One-on-one interviews ▪ Group interviews ▪ Cross-sectional, individual surveys	▪ Blin (1974) ▪ Blin & Whinston (1973) ▪ Brandon (1998) ▪ Creswell (1994) ▪ Haimes (2004) ▪ Leedy & Ormrod (2001)	▪ Triangulation ▪ Tabulation ▪ Fuzzy preference relations	▪ Blin (1974) ▪ Blin & Whinston (1973) ▪ Creswell (1994) ▪ Haimes (2004) ▪ Leedy & Ormrod (2001)	▪ Prioritized listing of greatest risks to ACTD. ▪ Degree of operations expert group agreement regarding prioritization.

Table 3. Continued

Research Phase 5

Research Question: How useful might ACTD managers and analysts find the ACTD design methodology developed and deployed with this research?

Collection Method	Reference	Analysis Method	Reference	Expected Products
▪ Cross-sectional, individual surveys	▪ Ayyub (2001) ▪ Creswell (1994) ▪ Leedy & Ormrod (2001)	▪ Descriptive statistics ▪ Inferential statistics	▪ Creswell (1994) ▪ Leedy & Ormrod (2001)	▪ Measure of ACTD expert-perceived utility of methodology.

RESEARCH METHOD

Creswell (1994) identifies a combined, quantitative- and qualitative-research design that captures methodological aspects significant to this research effort:

> *In (the dominant-less dominant) design the researcher presents the study within a single, dominant paradigm with one small component of the overall study drawn from the alternative paradigm. A classic example of this approach is a quantitative study based on testing a theory in an experiment with a small qualitative interview component in the data collection phase. Alternately one might engage in qualitative observations with a limited number of informants, followed by a quantitative survey of a sample from a population. The advantage of this approach is that it presents a consistent paradigm picture in the study and still gathers limited information to probe in detail one aspect of the study* (p. 177).

This dissertation's research Phases 1 and 2 comprised primarily less-dominant, qualitative pursuits supporting the dominant and distinctly quantitative Phases 3-5. Only this sort of combined design could have adequately addressed the problem and answered the questions that drove the research.

The Practical Impetus for Combined Designs

Though much popular literature portrays research as divided into two mutually exclusive camps of quantitative paradigm-adherent positivists and qualitative paradigm-adherent constructivists, that distinction has been often challenged by practitioners of both paradigms (Blaxter, Hughes, & Tight, 2001; Brandon, 1998;

Brannen, 2004; Kemmis & McTaggart, 2005; Ladkin, 2004; Patten, 2004; Seale, Gobo, Gubrium, & Silverman, 2004). “Instead of forcibly applying abstract methodological rules (regarding the use of quantitative or qualitative paradigms),” suggest Seale et al. (2004, p. 7), researchers might instead fix their “research situation…in a place of dialogue with methodological rules.” If in particular, as others have posited, “the notion of different paradigms defies the way research is carried out in practice” (Brannen, 2004, p. 312), then researchers need not necessarily heed common exhortations (Creswell, 1994) to avoid combinations of quantitative and qualitative approaches to research. They should instead remain open to research opportunities to which both paradigms would bring value, and they should do so without fear of linkages that do not truly exist between research methodologies and the ontological and epistemological assumptions of research’s two traditional paradigms (Brannen, 2004).

The nature of the research reality and the relationships between researchers and the researched may be considered relevant to the selection of research methods, but strict adherence to positivist or constructivist stances can blind researchers to the answers they seek (Kemmis & McTaggart, 2005). Quantitative and qualitative data should be viewed as compatible and so should be together collected and analyzed if such collection and analysis serves research needs (Brannen, 2004; Zaras, 2003). Researchers should not feel constrained by either of the quantitative or qualitative paradigms and associated underpinnings of ontology and epistemology (Blaxter et al., 2001; Patten, 2004). Applied researchers, in particular, must view paradigmatic constraints as largely relaxed (if not altogether artificial or imagined) as they attend to practical aspects of problems of interest.

Applied researchers normally do emphasize problems over paradigms in acting as translators between theoretic disciplines and the world of action (Miller & Salkind, 2002). Those wishing to apply research findings directly to practical programs or processes are commonly said to pursue evaluation research (Kelly, 2004; Patten, 2004), of which the 40 years of public program evaluations prompted by and since President Lyndon Johnson's Great Society initiatives may be the examples (Orcher, 2005; Rossi & Wright, 2002) best known in this country. Evaluation research routinely melds quantitative and qualitative methods (Blaxter et al., 2001) and has been plainly described in the following fashion (Patton, 1990, p. 11, as cited in Kelly, 2004, p. 523):

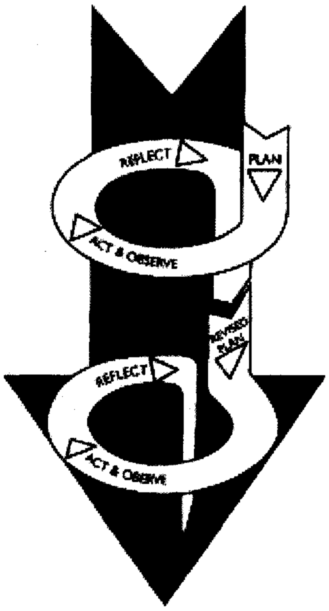
> *The term evaluation may be used quite broadly to include any effort to increase human effectiveness through systematic data-based inquiry. Human beings are engaged in all kinds of efforts to make the world a better place. These efforts include assessing needs, formulating policies, passing laws, delivering programs, managing people and resources, providing therapy, developing communities, changing organizational culture, educating students, intervening in conflicts, and solving problems. In these and other efforts to make the world a better place, the question of whether the people involved are accomplishing what they want to accomplish arises. When one examines and judges accomplishments and effectiveness, one is engaged in evaluation. When this examination of effectiveness is conducted systematically and empirically through careful data collection and thoughtful analysis, one is engaged in evaluation research.*

The discipline of evaluation research also serves as an umbrella for more refined categories such as action research (Kelly, 2004).

Characterizing Action Research

Since the approach's beginnings credited to social psychologist, Kurt Lewin and the United Kingdom's Tavistock Institute of Human Relations (Argyris, Putnam, & Smith, 1985; Kemmis & McTaggart, 2005), "the term 'action research' (has been) increasingly used to describe a [Figure 6] cycle of events that is intended to help the practitioner evaluate and modify practice. There are several models of action research...but, in essence, ...the...process is problem-driven, in that a practice-based problem is identified...[and] the practitioner and researcher design a research programme to investigate it, ...develop a package of change based on the [research] results, and then evaluate the impact of the change package" (Hicks, 2004, p. 8). The defined cooperation between practitioner and researcher serves to "empower practitioners and to integrate research with practice, thereby overcoming the well-known (practice-research) divide" (p. 8).

Figure 6. The Action Research Spiral



(Atweh et al., 1998, p. 22, as cited in Blaxter et al., 2001, p. 70. Reprinted with permission.)

Greenwood and Levin (1998, p. 21, as cited in Blaxter et al., 2001, p. 67) elaborate upon Hicks's description with:

> *(Action research) is a complex, dynamic activity involving the best efforts of both members of communities or organizations and professional researchers. It simultaneously involves co-generation of new information and analysis together with actions aimed at transforming the situation in democratic ways. (Action research) is holistic and also context bound, producing practical solutions and new knowledge as part of an integrated set of activities...(it) is a way of producing tangible and desired results for the people involved, and it is a knowledge-generation process that produces insights both for researchers and the participants. It is a complex action-knowledge generation process...the immense importance*

> *of insider knowledge and initiatives is evident, marking a clear distinction from orthodox research that systematically distrusts insider knowledge as co-opted.*

These latter authors' references repeat emphases applied earlier in this document to notions of holism, context, and complexity, all integral to a system of systems philosophy with which this dissertation's research corresponds.

Utilizing Action Research

"The purpose of action research is, always and explicitly, to improve practice" (Griffiths, 1998, p. 21, as cited in Blaxter et al., 2001, p. 67). It has therefore become increasingly popular with small-scale researchers working in professional areas (Blaxter et al., 2001).

"(Action research) is well suited to the needs of people conducting research in their workplaces, and who have a focus on improving aspects of their own and their colleagues' practices. For example, the teacher who is concerned to improve performance in the classroom may find action research useful because it offers a systematic approach to the definition, solution, and evaluation of problems and concerns" (Blaxter et al., 2001, p. 67). Variations of action research have even been demonstrated with attempts to correct deficiencies in large-scale systems, notably health care and higher education delivery systems (Clarke, 1998; Greenwood & Levin, 2005; Linden & Wen, 1998; Meltzoff, 1998). That action researchers can realize process improvements by working together with those whose processes they seek to improve is reflected in seven characteristics that Hart and Bond (1995, p. 37-38, as cited in Blaxter et al., 2001) maintain distinguish it from alternate research methods:

> Action research:
>
> (1) is educative;
>
> (2) deals with individuals as members of social groups;
>
> (3) is problem-focused, context-specific, and future-oriented;
>
> (4) involves a change intervention;
>
> (5) aims at improvement and involvement;
>
> (6) involves a cyclic process in which research, action and evaluation are interlinked;
>
> (7) is founded on a research relationship in which those involved are participants in the change process. (p. 69)

Hart's and Bond's characterization promotes action research as an appropriate vehicle for deploying and testing the ACTD military utility assessment design methodology proposed with this research.

STUDY LEADER SELECTION CRITERIA

As a combined effort of researcher and selected experts, the deployment of this study's ACTD MUA design methodology greatly depended on a study leader of "managerial and technical responsibility for executing the (study), overseeing all participants, and intellectually owning the results" (Ayyub, 2001, p. 235). The study leader would perform the roles of technical integrator and facilitator described in Appendix A; the leader would also possess characteristics aligned with general criteria drawn from Ayyub (2001):

(1) Competence based on academic training and relevant experience;

(2) Strong communication skills, interpersonal skills, flexibility, impartiality, and ability to generalize and simplify;

(3) A large contact base of (ACTD program) leaders, researchers…and decision makers; and

(4) Leadership qualities and the ability to build consensus. (p. 240)

Needed interactions with the operations expert group also required the study leader to meet the specific criteria prescribed in Appendix B for operations group participants. This dissertation's author met general and specific requirements for service as study leader and so performed that role.

EXPERT SELECTION CRITERIA

This study also greatly depended on characteristics of members selected for each of the required, joint military operations and ACTD expert groups. Though numerous studies point to difficulties associated with "expert" identification (Hutton & Klein, 1999; Shanteau, Weiss, Thomas, & Pounds, 2002; Vick, 2002), the following five general rules drove the participant selection criteria of both groups:

(1) Participants must be or represent ACTD program stakeholders (Brandon, 1998), with stakeholders defined as groups or individuals who can affect or be affected by some system of interest (Cornelissen et al., 2002; Turnley, 2002) and "have demonstrated their need and willingness to be involved in seeking a solution" (Sproles, 2000, p. 53) to whatever problem the system is intended to address.

(2) Participants must possess strong relevant expertise in the study's area of focus, gained through professional accomplishment and experience as well as academic training (Ayyub, 2001; Brandon, 1998);

(3) Participants must be willing to act as impartial evaluators (Ayyub, 2001);

(4) Participants must be available and willing to commit the time and effort required by the study (Ayyub, 2001); and

(5) Participants must possess the same degree of communication and interpersonal skills, flexibility, impartiality, and abilities to generalize and simplify as that required of the study leader (Ayyub, 2001).

Appendices B and C respectively identify these and more precise criteria applied for the selection of individuals to populate the operations and ACTD expert groups. All general and specific, individual expert selection criteria were complemented by other requirements desired for the compositions of both groups ultimately determined to promote the study.

Operations Expert Group Characteristics

The joint military operations expert group employed for this research comprised three joint warfare operations specialists purposively selected in accordance with Appendix B. Group sizing reflected a preponderance of literature relevant to the research, and the purposive selection process could be plausibly argued as that which would normally be available to ACTD managers pursuing development of their demonstrations' military utility assessments. The operations expert group displayed a degree of heterogeneity expected with military stakeholder experience, but – as with the purposive selection process – this degree of homogeneity was accepted by the researcher as closely aligned with realities of ACTD staffing.

ACTD Management and MUA Design Expert Group Characteristics

The expert group of ACTD managers and MUA designers employed for this research comprised 20 purposively selected individuals meeting the selection criteria specified in Appendix C. This second group's purpose of methodology review differed markedly from that of the operations group's methodology deployment charge, and its characteristics reflected that distinction.

The group's sizing represented a large portion of all individuals who have been or are involved with joint ACTD management or military utility assessment design. Its purposive origin, then, did not challenge routinely-voiced and accepted calls for random selection processes nearly as strongly as did the purposive origin of the operations expert group. The ACTD review group's heterogeneity could also be shown to have been more prominent than that of the operations-oriented group.

METASYSTEM MODEL DEVELOPMENT

Brandon (1998) identifies three broad procedural rules for guiding interactions among study leaders and study experts, rules that transcend mere procedure by also contributing to study validity. The first of these three rules requires the "participation of stakeholder groups with the appropriate (study) expertise" (p. 328), and this research observed that first rule with the criteria established for participation in its operations and ACTD expert groups. The second rule stipulates "that stakeholders' (study-related) expertise should be fully tapped by applying carefully developed, thorough methods for stakeholder participation" (p. 330), while the third holds that "the equitable participation of stakeholders...should be ensured" (p. 332). The second and third rules have been expanded by other researchers equally concerned with validity-related issues, and both were observed with processes executed during this dissertation's research Phase 1 of metasystem model development.

Ayyub (2001), Chicken and Hayns (1989), Cornelissen et al. (2002), and Pennock and Haimes (2002) suggest complementary criteria also applied during this research to prepare for and execute the Phase 1 development of a joint military operations metasystem HHM. Those complementary criteria included:

- Providing expert group members with statements of study objectives before the expert groups commenced their respective tasks;
- Providing expert group members with explanations of appropriate, study-significant terms and processes prior to commencement of each group's respective tasks;
- Providing expert group members with clear and concise explanations of their respective tasks;
- Providing expert group members with equitable, participation opportunities; and
- Comprehensive documentation of each group's proceedings in order to support acceptance of the results.

The operations expert group used supplied, preparatory information and brainstorming endorsed by Haimes (2004), Pennock and Haimes (2002), and others to develop the simulated ACTD-relevant, joint military operations metasystem HHM with which it was charged, a HHM of detail sufficient to capture substantive risks (Haimes, 2004; Saaty, 1987) but not so complex as to threaten the availability of expert time or commitment (Haimes, 2004). Phase 1 proceedings may be considered to have been semi-structured, group interviews orchestrated and recorded by the researcher as study lead.

METASYSTEM MODEL RISK ASSESSMENT AND PRIORITIZATION

Research Phases 2 and 3 each exhibited all appropriate, preparatory and execution process criteria observed during Phase 1. The second phase of research demonstrated a collaborative identification of risks made evident to the operations expert group by the joint operations metasystem model – the HHM – that the group developed during research Phase 1. A singular focus upon the independent, pairwise comparisons required by the Blin and Whinston (1973) method determined risk prioritizations of individual experts and marked Phase 3 as the operations expert group's lone departure from collaboration. The Phase 4, study leader aggregation of Phase 3 prioritizations drew further upon the Blin and Whinston work by defining a single, operations expert group preference regarding prioritization of risks thought most significant. All Phase 1 through 4 processes were next reviewed in Phase 5 by a group of experts distinct from the operations group and collectively versed in ACTD management and MUA design.

ASSESSMENT OF METHODOLOGY UTILITY

A group of 20 individuals expert in either ACTD management, MUA design, or both, reviewed during research Phase 5 the ACTD MUA design methodology developed and deployed by the study leader and joint military operations expert group in preceding phases. Once accorded the same preparatory and procedural treatments provided the operations expert group, each ACTD or MUA design expert independently reviewed the methodology's development, processes, and products with the aid of a lone, single-stage, cross-sectional survey instrument structurally like those of Monroe (1997), Yeh (1998), Morgan (1999), and Chytka (2003) and topically related to surveys used for related research in: (a) decision making (Yeh, 1998), (b) design performance evaluation (Sun, 2000); (c) risk and uncertainty assessment, including risk ranking (Chytka, 2003; Hampton, 2001; Monroe, 1997; Morgan, 1999; Wells, 1997); (d) technology adoption impact (Conway, 2003); and (e) evaluation of commercial product customer preferences (Liu, 1996).

APPROACH TO RELIABILITY AND VALIDITY

This study pursued a dominant-less dominant (Creswell, 1994), combined design approach to reliability and validity. Research and instrument reliability and validity issues were of particular concern during the less-dominant, action research-dependent Phases 1 and 2 of military metasystem model development and risk identification. Concerns reflected epistemological issues that Styhre et al. (2002, p. 98, as cited in Ladkin, 2004, p. 539) reveal to have engendered criticism for "action researchers…not taking a detached position vis-à-vis the research objects but rather actively becoming involved" in ways possibly consequential to research findings.

The effort's first two study phases pursued validity and reliability using an epistemological tack respecting the Argyris et al. (1985) definition of action contexts of high complexity wherein "unilateral control of variables is neither possible nor desirable" (p. 239). To meet the phases' contextual challenge, the research employed observations, interviews, and recordings (Argyris et al., 1985; Gorman & Clayton, 2005) typical of qualitative research together with a heavy emphasis on face, content, and construct validity deemed appropriate for an HHM and as defined by Bernard (2002), Gliner and Morgan (2000), and Orcher (2005) in Appendix A. Research Phases 1 and 2 also observed the very clear counsel of Greenwood and Levin (2005, p. 54) regarding the establishment of validity and reliability in action research studies:

> *Validity…and reliability in action research are measured by the willingness of…stakeholders to act on the results of the action research, thereby risking their welfare on the "validity" of their ideas and the degree to which the outcomes meet their expectations. Thus, cogenerated*

> *contextual knowledge is deemed valid if it generates warrants for action. The core validity claim centers on the workability of the actual...change engaged in, and the test is whether or not the actual solution to a problem arrived at solves the problem.*

The dominant, third through fifth research phases of risk prioritization, risk aggregation, and methodology review employed non-experimental but still thoroughly quantitative analysis and survey methods. These phases observed measures of reliability and validity commonly associated with quantitative tests and survey instruments.

The combined design acknowledged plainly visible and necessary, qualitative and quantitative aspects of the MUA design process. It, too, was necessary and so necessarily judged in accordance with qualitative and quantitative norms of reliability and validity.

SUMMARY

The ACTD MUA methodology developed for this dissertation was characterized as one displaying the attributes that some researchers have posited for system of systems engineering-based methodologies. That characterization supported researcher claims of an assessment design product applicable to numerous, complex systems other than the one simulated for this research.

The complex system simulated for this research was developed in accordance with criteria derived from the realities of the ACTD program, realities that include a prominent need for risk-based, expert judgments rendered either independently or collectively as group, or social, preferences. Elements of Haimes' (2004) risk filtering, ranking, and management method and Blin and Whinston's (1973) method for resolving small group preferences were identified as a pairing possibly able to address MUA design realities in a manner acceptable to program stakeholders. A five-phase research effort was planned to test the utility of a risk- and fuzzy set-based methodology for ACTD MUA design.

A mixed-method, action research plan was emplaced to govern less-dominant, qualitative proceedings of research Phases 1 and 2 as well as dominant, quantitative proceedings executed during Phases 3 through 5. The need for qualitative proceedings naturally derived from the expert perspective-based HHM development and risk identification that would occur during the first two research phases, while the need for quantitative measures derived equally naturally from the risk prioritizations and judgments regarding proposed methodology utility to define Phases 3 through 5. The research plan additionally incorporated distinct, selection criteria for the study lead and each of two expert groups respectively employed for the HHM development and risk prioritizations of research Phases 1 through 3 and the methodology utility assessment of research Phase 5. These selection criteria would buttress research validity and so complement other efforts regarding validity and reliability applied to qualitative and quantitative elements of the research.

RESULTS

This research addressed its purpose, its objectives, and its three foundational questions within a single cycle of the Figure 6 action research spiral. Once developed, the risk- and fuzzy set-based MUA design methodology was deployed within the context of a simulated ACTD of technologies, organizations, processes, and other components of joint military operations metasystems that utility assessments should accommodate. The joint operations expert group executed its deployment charge by first identifying a model its members believed to portray the most relevant aspects of a joint military operations metasystem incorporated with the simulated demonstration. That same group then used the model to identify and classify in terms of high, moderate, and low the risks associated with adoption of the simulated ACTD within the superior metasystem. The classification was next refined with individual member prioritizations of those risks that the entire group had assessed as most serious. In a role of study leader granted under the action research format that governed the conduct of methodology deployment, the researcher concluded the exercise by determining a single, operations expert group prioritization of selected risk criticality, a prioritization the methodology holds to enable identification of measures of effectiveness fundamental to ACTD MUA design. All of these research processes were lastly reviewed by a distinct and consequentially-sized group of individuals prominent in the management or assessment of actual, joint operations demonstrations.

SIMULATED ACTD

The ACTD simulated for this research, the Operational Mine Detection ACTD, strongly reflected for validity purposes certain elements of an actual demonstration, the

Class III, Joint Countermine (JCM) ACTD conducted 1994-2000 (Blumenthal, no date; Elliott, Madden, & Dean, 1996; Schaffer, Arnold, Smith, & Jackson, 1997; Schnoor, no date; U.S. Atlantic Command [USACOM], 1998). Aspects of the simulated, joint, amphibious, forcible entry operations-related, OMD ACTD included programmatic, technical, and operational traits that would be typically known to staffs early in a demonstration's life cycle, when MUA design begins. Operations expert group members were given a statement of critical military need, a statement of OMD ACTD purpose, critical operational issues, and key technical and operational characteristics associated with the OMD system's two principal and complementary components: the covert, national-level, Remote Littoral Sensing System (RLSS); and the Proximate Littoral Sensing System (PLSS) organic to the joint forces it would serve for joint, amphibious, forcible entry operations planning. The RLSS was characterized as using novel computational techniques to exploit capabilities of existing national-level reconnaissance assets and provide joint forces with cuing information required of the PLSS, an unmanned aerial vehicle, surveillance platform. Appendix D detail the OMD ACTD prototype and all other information provided the operations group in anticipation of research Phase 1.

METASYSTEM MODEL

Research Phase 1 saw the joint warfare operations expert group development of a joint military operations metasystem model suited to the OMD ACTD. That model was the fundamental element produced during the MUA design methodology deployment, and it was identified in accordance with Haimes' (1998, 2004) notions of a HHM. The operations expert group crafted and achieved consensus on the HHM using a seed model provided by the study lead and that the balance of the group modified through 10 hours of deliberations over five meeting sessions. The final HHM comprised 13 perspectives – the principal, military operations metasystem components or, equivalently, those highest-level systems constituting the military operations metasystem with which the OMD ACTD was to be incorporated – derived from a seed model total of 7. The 13 perspectives together encompassed 93 domains and 95 subdomains, and they were derived through major, model configurations that included the seed's 7 perspectives and an intermediate model's 11. Table 4 describes the final HHM perspective evolution and Appendix E identifies the entire final model of perspectives, domains, and subdomains.

Table 4. OMD ACTD HHM Perspective Development

Seed Model Configuration

- Friendly Military and Non-Military Organizations
- OMD ACTD Critical Operational Issues
- OMD System Missions
- OMD System Users
- OMD System Functions
- OMD System Operations
- Adversary Threats to OMD Operations

Intermediate Model Configuration

- Classes of Threat Mines
- Potential Global Areas of Interest
- OMD ACTD Critical Operational Issues
- OMD System Missions
- Friendly Military and Non-Military Organizations
- Adversary Military and Non-Military Organizations
- Neutral Military and Non-Military Organizations
- RLSS Functions, Command and Control, Users, and Operations
- PLSS Functions, Command and Control, Users, and Operations
- Adversary Threats to OMD Operations

Final Model Configuration

- Engineering Aspects of Threat Mine Employment
- Environmental Aspects of OMD Operating Areas
- OMD ACTD Critical Operational Issues
- OMD System Missions
- Friendly Forces and Other Support Capabilities
- Adversary Forces and Other Support Capabilities
- Neutral Forces and Other Support Capabilities
- RLSS Technical Attributes
- RLSS Operational Attributes
- PLSS Technical Attributes
- PLSS Operational Attributes
- Adversary Threats to OMD Operations
- Temporal Aspects of OMD ACTD.

METASYSTEM MODEL RISK ASSESSMENT

Research Phase 2 constituted an operations expert group assessment of risks represented to it by the HHM. Supported by the researcher as a study leader otherwise extracted from the assessment process, and mindful of Slovic et al. (2004) admonitions to regard "risk as feelings....[together with] risk as analysis" (p. 311), the three operations experts initially identified a collection of 104 risks they perceived associated with the adoption of the OMD ACTD by a superior, joint military operations metasystem. That number was refined through 25 hours of deliberation to the 86 identified in Appendix F, and the experts used an enhanced version of the RFRM Phase III and DoD-conventional risk matrix to classify each element of the resolved set as high, moderate, or low. This classification was achieved by associating with each risk one of the ordered pairs of consequence and likelihood, (consequence, likelihood), depicted in Figure 7.

Figure 7. Enhanced RFRM Phase III and DoD-Conventional Risk Matrix

	LIKELIHOOD				
CONSEQUENCE	***Remote***	***Unlikely***	***Likely***	***Highly Likely***	***Frequent***
Unacceptable	Moderate (5, 1)	High (5, 2)	High (5, 3)	High (5, 4)	High (5, 5)
Minimally Acceptable	Low (4, 1)	Moderate (4, 2)	Moderate (4, 3)	High (4, 4)	High (4, 5)
Acceptable with Significant Utility Loss	Low (3, 1)	Low (3, 2)	Moderate (3, 3)	Moderate (3, 4)	High (3, 5)
Acceptable with Slight Utility Loss	Low (2, 1)	Low (2, 2)	Low (2, 3)	Moderate (2, 4)	Moderate (2, 5)
Little or None	Low (1, 1)	Low (1, 2)	Low (1, 3)	Low (1, 4)	Moderate (1, 5)

Operations expert group members initially assigned (consequence, likelihood) pairings to risks on an independent basis. Once each of the three experts had completed their individual assessments, those risks that had been identified as high by any expert were again evaluated by the entire group, with the aim to resolve high risks to precise, (consequence, likelihood) assessments. This precise resolution facilitated two purposes. First, it offered opportunities to settle upon or at least understand group members' possibly distinct definitions of "acceptable with significant utility loss," "unacceptable," "highly likely," and other risk matrix terms; common understandings so achieved accommodated fuzzy terminology and issues beyond the scope of the research. Second, precise (consequence, likelihood) evaluations of risks considered to be high promoted the prioritization mechanics pursued in research Phases 3 and 4. Only high risks were resolved to consensus because: to identically resolve moderate or low risks would have added nothing to the deployment demonstration of the MUA design methodology; and because constraints of resources of other factors might force actual ACTD managers and analysts to design utility assessments based on effectiveness measures derived only from the most serious of methodology-identified risks.

Group consensus held eight risks as high once each had been associated with a particular ordered pair of (consequence, likelihood). Those eight high risks and their ordered pair assignments were:

- (5, 3). OMD system yields false positive indications of mines or minefields.
- (5, 3). OMD system yields false negative indications of mines or minefields.
- (5, 3). Mines are concealed or camouflaged by natural or manmade objects expected to be seen within surf and beach zones.

- (5, 4). Adversaries use various means to counter OMD system detection capabilities.
- (4, 4). RLSS algorithms are not sufficiently robust to provide useful information regarding areas of operational interest.
- (4, 4). PLSS UAV airframe is vulnerable to adversary anti-aircraft weapons and tactics, including small arms fire.
- (5, 4). PLSS deployment concept of one system per host vessel insufficiently supports operational needs.
- (5, 3). Adversary electronic attacks impair PLSS navigation or surveillance functions.

Figure 8 is a pictorial representation of the distribution of high risks that operations experts unanimously perceived linked to the OMD ACTD and its relevant metasystem.

Figure 8. High Risk Distribution Derived from the OMD ACTD HHM

	LIKELIHOOD				
CONSEQUENCE	***Remote***	***Unlikely***	***Likely***	***Highly Likely***	***Frequent***
Unacceptable			4 High Risks (5, 3)	2 High Risks (5, 4)	
Minimally Acceptable				2 High Risks (4, 4)	
Acceptable with Significant Utility Loss					
Acceptable with Slight Utility Loss					
Little or None					

METASYSTEM MODEL RISK PRIORITIZATION

Research Phase 3 directed individual expert prioritizations of the eight high risks determined in Phase 2, and those prioritizations might have been executed in two primary ways. The experts might have ignored their earlier (consequence, likelihood) evaluations and treated the eight risks as elements of a single set to be ranked first through eighth in terms of seriousness. Alternately, they might have first prioritized in terms of seriousness the (consequence, likelihood) pairings assigned each of the high risks and then prioritized the risks assigned identical pairings. With neither suggestions from the study leader nor external guidance available to them from risk literature sources like Haimes (2004), the remaining three operations expert group members unanimously endorsed the alternative scheme of prioritization.

The operations expert group felt quite strongly that the two risks assigned a (5, 4) (consequence, likelihood) pairing should be, in some order, the most and second-most serious risks of the eight high risks identified. They felt equally strongly that risks categorized as (5, 3) should constitute those third- through sixth-most serious of the eight and that the (4, 4)-assigned risks should be considered seventh- and eighth-most serious. The group's intent dictated the format of the individual, pairwise comparisons that would immediately follow.

The three operations expert group members participating in research Phase 3 were asked to use pairwise comparisons to prioritize elements of three risk sets, or categories. Those three categories comprised the two risks assigned (5, 4) pairings of consequence and likelihood:

(A) PLSS deployment concept of one system per host vessel insufficiently supports operational needs and

(B) Adversaries use various means to counter OMD system detection capabilities;

the four risks of

(C) Adversary electronic attacks impair PLSS navigation or surveillance functions,

(D) OMD system yields false negative indications of mines or minefields,

(E) Mines are concealed or camouflaged by natural or manmade objects expected to be seen within surf and beach zones, and

(F) OMD system yields false positive indications of mines or minefields,

that were assigned (5, 3) pairings; and the two risks of

(G) RLSS algorithms are not sufficiently robust to provide useful information regarding areas of operational interest.

(H) PLSS UAV airframe is vulnerable to adversary anti-aircraft weapons and tactics, including small arms fire,

both assigned the pairings of (4, 4). Given these three categories of seriousness and the $(\frac{1}{2})(n)(n - 1)$ number of pairwise comparisons needed to prioritize all elements of each of the two-, four-, and two-risk element sets respectively representing those categories, the researcher as study leader constructed a questionnaire of

$$1 + 6 + 1 = 8$$

pairwise comparisons randomly ordered in a fashion unlike any to which the operations expert group had been previously exposed. The members then independently used the questionnaire, presented in Appendix G, to identify three distinct prioritizations that can be portrayed using the preceding, (A) - (H) lettering scheme:

Operations Expert Group Participant A: ***(B, A, D, F, E, C, H, G)***

Operations Expert Group Participant B: ***(A, B, D, F, E, C, G, H)***

Operations Expert Group Participant C: ***(A, B, D, E, F, C, G, H)***

These disparate prioritizations concluded research Phase 3. They also provided all the elements necessary for the researcher, as study leader, to execute research Phase 4 in accordance with the Blin and Whinston (1973) and Blin (1974) method for identifying a group preference regarding, in this case, the most serious risks to the joint military operations metasystem with which the OMD ACTD system might be incorporated. In fact, the operations expert group's use of three seriousness categories drove three distinct applications of the fuzzy group preference approach executed during Phase 4.

A first application of the fuzzy group preference method to (5, 4)-assessed risks ***A*** and ***B*** determined a fuzzy, group preference relation, $\tilde{S}_1$, described by the reciprocal matrix

$$\tilde{S}_1 = \begin{array}{c} \\ A \\ B \end{array} \begin{array}{c} \begin{array}{cc} A & B \end{array} \\ \left[\begin{array}{cc} 0 & \frac{2}{3} \\ \frac{1}{3} & 0 \end{array}\right] \end{array} .$$

The cut-sets of this fuzzy relation that correspond with its matrix values are, almost trivially,

$\tilde{S}_1^{1} = \emptyset$

$\tilde{S}_1^{2/3} = \{ (A, B) \}$

$\tilde{S}_1^{1/3} = \{ (A, B), (B, A) \}$.

The only possible crisp orderings of risks ***A*** and ***B*** are the 2! = 2 pairs (***A***, ***B***) and (***B***, ***A***), where

O_1^{1} = Trivial solution (both orderings are compatible with $\tilde{S}_1^{1} = \emptyset$) and

$O_1^{2/3} = \{ (A, B) \}$

identified the (A, B) ordering as the one preferred by the operations expert group at an agreement level of ⅔.

A second application of the fuzzy group preference method to (5, 3)-assessed risks C through F yielded a fuzzy, group preference relation, $\tilde{S}_2$ of

$$\tilde{S}_2 = \begin{array}{c} \\ C \\ D \\ E \\ F \end{array} \begin{array}{c} \begin{array}{cccc} C & D & E & F \end{array} \\ \left[\begin{array}{cccc} 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 \\ 1 & 0 & 0 & \frac{1}{3} \\ 1 & 0 & \frac{2}{3} & 0 \end{array} \right] \end{array} .$$

This fuzzy relation matrix determines cut-sets of

$\tilde{S}_2^{1} = \{ (D, C), (D, E), (D, F), (E, C), (F, C) \}$

$\tilde{S}_2^{2/3} = \{ (D, C), (D, E), (D, F), (E, C), (F, C), (F, E) \}$

$\tilde{S}_2^{1/3} = \{ (D, C), (D, E), (D, F), (E, C), (F, C), (F, E), (E, F) \}.$

Table 5 portrays the set of $4! = 24$ possible crisp orderings with which $\tilde{S}_2$ cut-sets were compared to determine the one that constituted the group prioritization of risks C-F.

Table 5. Crisp Orderings of Risks *C-F*

(C, D, E, F)	(C, E, F, D)	(E, C, D, F)	(D, E, C, F)	(E, F, C, D)	(E, D, F, C)
(C, D, F, E)	(C, F, E, D)	(F, C, D, E)	(D, F, C, E)	(F, E, C, D)	(F, D, E, C)
(C, E, D, F)	(D, C, E, F)	(E, C, F, D)	(E, D, C, F)	(D, E, F, C)	(E, F, D, C)
(C, F, D, E)	(D, C, F, E)	(F, C, E, D)	(F, D, C, E)	(D, F, E, C)	(F, E, D, C)

A review of these possible orderings in the descending, α-cut value sequence of

$O_2^{1} = \{ (D, E, F, C), (D, F, E, C) \}$

$O_2^{2/3} = \{ (D, F, E, C) \}$

identified the ordering (***D***, ***F***, ***E***, ***C***) as that preferred by the operations expert group at an agreement level of ⅔ identical to that achieved for the (***A***, ***B***) ordering of the two most serious risks.

A third and final application of the Blin and Whinston (1973) and Blin (1974) method to (4, 4)-assessed risks ***G*** and ***H*** determined a fuzzy, group preference relation, $\tilde{S}_3$, described by the reciprocal matrix

$$\tilde{S}_3 = \begin{array}{c} \\ G \\ H \end{array} \begin{array}{c} \begin{array}{cc} G & H \end{array} \\ \begin{bmatrix} 0 & \frac{2}{3} \\ \frac{1}{3} & 0 \end{bmatrix} \end{array}.$$

The cut-sets of this fuzzy relation that correspond with its matrix values are

$\tilde{S}_3^{1} = \varnothing$

$\tilde{S}_3^{2/3} = \{ (G, H) \}$

$\tilde{S}_3^{1/3} = \{ (G, H), (H, G) \}$.

Similar to the case of the two most serious risks, ***A*** and ***B***, the only possible crisp orderings of the least serious of operations expert group-identified, high risks are (***G***, ***H***) and (***G***, ***H***), where

O_3^{1} = Trivial solution and

$O_3^{2/3} = \{ (G, H) \}$

identified the (***G***, ***H***) pair to represent the operations expert group prioritization at an agreement level of ⅔. Merging these (4 4)-risk category results with those of the (5, 4)- and (5, 3)-assessed categories – all three attained with agreement levels of ⅔ – yielded a comprehensive prioritization of

$$(A, B, D, F, E, C, G, H)$$

carrying a comprehensive agreement level of ⅔ and that only coincidentally matched the individual prioritization of expert group Participant B.

All operations expert group participants expressed satisfaction with this final accord elaborated with Table 6. They also believed their prioritization would facilitate the identification of measures of effectiveness – such as those inviting counts of operational deficiencies imposed by a PLSS deployment concept of one surveillance vehicle per host vessel – by affording the pertinence, completeness, and accuracy required of a MUA design process.

Table 6. Final Operations Expert Group Ranking of OMD ACTD High Risks

(1) *PLSS deployment concept of one system per host vessel insufficiently supports operational needs.*

(2) *Adversaries use various means to counter OMD system detection capabilities.*

(3) *OMD system yields false negative indications of mines or minefields.*

(4) *OMD system yields false positive indications of mines or minefields.*

(5) *Mines are concealed or camouflaged by natural or manmade objects expected to be seen within surf and beach zones.*

(6) *Adversary electronic attacks impair PLSS navigation or surveillance functions.*

(7) *RLSS algorithms are not sufficiently robust to provide useful information regarding areas of operations interest.*

(8) *PLSS UAV airframe is vulnerable to adversary anti-aircraft weapons and tactics, including small arms fire.*

RELIABILITY AND VALIDITY

The satisfaction that operations expert group members expressed regarding their efforts and results hints at reliability- and validity-related aspects of research Phases 1 through 4. A more complete review of reliability and validity associated with this study can be generated.

The first two phases of this research observed identical, qualitative approaches to reliability and validity. Reliability – or an equivalent term of dependability preferred by some adherents of the qualitative paradigm of research (Denzin & Lincoln, 2005) – can be argued to have been introduced primarily with the operations expert selection criteria promoted by numerous sources (Ayyub, 2001; Brandon, 1998; Cornelissen et al., 2002; Turnley, 2002; Sproles, 2000), together with the holistic perspective integral to Haimes' (2004) RFRM and with which this study's operations experts, given their selection, can be said to have been facile. Arguments addressing research Phases 1-2 validity rest primarily upon action research tenets as well as the same expert selection criteria and Haimes' holism that supported reliability.

The instrumental case study-like (Stake, 2005) effort of research Phases 1-2 depended for its reliability upon a qualitative scheme by Gorman and Clayton (2005) supposing persistent recording as "perhaps the main key to reliability" (p. 56); such recording was a hallmark of researcher activity during Phases 1-2 development of the OMD ACTD HHM and following identification of associated risks. The action research formula that placed the researcher as the operations expert group leader represented a second reliability technique endorsed by Gorman and Clayton, that of researcher immersion in the problem context; this circumstance was reinforced by the participation criteria established prior to methodology deployment for the study leader and all members of the operations expert group. Expert selection criteria demanding a high degree of pertinent operations and operational testing experience also represented a third Gorman and Clayton technique of drawing upon "other research...for assistance" (p. 57).

This third technique was itself buttressed by a prominent history of RFRM applications available to the operations group through the literature.

The measurement validity of this work's Phase 1-2 effort should also be gauged from the perspective of qualitative or, more precisely, action research. That may be done using five criteria suggested by Reason and Bradbury (2001, p. 5, as cited in Ladkin, 2004):

- The extent to which the research demonstrates emergence and enduring consequences;
- The extent to which the research deals with pragmatic issues of practice and practising;
- The extent to which the inquiry demonstrates good qualities of relational practice, such as democracy and collaboration;
- The extent to which the research deals with questions of significance; and
- The extent to which the research takes into account a number of different ways of knowing. (p. 539)

These criteria can be shown to encompass measurement validation concepts more traditionally termed (Gliner & Morgan, 2000; Gorman & Clayton, 2005; Leedy & Ormrod, 2001) face, content, and construct validity. Satisfying the criteria represented the culmination of efforts to establish the face, content, and construct validity of the operations expert group-derived HHM and set of 86 risks.

The Phase 1 development of the OMD ACTD HHM and the Phase 2 identification of 104 model-derived risks later resolved to 86 each plainly evinced an emergence of expert understanding and concerns stimulated by the collaborative environment emplaced for those two research phases. The very nature of the complex, joint military operations metasystem to be modeled drove "a number of different ways of knowing" (p. 539) that were manifested in the use of Haimes' (1998, 2004) RFRM and, particularly, HHM development processes. The significance of the pragmatic issue simulated – OMD ACTD MUA design – provided the impetus for all research and supported a supposition of "enduring consequence" plausible for one last and notable characteristic of action research: that the validity of such research is "measured by the willingness of...stakeholders to act on the results of (their work), thereby risking their welfare on the 'validity' of their idea and the degree to which the outcomes meet their expectations" (Greenwood & Levin, 2005, p. 54). Given that operations expert group selection criteria stipulated members to be either stakeholders or representatives of stakeholders, and given that each of those members expressed comfort with the final HHM and associated set of risks, the "enduring consequence" criterion may be portrayed as satisfied.

Research Phase 3-4 reliability and measurement validity concerns reflected attributes of quantitative research practice. Phase 3 reliability concerns rested strictly with the instrument reliability of an eight-question survey that invited only pairwise comparisons of risks earlier collectively identified and defined by the operations expert group, and it is easy to argue that multiple applications of the instrument would have yielded precisely the same number of identical results. The practically deterministic, Blin and Whinston (1973) and Blin (1974) fuzzy group preference method applied in research Phase 4 to Phase 3 results effectively dismisses concerns regarding Phase 4 reliability. The issue of Phase 3 measurement validity may be characterized as trivial in that a survey eliciting only eight pairwise comparisons must surely have accurately indicated the individual preferences of operations expert group members. The measurement validity of research Phase 4 seems only slightly more difficult to judge with its exceedingly straightforward derivation of a group prioritization of risks and its identification of a level of group agreement invoking an arithmetic mean easily accepted as accurate.

The measures of internal and external validity – respectively, the evaluation of extraneous variable control and generalizability – that may be assigned this research proved high, largely for a design that accommodated the Argyris et al. (1984) definition of action research problem contexts as highly complex and wherein "unilateral control of variables is neither possible nor desirable" (p. 239). The RFRM and fuzzy group preference methods of this research were employed precisely for their suitability to processes demanding holistic perspectives and the necessarily dense array of variables associated with those perspectives. It was the collective reasoning process utilized by the operations expert group during research Phases 1-2 that established order over numerous and legitimate, group concerns and that therefore afforded the variable control expected for internal validity.

The study's external validity, or "the extent to which its results [could] apply to situations beyond the study itself" (Leedy & Ormrod, 2001, p. 105), was likewise promoted by the research design. The OMD ACTD simulation did, indeed, simulate essential elements of problem contexts evident with actual demonstrations like that from which it was derived. The operations expert selection criteria established for the deployment stage of this research ensured that individuals chosen to execute the research-proposed, MUA design methodology truly represented those available to and desired by assessment designers and managers preparing to conduct actual demonstrations. These research design factors reflected strategies commonly pursued to “enhance the external validity of research” (Leedy & Ormrod, 2001) projects. They also promoted an assertion that the study’s methodology could be applied to: all ACTDs; to ACTD program-derivative, joint capability technology demonstrations; and quite possibly to assessment settings beyond those two programs and that equally depend on the holistic perspectives of small groups of experts upon which this study so greatly depended.

ASSESSMENT OF METHODOLOGY UTILITY

The methodological and practical aspects of a research effort emphasizing joint service ACTD assessment designs prompted review by: persons who have managed the joint service-oriented ACTD programs of major organizations; persons who have served individual demonstrations as the operational managers and deputy managers most responsible for the implementation and conduct of joint service-oriented ACTD MUA; and persons who have designed and conducted military utility assessments of joint service-oriented ACTDs for those demonstrations’ operational managers. While not required for research validation purposes, the researcher adjudged the solicitation of these persons’ perspectives as an indispensable appendage of the methodology development and its deployment executed during research Phases 1 through 4. Research Phase 5 therefore pursued ACTD expert opinion regarding the MUA design methodology, its derivation, and its testing.

In Phase 5 a group of 20 ACTD experts reviewed the methodology and research Phases 1-4 application by the operations expert group, with no members of the ACTD expert group having served as a member of the latter body. The ACTD experts included: four individuals primarily experienced in large-organization management of joint service ACTDs; eight individuals primarily experienced as operational or deputy operational managers of one or more, joint service demonstrations, with operational management arguably the most central of all, ACTD managerial tasks and operational managers those persons most responsible for military utility assessments; and eight individuals primarily experienced in the design and conduct of military utility assessments applied to the joint service demonstrations guided by operational managers. The group represented a large portion of individuals known by the researcher to have participated in demonstrations emphasizing joint service needs that the U.S. Joint Forces Command (USJFCOM), perhaps most among major U.S. military commands and organizations, is directed to support (USJFCOM, no date). The command has served a major sponsorship role for 33 (G. A. Koumbis, personal communication, January 9, 2007) of nearly 150 demonstrations executed since ACTD program initiation (DoD, 2006), and it was sponsoring 12 of the 74 demonstrations active at the time of this research (G. A. Koumbis, personal communication, January 9, 2007). Three of the four ACTD program managers served the USJFCOM, all of the operational managers and deputy operational managers had pursued their positions in the service of USJFCOM ACTD efforts, and all individuals of MUA design and conduct experience had gained their experience by supporting USJFCOM-sponsored demonstrations. Length of ACTD expert group participant experience varied from between one and two years to periods of continuing involvement that began with ACTD program inception in 1994.

Over a series of seven lecture sessions directed toward mixed groups of between one and five ACTD program managers, operational or deputy operational managers, or MUA designers, the researcher reviewed the risk- and fuzzy set-based, MUA design methodology development and deployment, including the final application results achieved during research Phase 4. Following their respective sessions, the ACTD experts were asked to complete a 49-question survey that offered each participant an opportunity for 47 Likert scale- and 2 free form-type responses. Nineteen ACTD experts responded to the researcher's request to complete the questionnaire of Appendix H, three of the four ACTD program managers and all remaining of the group of 20. Responses identified in Appendix I proved instructive:

- Sixteen respondents agreed or "strongly" agreed that user assessments of military utility constituted the most important aspect of ACTDs;
- All respondents agreed or "strongly" agreed that ACTD program intent established military utility assessments as the chief mechanism by which should be gauged ACTDs' potential value to military users;
- Seventeen respondents agreed or "strongly" agreed that ACTD program intent assigned MOEs to be the chief mechanism for determining if prototype system demonstrations address critical operational issues identified by potential, system users. All 19 agreed or "strongly" agreed that MOEs are indispensable to MUA design;
- Fifteen ACTD experts agreed that the Department of Defense (DoD) has suggested no rigorous methodology for MUA design, two claimed they did "not know," and

two considered local processes to represent DoD-level suggestions they otherwise conceded had not been promulgated;

- Eighteen of the 19 respondents agreed or "strongly" agreed upon a need for more rigor in ACTD MUA design. One "strongly" disagreed;
- Seventeen respondents agreed or "strongly" agreed that the design methodology proposed with this research promoted a degree of MUA rigor appropriate for ACTDs;
- Eighteen respondents agreed or "strongly" agreed that the design methodology proposed with this research represented a treatment of joint military operations metasystems appropriate for ACTDs. Eighteen also rendered an identical judgment regarding the methodology's treatment of risk, with 16 likewise endorsing the methodology's treatment of the ambiguities of human judgment. The balance of respondents in each of these three cases considered themselves unable to render the requested judgments;
- Questionnaire responses and complementary inquiries of the researcher demonstrated that none of the 19ACTD experts had been previously exposed to a MUA design methodology comprising the treatments of complex systems, risk, and fuzzy set theory essential to the methodology proposed with this research. In particular, no respondents had before been exposed to a methodology based on the work of Haimes (1998, 2004), Blin and Whinston (1973), and Blin (1974).
- Fourteen respondents agreed or "strongly" agreed that the methodology proposed with this research "(filled) a gap in the ACTD MUA design process," and 15 believed that the methodology would promote the identification of MOE needed of

assessment design processes. The balance of respondents conceded they did "not know" and so could render no judgments regarding those elements of the survey; and, lastly,

- Seventeen respondents agreed or "strongly" agreed that the MUA design methodology proposed with this research could be applied by analysts immediately assigned MUA design tasks as well as managed by demonstrations' operational managers ultimately responsible for assessment design and execution.

SUMMARY

The deployment stage of this study was executed using a demonstrably reliable and valid, action research process the researcher considered most appropriate for the research context and aims. A group of three volunteers expert in joint, amphibious forcible entry operations coupled foundational information supplied by the researcher with elements of Haimes' (1998, 2004) Risk Filtering, Ranking, and Management method to develop a hierarchical holographic model they believed represented the simulated, Operational Mine Detection ACTD incorporated with what would be its superior, joint military operations metasystem. That same group of three next drew from the HHM the most serious risks posed by the ACTD and its metasystem to joint military utility. The three group members then individually prioritized eight risks that the group had categorized as high, and the researcher followed with an application of the Blin and Whinston (1973) and Blin (1974) fuzzy method for resolving preferences of small groups and identifying associated levels of agreement. All results as well as the rationale and processes leading to those results were finally reviewed by a total of 20 ACTD management and MUA experts, 19 of whom used the information to judge the worth to practice of the MUA design methodology proposed with the study.

The OMD ACTD metasystem model developed by the operations expert group required approximately 10 hours of collaborative work and comprised 13 perspectives, 93 perspective-subordinate domains, and 95 subdomains identified in accordance with Haimes' (1998, 2004) notions of an HHM. From that HHM the operations experts drew a total of 104 risks to joint operations utility that the model represented to them, over time refining the 104 to a number of 86. Of the 86 risks, the operations group noted 8 to be distinctly more serious than the others and classified them as high risks.

The three operations expert group members then departed from their previously strictly collective processes to individually prioritize the group-identified high risks using a survey that offered a series of pairwise comparisons in accordance with the fuzzy group preference method of Blin and Whinston (1973) and Blin (1974). The researcher, too, employed the fuzzy preference method to transform the three individual prioritizations into a single, group-preferred prioritization from which could be derived measures of effectiveness required for an OMD ACTD MUA. The researcher additionally used the fuzzy preference method to assess and associate with the group preference a ⅔ level of agreement useful to any following process of MOE development.

Prominent methodological and practical aspects of the MUA design methodology development and deployment prompted a corollary review of its worth to practice by 20 volunteers expert in the management, design, and conduct of ACTD military utility assessments. The review indicated a potential user community that recognized the value of a MUA design standard not presently available and which the proposed methodology would provide with a complement of attributes the ACTD experts considered necessary.

CONCLUSIONS

This research pursued the development and deployment of a risk- and fuzzy set-based methodology for advanced concept technology demonstration military utility assessment design. The research was prompted by the lack of a standard for rigorously identifying the assessment criteria that individual demonstration MUA designs should emplace. It was guided by two principal propositions that MUA design standards should:

- holistically account for risks precipitated when ACTD systems and processes are considered for incorporation within the complex metasystems of joint military operations; and
- respect ACTD end-user perspectives necessary for MUA designs by employing analytical schemes suited to the ambiguities and other of what have been termed "fuzzy" (Zadeh, 1965, p. 338) manifestations of human cognition and language.

It was also guided by a set of three research questions.

RESEARCH QUESTIONS

A purpose to develop and deploy an ACTD MUA design methodology prompted three research questions:

(1) How might joint military operations metasystem models guide the identification of ACTD MUA measures of effectiveness?

(2) How might be developed and employed joint military operations metasystem models with which can be identified ACTD MUA measures of effectiveness?

(3) How useful might ACTD managers and analysts find the MUA design methodology developed and deployed with this research?

Each of these was answered during the course of the study.

The research demonstrated that an ACTD-tailored, joint military operations metasystem model developed by appropriate experts could promote the identification of risks evident in the model and that those risks could, in turn, promote the identification of effectiveness measures by which ACTD utility could be gauged. Table 8 confirms this assertion with samples of MOEs derivable from the Table 7 risks identified during this research.

The research also demonstrated how an ACTD-tailored, joint military operations metasystem model could be developed and employed for the purpose of MUA MOE identification, and it did so by observing its own risk- and fuzzy set-related propositions regarding MUA design standards. A holistic approach afforded model developers a construct able to promote the identification of an equally holistic set of risks from which could be derived needed effectiveness measures. Certain risk filtering elements of Haimes' (1998, 2004) eight-phase, Risk Filtering, Ranking, and Management method were first used to develop a hierarchical holographic model of a joint military operations metasystem appropriate for a simulated ACTD. Other filtering elements were next employed to determine and categorize as high, moderate, or low a set of risks that the model represented to its developers. A fuzzy group preference method of Blin and Whinston (1973) and Blin (1974) was then used to transform independently-formulated prioritizations of identified high risks into a single, group preference with associated agreement level and from which could be derived MOEs like those displayed in Table 7. As a guide to ACTD practitioners, Appendix J provides a review of proceedings that met expected reliability and validity criteria while satisfying the second of the three research questions.

Table 7. HHM-Identified Risks and Sample Derivative Measures of Effectiveness

HHM-Identified Risks	Sample Derivative MOE
PLSS deployment concept of one system per host vessel insufficiently supports operational needs.	▪ Percentage of operations impeded by PLSS deployment concept of one surveillance vehicle per host vessel. ▪ Types of operations impeded by PLSS deployment concept of one surveillance vehicle per host vessel.
Adversaries use various means to counter OMD system detection capabilities.	▪ False negative rate of surveillance determined by adversary countermeasures. ▪ False positive rate of surveillance determined by adversary countermeasures.
OMD system yields false negative indications of mines or minefields.	▪ False negative rate of surveillance.
OMD system yields false positive indications of mines or minefields.	▪ False positive rate of surveillance.
Mines are concealed or camouflaged by natural or manmade objects expected to be seen within surf and beach zones.	▪ False negative rate of surveillance determined by natural objects, including those positioned as adversary countermeasures. ▪ False negative rate of surveillance determined by manmade objects, including those positioned as adversary countermeasures.
Adversary electronic attacks impair PLSS navigation or surveillance functions.	▪ Percentage of missions impaired due to adversary electronic attacks upon PLSS navigation system. ▪ Percentage of missions impaired due to adversary electronic attacks upon PLSS surveillance system.
RLSS algorithms are not sufficiently robust to provide useful information regarding areas of operations interest.	▪ Percentage of geographically and operationally representative missions for which RLSS failed to provide adequate, PLSS cuing.
PLSS UAV airframe is vulnerable to adversary anti-aircraft weapons and tactics, including small arms fire.	▪ Estimated percentage of missions in which the PLSS platform proved vulnerable to adversary anti-aircraft weapons and tactics. ▪ Estimated percentage of individual flight profiles for which the PLSS platform proved vulnerable to adversary anti-aircraft weapons and tactics.. ▪ Types of flight profiles for which the PLSS platform displayed vulnerability to adversary anti-aircraft weapons and tactics.

The third of three research questions addressed the utility that might be assigned by expert, ACTD managers and analysts to the MUA design methodology proposed with this research. A survey of 20 such experts indicated an almost complete endorsement of the methodology and its value to practice.

SUITABILITY AS A METHODOLOGY

The risk- and fuzzy set-based approach to ACTD MUA design taken with this research proved to be, as originally claimed by the researcher, one properly characterized as a methodological level of study applicable to complex systems. Accordingly, it displayed all nine attributes that Keating et al. (2004) assign to system of systems-, or complex system-oriented methodologies: the emphasis upon assessment design rather than conduct, in particular, gave the approach a transportability feature suiting it to application to ACTDs, to demonstrations of the joint capability technology demonstration program recently initiated by the Department of Defense, to rapid acquisition test and evaluation design, to operational tests like those developed for DoD acquisition programs, and to similar assessment design needs that could or even must be met using the perspectives of small groups of appropriate experts; key artifacts of the Haimes (1998, 2004), Blin and Whinston (1973) and Blin (1974) methods pointed directly to the approach's grounding in theory and philosophy associated with risk assessment, fuzzy sets, and complex systems; the holistic perspective required by complex systems theory and afforded by Haimes' RFRM and Blin and Whinston's method for resolving group preferences marks the approach as a "guide to action…[of] significance, consistency, adaptability, neutrality, and multiple utility" (Keating et al., 2004, p. 6) ; and numerous aspects of the Haimes and Blin and Whinston methods provide the approach a degree of "rigor" (p. 6) needed for justifiable employment and that does not exist among ad hoc MUA design schemes presently used. The Appendix J practitioner's guide embodies and directly or indirectly requires the observance of each of these attributes.

RESEARCH CONTRIBUTIONS

This research contributed to the theory, methodology, and practice associated with joint military operations metasystem transformations driven by new technology and process insertion. It did that by suggesting theoretical, methodological, and practical considerations applicable to similar transformations of other types of metasystems.

The study revealed undeniable and significant links among domains of risk, fuzzy set theory, and complex systems theory; and it forced consideration of synergies to be gained by exploiting those links. It recognized the advantage of using fuzzy set theory to accommodate the epistemic uncertainties and describe the associated risks so prominent in complex system settings, with that emphasis upon risk, in particular, prompting additional considerations regarding analyses of complex system failure modes.

The work demonstrated a valid, risk- and fuzzy set-based methodology for ACTD military assessment design, and in doing so provided a flexible yet common scheme for assessments quite unlike the ad hoc approaches previously used. The methodology itself promoted a merger of risk assessment and fuzzy set theory that reflected theoretical findings regarding the inextricability of fuzzy approaches to particular risk settings, and the methodology's deployment under an action research format endorsed the efficacy of that qualitative scheme for assessment design efforts.

The research lastly and perhaps most significantly contributed to practice. The MUA design methodology produced offers ACTD program executives, managers, and analysts a standard they concede as lacking and necessary. A practitioner's guide also produced can rigorously enable the identification and emplacement of measures of effectiveness fundamental to ACTD MUA designs or designs needed for assessments of ACTD-like enterprises. Indeed, the methodology and its derivative techniques suggest means with which complex system transformations of many kinds can be anticipated, whether those transformations will be evaluated using the relatively informal assessment formats of ACTDs, the more particular evaluation designs typically associated with formalized operational testing, or other assessment conventions.

FUTURE RESEARCH

Future research could explore and possibly advance several of this study's assumptions and findings. That research would address methodology elements such as model development, expert identification, the significance of fuzzy set theory and derivative applications, and methodology application.

The identification of HHM perspectives appeals for possible enhancement. In this and apparently other research, the highest-level HHM components were derived from the collective and holistic wisdom of a group of experts, with that derivation a process as much art as science. A more rigorous, if not more complete or accurate, approach might apply grounded theory to the effort of identifying the most prominent parts of a complex system characterized in terms of system context. Crownover's (2005) recent proposals regarding construction of complex system contextual frameworks could provide one path toward more rigorously defined, HHM constructs.

Additional research might also enhance this study's expert identification methods. Much work has been done and continues to be done in the field of expert identification, and reason points toward some merger of that work with the work of this study.

This research demonstrated the pertinence of fuzzy set theory to assessment design through the need to resolve independent, expert prioritizations to a single, group prioritization preferred by all group members. That demonstration ignored other aspects of the chosen problem that equally called for applications of fuzzy mathematics, such as the definition of risk assessment-related and patently fuzzy descriptors like "military utility," "unacceptable" consequence, "frequent" likelihood, and "high risk." A more encompassing application of fuzzy set theory to risk-based assessment design seems in order.

A final suggestion for future research must address the breadth of problems to which this study's methodology should be applied. A superficial case can and has been made for the methodology's applicability to ACTD assessment design, JCTD assessment design, rapid acquisition test and evaluation, operational test planning, and other semiformal or formal assessment design needs. However, the methodology was tested upon only a simulated ACTD and only within a single cycle of the action research spiral (Figure 6); although it does seem to exhibit tenets prescribed for transportability and other methodological attributes, the true bounds of its applicability remain undetermined.

SUMMARY

This research pursued the development and deployment of a risk- and fuzzy set-based methodology for advanced concept technology demonstration military utility assessment design. It was prompted by the lack of a standard for rigorously identifying the assessment criteria that individual demonstration MUA designs should emplace, and it was guided by propositions regarding the pertinence of holistic risk assessments and fuzzy set theory. The research pursued and answered three questions in demonstrating a rigorous approach – well received by potential users – to determining measures of effectiveness by which ACTD military utility must be gauged. It also showed a methodology observant of standards established for research and measurement reliability and validity, with study limitations and delimitations addressed by calls for future research.

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APPENDIX A

DEFINITION OF TERMS

Command and Control. The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission (DoD, 2005).

Complex System. A bounded set of richly interrelated elements of collective structural and behavioral patterns together producing a system performance that emerges over time through interactions among system elements and elements of the environment in which the complex system operates (Keating et al., 2004).

Complex System Context. The set of factors that influence a complex system or metasystem (Keating et al., 2004; Keating et al., 2005).

Construct Validity. A characteristic of measurement instruments like surveys or structured interviews that can be judged by researchers or stakeholder participants as producing measurements and even supporting predictions regarding complex traits of the objects of measurement, such as risks associated with ACTDs (Bernard, 2002; Gliner & Morgan, 2000; Orcher, 2005).

Content Validity. A characteristic of measurement instruments like surveys or structured interviews that can be judged by researchers or stakeholder participants to possess contents representative of the concepts, such as risk, instruments are intended to measure (Bernard, 2002; Gliner & Morgan, 2000; Orcher, 2005).

Critical Operational Issues. In terms of ACTDs, incontrovertible, military operator identified requirements for mission success; essentials of capability without which an ACTD would be adjudged unacceptable on functional grounds (DoD, no date-a; Sproles 2001, 2002).

Face Validity. A characteristic of measurement instruments like surveys or structured interviews that can be judged by, or appear to, researchers or stakeholder participants as appropriate for the instruments' purposes (Bernard, 2002; Gliner & Morgan, 2000; Orcher, 2005).

Joint, Amphibious, Forcible Entry Operations. The use of a joint military force and ship-to-shore maneuver to seize and hold a shore-area, military lodgment in the face of armed opposition (DoD, 2005).

Joint Military Operations. Single-command operations of forces composed of significant elements assigned from two or more of the United States Army, Navy, Air Force, Marine Corps, or Coast Guard (DoD, 2001, 2005).

Measures of Effectiveness. In terms of ACTDs, high-level indicators of military effectiveness and suitability; standards directly derived by military operators from critical operational issues, independent of particular demonstrations or demonstrations' performance, and against which should be assessed the performance of ACTDs (DoD, no date-a; Sproles, 2000, 2001, 2002).

Measures of Performance. In terms of ACTDs, technical characteristics that determine a particular aspect of a system's effectiveness or suitability, evaluations of system-internal functions, and the system performance values that can be judged against MOEs to assess demonstration effectiveness and suitability (DoD, no date-a; Sproles, 2000, 2001, 2002).

Metasystem. Synonymous with the term, *system of systems*, a system of functionally integrated and complex subsystems necessarily complex in its own right (Keating et al., 2003; Keating et al., 2004; Keating et al., 2005).

Military Effectiveness. In terms of ACTDs, the ability of a demonstration system to provide its postulated capabilities within a military environment (DoD, no date-a).

Military Suitability. In terms of ACTDs, a function of the operational facility, sustainability, reliability, and like characteristics associated with a demonstrated system's use in a military environment (DoD, no date-a).

Military Utility. In terms of ACTDs, a function of a demonstration system's military effectiveness, military suitability, and contribution to military operations (DoD, no date-a).

Risk. A function of some risk event's likelihood and consequence (Bedford & Cooke, 2001; DoD, 2003c; Haimes, 2004; Kaplan & Garrick, 1981; Kaplan et al., 2001; Kosmowski, 2000; Kujawski, 2002; Thompson & Montagne, 1998), characterized by one or both of aleatory and epistemic uncertainty (Bae et al., 2004; Bedford & Cooke, 2001; Quelch & Cameron, 1994; Williams, 1995). In terms of ACTDs, a demonstration's potential inability to perform well against military utility assessment measures of effectiveness (DoD, 2003c).

Risk Assessment. In terms of ACTDs, the process of identifying events (Tchankova, 2002) possibly limiting demonstrations' ability to enhance the utility of joint military operations metasystems with which the demonstrations could be incorporated (DoD, 2003c). The process is intended to answer the three questions of: (1) What can go wrong?; (2) What is the likelihood that it will?; and (3) What would be the consequences if it does? (Haimes, 1991, 2004; Kaplan & Garrick, 1981).

Risk Event. In terms of ACTDs, an event or circumstance potentially constraining a demonstration's effectiveness and which therefore merits assessment in terms of likelihood and consequence (DoD, 2003c).

Stakeholder. An individual or group of individuals who can affect or be affected by some system of interest and has demonstrated a desire and need to engage in that system's development or analysis (Cornelissen, 2002; Sproles 2000; Turnley, 2002).

System of Systems. Synonymous with the term, *metasystem*, a complex system of functionally integrated, complex subsystems that can be diverse in technology, context, operation, geography, and conceptual perspectives of persons associated with the system of systems or its components (Keating et al., 2004; Keating et al., 2005).

Technical Facilitator. An individual responsible for structuring and facilitating the interactions of experts employed for expert-elicitation processes (Ayyub, 2001).

Technical Integrator. An individual responsible for developing the composite representation of expert judgments (Ayyub, 2001).

APPENDIX B

JOINT MILITARY OPERATIONS EXPERT SELECTION CRITERIA

This research imposed general and specific requirements for the selection of operations expert group participants. General requirements were that:

(1) Participants be or represent ACTD program stakeholders (Brandon, 1998), with stakeholders defined as in Appendix A.

(2) Participants possess expertise strongly relevant to the simulated ACTD of the study and gained through professional accomplishment, experience, and academic training (Ayyub, 2001; Brandon, 1998);

(3) Participants be willing to act as impartial evaluators (Ayyub, 2001);

(4) Participants be available and willing to commit the time and effort required by the study (Ayyub, 2001); and that

(5) Participants possess strong communication and interpersonal skills, flexibility, impartiality, and an ability to appropriately generalize and simplify (Ayyub, 2001).

Specific requirements were that:

(6) Participants had attained an active duty rank of: major in the U.S. Army, Air Force, or Marine Corps; or lieutenant commander in the U.S Navy; and

(7) Participants could demonstrate experience with or formal training in joint operations of attributes similar to those of the ACTD simulated for this research; and

(8) Participants could demonstrate experience with or formal training in the operational test and evaluation of military systems or prototypes; and that

(9) Participants had been awarded graduate degrees in a physical science, mathematical sciences, or a field of engineering.

APPENDIX C

ACTD EXPERT SELECTION CRITERIA

This research imposed general and specific requirements for the selection of ACTD management- and MUA design-experienced participants, collectively termed the ACTD expert group. General requirements were that:

(1) Participants be ACTD program stakeholders (Brandon, 1998), with stakeholders defined as in Appendix A.

(2) Participants possess expertise strongly relevant to ACTD management, MUA design, or both, and gained through professional accomplishment, experience, and academic training (Ayyub, 2001; Brandon, 1998);

(3) Participants be willing to act as impartial evaluators (Ayyub, 2001);

(4) Participants be available and willing to commit the time and effort required by the study (Ayyub, 2001); and that

(5) Participants possess strong communication and interpersonal skills, flexibility, impartiality, and abilities to generalize and simplify (Ayyub, 2001).

Specific requirements were that:

(6) Participants had been assigned as ACTD operational managers or deputy operational managers for periods of at least one year; or

(7) Participants had been assigned ACTD military utility assessment or supporting analysis tasks for periods of at least one year; or

(8) Participants had been assigned general or specific, ACTD program management or training responsibilities at U.S. Department of Defense or major military command levels for periods of at least one year; and that

(9) Participants had been awarded baccalaureate degrees.

APPENDIX D

SIMULATED ACTD

The ACTD simulated for this research, the Operational Mine Detection ACTD, strongly reflected for validity purposes certain elements of an actual demonstration, the Joint Countermine (JCM) ACTD conducted 1994-2000 (Blumenthal, no date; Elliott et al., 1996; Schaffer et al., 1997; Schnoor, no date; USACOM, 1998). Aspects of the simulated, joint forcible entry operations planning-related ACTD generated for this research included technological and operational traits typical of those available to ACTD staffs early in a demonstration's life cycle, when MUA design begins. These and other appropriate planning details were provided to the joint military operations expert group under the following format:

The Operational Mine Detection (OMD) ACTD has been selected for an immediate start. Key demonstration initiatives, issues, and attributes include:

Statement of Critical Military Need. Near- and on-shore mining by threat forces can impede or deny amphibious forcible entry operations. With no significant improvements having been made to amphibious forcible entry operations capabilities since the 1991 Operation Desert Storm, U.S. joint military forces now face a critical deficiency in a key mission area.

Statement of ACTD Purpose. The OMD ACTD is intended to offer a near- and on-shore mine surveillance capability suited to present-day, U.S. joint, amphibious forcible entry operations needs.

Critical Operational Issues (COI) and Component Issues. Military sponsors of the OMD ACTD have stipulated three top-level, critical operational issues, or questions, they wish the demonstration to address. Sponsors have additionally identified limited sets of components associated with each top-level COI, and they reserve the right to alter those sets during the course of the demonstration's MUA. Current issues and component issues are:

Critical Operational Issue 1. Functionality. *Do OMD systems and processes represent a credible, near- and on-shore mine detection capability suited to present-day, joint amphibious forcible entry operations?*

Component Issue 1.a. *Are OMD capabilities equally available under all (nonthreat-induced) operational conditions typically encountered by joint, amphibious forces?*

Component Issue 1.b. *Can OMD capabilities be routinely realized given their dependence upon systems and processes controlled by other than the joint forces seeking to employ those capabilities?*

Critical Operational Issue 2. Impact. *Given that desired, OMD functionality is observed, does it significantly enhance the totality of operations that might be executed by U.S. joint military forces?*

Component Issue 2.a. *Are OMD capabilities equally available under all threat-induced operational conditions expected to be encountered by joint, amphibious forces?*

Component Issue 2.b. *Do systems or processes providing the OMD capability in any way degrade or interfere with other joint force capabilities?*

Critical Operational Issue 3. Suitability. *Can OMD capabilities be integrated with current systems and processes without undue logistical burdens?*

Component Issue 3.a. *Would the integration of OMD capabilities with extant systems and processes adversely affect personnel staffing or training processes?*

Component Issue 3.b. *Would adoption of OMD capabilities pose untenable problems regarding system-level integration?*

ACTD Technical and Operational Characteristics. The Operational Mine Detection ACTD comprises covert and overt elements. Those complementary elements are intended to yield a prototype, amphibious forcible entry capability significantly better than any presently available and suited to today's threats.

One of the OMD prototype's two principal components is the covert, Remote Littoral Sensing System, or RLSS, that uses novel computational techniques to exploit capabilities of existing national-level reconnaissance assets and provide joint forces with cuing information required of the OMD prototype's second major element, the Proximate Littoral Sensing System, or PLSS. The PLSS is an operational-level, overt asset organic to the joint forces it serves.

The RLSS may be characterized by its unique set of technical and operational attributes. Most significant of the technical attributes are:

- An infrared and visible spectrum imaging capability;
- A capability to detect the presence of minefields in surf zones and very shallow water, as well as on beaches;
- A capability to provide atmospheric and bathymetric data in the vicinity of beaches of interest;
- A very limited capability to detect individual mines or to determine geospatial parameters of minefields;

- A capability to detect mine laying activities; and
- No practical capability to detect the presence of mines in land or ocean settings unlike those already described. The system is optimized for clear-day, very-near shore environments.

Most significant of RLSS operational attributes are:

- Strategic national-level control of those reconnaissance assets from which the RLSS draws its data;
- Strategic theater-level (typically a joint force higher headquarters) control of RLSS data requests, processing, and dissemination;
- Data collection, processing, and dissemination times markedly dependent on factors such as atmospheric and oceanographic conditions in the vicinity of beaches of interest, availability of transmission media for processed information, and competing demands for the use of national-level reconnaissance systems.

The PLSS may be characterized by its own unique set of attributes. Most significant of its technical attributes are:

- A medium-sized, single propeller-driven unmanned aerial vehicle (UAV) platform hosting an infrared sensor dedicated to preprogrammed, self-navigation and two multi-spectral optical sensors constituting the system's primary, surveillance elements;
- A UAV platform designed to be catapult-launched from and net-recovered to U.S. Navy amphibious class, aviation and aviation-capable ships. Such ships normally carry a single, PLSS system;

- A UAV platform possessing a programmable, self-navigation capability. Once launched by a catapult, the UAV executes a mission program and returns to its launching platform in accordance with that program. The system can remain airborne for up to four hours but possesses no in-flight, reprogramming capability. The system can only be net-recovered;
- A UAV platform of 60 knots maximum airspeed and 20 knot stall speed;
- Tandem-mounted and gimballed, infrared- and visible spectrum-sensitive sensors operating redundantly for sensor data fusion purposes. Independent operations are not possible, though single-imager operations remain available when an imager's optical system fails but the tandem gimballing mechanism does not;
- Algorithms within the PLSS onboard, intelligent target recognition (ITR) software package manipulate sensor data to determine whether the presence of individual mines represents the presence of whole minefields. One of three determinations is possible: minefields are present; minefields are not present; or no determination. The ITR processing outcomes are transmitted to launch vessels via encrypted, radio frequency communications;
- The equivalent of two hours of digitized optical data can be retained onboard the UAV and retrieved with recovered vehicles for post-mission processing. Optical data cannot be transmitted from the PLSS UAV to launching vessels;
- Launching vessels house personnel and facilities able to independently analyze data employed during missions by the ITR system and recovered with the PLSS UAV;
- A capability to detect individual mines or obstacles presenting to PLSS sensors cross-sectional areas no less than the equivalent of 12 inch diameter, circular mines;

- A capability to detect individual mines or obstacles positioned on or very near the surface of dry beach areas as well as beach areas washed by breaking waves;
- A capability to detect individual, submerged mines or obstacles positioned on or very near the sea floor surface to depths of 10 feet;
- Given ideal atmospheric and oceanographic conditions, a capability to detect individual mines or obstacles from altitudes as high as 1000 feet above beach areas. And
- A limited capability, constrained by sensor and algorithmic limitations, to distinguish between mines and natural or man-made obstacles.

The most significant of PLSS operational attributes are:

- Surveillance and related parameters optimized for RLSS cuing. System operations independent of RLSS cuing are generally difficult and time-consuming;
- With RLSS cuing and ideal atmospheric and oceanographic conditions, PLSS systems may survey beach areas of up to 10,000 square meters within three hours. Identically-sized submerged areas may be surveyed within six hours. Survey times are highly dependent upon constraints built into the ITR system with intelligent software agents;
- Semi-autonomous operations of the UAV platform may only be interrupted by PLSS personnel positioned aboard launching vessels. These personnel may terminate PLSS missions and direct platforms to return to their launch sites but cannot reprogram UAV flight profiles or control surveillance sensor fields of view during vehicle operations;

- The specially trained, PLSS personnel stationed aboard system launch vessels execute a primary role of post-mission analysis. These same personnel also execute a very limited, flight operations and data transmission monitoring function;
- Launch vessel personnel are able to destroy PLSS UAV platforms in flight;
- System personnel positioned aboard PLSS UAV launch vessels may monitor real-time transmissions of ITR products.

APPENDIX E

SIMULATED ACTD METASYSTEM MODEL

The following Operational Mine Detection Advanced Concept Technology Demonstration hierarchical holographic – ACTD metasystem – model (HHM) was the fundamental element of the deployment phase of research regarding a risk- and fuzzy set-based methodology for ACTD MUA design. The model was developed in accordance with the general work of Haimes (1998, 2004) and was the particular result of a simulated, action research process pursued by the researcher as study lead and three volunteer participants expert in what the U.S. Department of Defense terms amphibious, joint forcible entry operations (DoD, 2002, 2005). The operations expert group crafted and achieved consensus on this HHM using a seed model provided by the study lead that the balance of the group modified through a total of 10 hours of deliberations over five meeting sessions:

Perspective 1. Science and Engineering Aspects of Threat Mines and Employment

Domain 1.A. Mine Physical Characteristics

Subdomain 1.A.a. Distinctiveness

Subdomain 1.A.b. Size

Subdomain 1.A.c. Shape

Subdomain 1.A.d. Visible and Infrared Spectral Reflectivity

Domain 1.B. Mine Emplacement

Subdomain 1.B.a. Presented Area

Subdomain 1.B.b. Visible and Infrared Spectral Contrasts with Surroundings

Subdomain 1.B.c. Concealment

Subdomain 1.B.d. Camouflage

Subdomain 1.B.e. Emplacement Tactics, Techniques, and Procedures

Domain 1.C. Recognizable Features of Mine Type

Perspective 2. Environmental Aspects of OMD System Operating Areas

Domain 2.A. Seasonal Factors

Domain 2.B. Atmospheric Factors

Subdomain 2.B.a. Temperature and Humidity

Subdomain 2.B.c. Cloudiness and Other Spectral Attenuation

Subdomain 2.B.c. Wind and Turbulence

Subdomain 2.B.d. Ambient Light

Domain 2.C. Oceanographic Factors

Subdomain 2.C.a. Clarity

Subdomain 2.C.b. Salinity

Subdomain 2.C.c. Turbidity

Subdomain 2.C.d. Temperature

Perspective 3. OMD ACTD Critical Operational Issues

Domain 3.A. Functionality. Do OMD systems and processes represent a credible, near- and on-shore mine detection capability suited to present-day, joint amphibious forcible entry operations?

Subdomain 3.A.a. Are OMD capabilities equally available under all (nonthreat-induced) operational conditions typically encountered by joint, amphibious forces?

Subdomain 3.A.b. Can OMD capabilities be routinely realized given their dependence upon systems and processes controlled by other than the joint forces seeking to employ those capabilities?

Domain 3.B. Impact. Given that desired, OMD functionality is observed, does it significantly enhance the totality of operations that might be executed by U.S. joint military forces?

Subdomain 3.B.a. Are OMD capabilities equally available under all threat-induced operational conditions expected to be encountered by joint, amphibious forces?

Subdomain 3.B.b. Do systems or processes providing the OMD capability in any way degrade or interfere with other joint force capabilities?

Domain 3.C. Suitability. Can OMD capabilities be integrated with current systems and processes without undue logistical burdens?

Subdomain 3.C.a. Would the integration of OMD capabilities with extant systems and processes adversely affect personnel staffing or training processes?

Subdomain 3.C.b. Would adoption of OMD capabilities pose untenable problems regarding system-level integration?

Perspective 4. OMD System Missions

Domain 4.A. Near-shore Mine Surveillance

Subdomain 4.A.a. Forcible Entry Operations Near-Shore Route Planning

Subdomain 4.A.b. Special Operations Near-Shore Route Planning

Domain 4.B. On-Shore Mine Surveillance

Subdomain 4.B.a. Forcible Entry Operations On-Shore Route Planning

Subdomain 4.B.b. Special Operations On-Shore Route Planning

Perspective 5. Friendly Forces and Other Support Capabilities

Domain 5.A. Senior Military Forces

Subdomain 5.A.a. Allied Forces

Subdomain 5.A.b. U.S. Regional Combatant Commands

Subdomain 5.A.c. U.S. Joint Task Forces

Subdomain 5.A.d. U.S. Joint Component Commands

Subdomain 5.A.e. U.S. Amphibious Forces

Domain 5.B. Subordinate Military Forces

Subdomain 5.B.a. Allied Forces

Subdomain 5.B.b. U.S. Amphibious Forces

Domain 5.C. Coordinating U.S. Military Forces and Defense Organizations

Subdomain 5.C.a. U.S. Strategic Command

Subdomain 5.C.b. U.S. Special Operations Command

Subdomain 5.C.c. U.S. Defense Intelligence Agency

Subdomain 5.C.d. U.S. National Reconnaissance Office

Subdomain 5.C.e. U.S. National Geospatial-Intelligence Agency

Subdomain 5.C.f. U.S. Military Service Intelligence Organizations

Subdomain 5.C.g. U.S. Air Force Space Command

Subdomain 5.C.h. U.S. Naval Network Warfare Command

Subdomain 5.C.i. U.S. Army Space and Missile Defense Command

Subdomain 5.C.j. U.S. Military Service Systems Commands

Domain 5.D. Coordinating Allied Military Forces and Defense Organizations

Domain 5.E. Other Support Capabilities

Subdomain 5.E.a. U.S. Central Intelligence Agency

Subdomain 5.E.b. U.S. National Oceanic and Atmospheric Administration

Subdomain 5.E.c. Governmental Space Agencies

Subdomain 5.E.d. Commercial Space-Borne Imagery Organizations

Perspective 6. Adversary Forces and Other Support Capabilities

- **Domain 6.A.** Military Forces
  - **Subdomain 6.A.a.** Defensive (Geographic) Area
  - **Subdomain 6.A.b.** Defensive Forces
  - **Subdomain 6.A.c.** Mining Forces
- **Domain 6.B.** Defense Organizations
- **Domain 6.C.** Adversary-Allied Military Forces and Defense Organizations
- **Domain 6.D.** Other Support Capabilities
  - **Subdomain 6.D.a.** Governmental Space Agencies
  - **Subdomain 6.D.b.** Commercial Space-Borne Imagery Organizations
  - **Subdomain 6.D.c.** Non-Military Population

Perspective 7. Neutral Forces and Other Support Capabilities

- **Domain 7.A.** Military Forces
- **Domain 7.B.** Defense Organizations
- **Domain 7.C.** Other Support Capabilities
  - **Subdomain 7.C.a.** Governmental Space Agencies
  - **Subdomain 7.C.b.** Commercial Space-Borne Imagery Organizations

Perspective 8. RLSS Technical Attributes

- **Domain 8.A.** Ground-Based Computational Venues
- **Domain 8.B.** Raw Data Receipt
- **Domain 8.C.** Novel Computational Techniques
- **Domain 8.D.** Optimized for Clear-Day, Near-Shore Environmental Data
- **Domain 8.E.** Visible Spectrum Image Processing

Domain 8.F. Infrared Spectrum Image Processing

Domain 8.G. Surf and Beach Zone Minefield Detection Capability

Domain 8.H. Limited Minefield Parameter Detection Capability

Domain 8.I. Limited Individual Mine Detection Capability

Domain 8.J. Beach and Surf Zone Area Atmospheric Data Processing Capability

Domain 8.K. Beach and Surf Zone Area Bathymetric Data Processing Capability

Domain 8.L. Capability to Detect Mine Laying Activities in Surf and Beach Zone Areas of Interest

Domain 8.M. No Practical Capability to Process Other Than Beach and Surf Zone Surveillance Data

Domain 8.N. Processed Data Dissemination

Perspective 9. RLSS Operational Attributes

Domain 9.A. Data Collection Greatly Dependent On Atmospheric and Oceanographic Conditions in Areas of Interest

Domain 9.B. Operators

Subdomain 9.B.a. Requesting Joint Task Forces

Subdomain 9.B.b. Requesting Joint Task Force Theater-Level Headquarters

Subdomain 9.B.c. National Reconnaissance Asset Control Authorities

Domain 9.C. Concept of Operations

Subdomain 9.C.a. Completeness

Subdomain 9.C.b. Doctrinal, Organizational, Training, Material, Leadership, Personnel, and Facilities (DOTMLPF) Implications

Subdomain 9.C.c. Operator Employment

Domain 9.D. Command and Control

Subdomain 9.D.a. Joint Forces Issue Requests for RLSS Data to Theater-Level Headquarters

Subdomain 9.D.b. Theater-Level Control of RLSS Data Requests, Data Processing, and Processed Data Dissemination

Subdomain 9.D.c. National-Level Control of Reconnaissance Assets

Subdomain 9.D.d. Data Collection Greatly Dependent On Competing Demands for National-Level Reconnaissance Systems

Subdomain 9.D.e. Processed Data Dissemination Greatly Dependent On Availability of Transmission Media

Domain 9.E. System Usability

Domain 9.F. Operator Staffing and Proficiency

Domain 9.G. System Availability, Reliability, and Maintainability

Domain 9.H. Maintenance Personnel Staffing and Proficiency

Perspective 10. PLSS Technical Attributes

Domain 10.A. Medium-Sized, Single Propeller-Driven Unmanned Aerial Vehicle (UAV) Platform

Domain 10.B. U.S. Navy Aviation or Aviation-Capable Amphibious Ship-Based

Domain 10.C. Semi-Autonomous Flight Operations Using Programmable Navigation Augmented by Onboard, Infrared Navigation Sensor

Domain 10.D. No Inflight Navigation Programming Capability

Domain 10.E. Catapult-Launched

Domain 10.F. Net-Recovered

Domain 10.G. Maximum Flight Endurance of Four Hours

Domain 10.H. Maximum Airspeed of 60 Knots and Stall Speed of 20 Knots

Domain 10.I. UAV Platform Equipped with Two Multi-Spectral Optical Surveillance Sensors

Domain 10.J. One Visible-Spectrum and One Infrared-Spectrum Surveillance Sensor Tandem-Mounted and Gimballed for Redundant Surveillance

Domain 10.K. No Capability for Independent Operations of Visible-Spectrum and Infrared-Spectrum Sensors

Domain 10.L. Onboard Intelligent Target Recognition (ITR) System Processes Sensor Data for Outcome of Minefields Present, Minefields Not Present, or No Determination

Domain 10.M. ITR Processing Outcomes Transmitted to the PLSS Host via Encrypted Radio Frequency (RF) Transmissions

Domain 10.N. ITR System Can Store and Process Up to Two Hours of Optical Data

Domain 10.O. ITR-Stored Optical data Cannot be Transmitted to the PLS Host

Domain 10.P. ITR-Stored Data May be Recovered with the PLSS UAV for Analysis by PLSS Support Personnel Aboard the Host Vessel

Domain 10.Q. Capability to Detect Individual Mines Presenting to Sensors Equivalent of 12-Inch Diameter, Circular Mines

Domain 10.R. Capability to Detect Individual Mines On or Very Near Surface of Dry or Wave-Washed Beach Areas

Domain 10.S. Capability to Detect Individual Submerged Mines On or Very Near the Surf Zone Surface to Depths of 10 Feet

Domain 10.T. Under Ideal Atmospheric and Oceanographic Conditions, a Capability to Detect Individual Mines from Altitudes As High As 1000 Feet Above Beach Zones

Domain 10.U. Onboard PLSS Sensor Characteristics and Processing Algorithms Limit ITR System Capability to Distinguish Between Mines and Natural or Manmade Obstacles

Perspective 11. PLSS Operational Attributes

Domain 11.A. Normal Deployment Complement of One System Per Host Vessel

Domain 11.B. Surveillance Capability Strongly Dependent On RLSS Cuing, with Non-Cued Operations Very Difficult and Time-Consuming

Domain 11.C. With RLSS Cuing and Ideal Atmospheric and Oceanographic Conditions, PLSS Systems Require Three Hours to Survey 10,000 Square Meters of Dry or Wave-Swept Beach Areas

Domain 11.D. With RLSS Cuing and Ideal Atmospheric and Oceanographic Conditions, PLSS Systems Require Six Hours to Survey 10,000 Square Meters of Submerged Surf Zone Areas

Domain 11.E. PLSS Personnel Aboard Host Execute Primary Role of Post-Mission Analysis

Domain 11.F. PLSS Personnel Aboard Host Vessel Execute Secondary Role of Real-Time Flight Operations and ITR-Processed Data Transmission Monitoring

Domain 11.G. Semi-Autonomous Flight Operations May Be Terminated by Return-to-Vessel (RF) Signal from Host Vessel

Domain 11.H. Semi-Autonomous Flight Operations May Be Terminated by Destruct (RF) Signal from Host Vessel

Domain 11.I. Operators

Subdomain 11.I.a. PLSS Support Personnel

Subdomain 11.I.b. Host Vessels

Subdomain 11.I.c. Joint Task Forces

Subdomain 11.I.d. Joint Task Force Theater-Level Headquarters

Domain 11.J. Concept of Operations

Subdomain 11.J.a. Completeness with Integration of Host Vessel and Other Operator Processes

Subdomain 11.J.b. Implications for Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities

Subdomain 11.J.c. Operator Employment

Domain 11.K. Command and Control

Subdomain 11.K.a. Joint Force Initiates Forcible Entry Operations Planning

Subdomain 11.K.b. UAV Platform Navigation Programmed

Subdomain 11.K.c. Joint Force Coordinates PLSS Operations Among Force Elements

Subdomain 11.K.d. Joint Force Governs PLSS Flight Operations from Launch Through Recovery

Subdomain 11.K.e. Joint Force Governs Post-Mission Analysis and Processed Data Dissemination

Domain 11.L. Weather and Environmental Influences

Domain 11.M. System Usability

Domain 11.N. Operator Staffing and Proficiency

Domain 11.O. System Availability, Reliability, and Maintainability

Domain 11.P. Maintenance Personnel Staffing and Proficiency

Perspective 12. Adversary Threats to OMD Operations

Domain 12.A. Anti-Aircraft Weapons

Domain 12.B. Small Arms Fire

Domain 12.C. Anti-Ship Kinetic Weapons

Subdomain 12.C.a. Surface Kinetic Weapons

Subdomain 12.C.b. Subsurface Kinetic Weapons

Domain 12.D. Anti-Satellite Weapons

Subdomain 12.D.a. Kinetic Weapons

Subdomain 12.D.b. Non-Kinetic Weapons

Domain 12.E. Electronic Warfare

Subdomain 12.E.a. Onboard PLSS Communication System Disruption

Subdomain 12.E.b. Offboard PLSS Communication System Disruption

Subdomain 12.E.c. PLSS Surveillance System Disruption

Subdomain 12.E.d. PLSS Navigation System Disruption

Subdomain 12.E.e. Onboard RLSS Communication System Disruption

Subdomain 12.E.f. Offboard RLSS Communication System Disruption

Subdomain 12.E.g. RLSS Surveillance System Disruption

Subdomain 12.E.h. RLSS Navigation System Disruption

Domain 12.F. Passive Mine Protection Tactics

Subdomain 12.F.a. Camouflage

Subdomain 12.F.b. Concealment

Subdomain 12.F.c. Deception

Subdomain 12.F.d. Stealth

Perspective 13. Temporal Aspects of OMD ACTD

Domain 13.A. Demonstration Preparation Phase

Domain 13.B. Demonstration Phase

Domain 13.C. Residual Phase

Domain 13.D. Acquisition Phase

Domain 13.E. Deployment Phase

APPENDIX F

SIMULATED ACTD METASYSTEM RISKS

The Operational Mine Detection ACTD hierarchical holographic, or metasystem, model identified in research Phase 1 was the fundamental element of the deployment phase of this research. The model stimulated the research Phase 2 identification of risks - shown following – that it represented to the operations expert group. As with Phase 1, Phase 2 processes utilized portions of the RFRM convention practiced extensively by Haimes (1998, 2004) and others (Haimes et al., 2002; Haimes et al., 2004; Horowitz & Haimes, 2003; Jones et al., 2003; Lambert et al., 2001; Leung et al., 2004; Pennock & Haimes, 2002).

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(1) OMD system yields false positive indications of mines or minefields.

(2) OMD system yields false negative indications of mines or minefields.

(3) Mines are buried too deeply beneath (dry or submerged) surfaces to detect.

(4) Mines present visible areas of less than 113 inches^2 to PLSS system optics.

(5) Mine coatings lessen visible signature available to OMD system optics.

(6) Mine coatings lessen infrared signature available to OMD system optics.

(7) Glare or other natural mechanisms of visible spectrum saturation impair OMD system optical sensors.

(8) Noise equivalent temperature differences (NETD) between mines and mine surroundings are less than the thermal resolution capabilities of OMD system infrared sensors.

(9) Mine thermal characteristics and spacing impose minimum resolvable temperature (MRT) differences confounding OMD system infrared sensors.

(10) Mine designs incorporating acoustic fusing or floating contact fuses would present little to no visible area to OMD system sensors.

(11) Mines are concealed or camouflaged by natural or manmade objects expected to be seen within surf and beach zones.

(12) Near-shore currents cause mines to migrate along the beach, confounding OMD system sensors and algorithms

(13) Precipitation confounds OMD system sensors.

(14) Beach or surf zone ice confounds OMD system sensors.

(15) Air temperature and humidity adversely affects PLSS UAV endurance.

(16) Clouds or other spectral attenuation mechanisms degrade OMD sensor capability.

(17) Excessive low-level winds or turbulence adversely affect or altogether preclude PLSS UAV launch, recovery, or flight stability necessary for sensor operations.

(18) Water clarity or turbidity adversely affects OMD system sensor capability.

(19) Water temperature may adversely affect OMD system sensor capability.

(20) Fall and winter season restrictions of available daylight impair OMD system utility.

(21) When fielded, the OMD system will no longer resolve the critical (mine surveillance) problem it is intended to resolve.

(22) PLSS UAV operations interfere with other operations preliminary to forcible entry operations.

(23) Neither joint task forces nor their higher headquarters control the national-level systems providing data to the RLSS.

(24) Operators do not sufficiently trust the OMD system and will therefore not take optimal advantage of its capabilities.

(25) PLSS employment impairs other joint task force operations, such as frequency spectrum usage or flight operations other than those of the PLSS UAV.

(26) Times required for OMD system and, particularly, PLSS employment, prove too lengthy for unplanned missions of immediate precedence.

(27) Tidal or current conditions demand search patterns of course or duration infeasible under operational constraints

(28) OMD system employment precipitates system-level issues of interoperability among joint task forces and senior, subordinate, or coordinating military forces or organizations.

(29) RLSS and PLSS operations in widely separated time zones precipitate operational coordination problems.

(30) RLSS communications impair other joint task force operations, such as frequency spectrum usage.

(31) Coordinating OMD system operations with allied forces poses operational security risks.

(32) Competing priorities of higher headquarters or other responsible organizations slow delivery of RLSS products requested by joint task forces.

(33) Inadequate operations personnel staffing of higher headquarters or other responsible organizations slows delivery of RLSS products requested by joint task forces.

(34) Inadequate training of higher headquarters or other responsible organization operations staffs slows delivery of RLSS products requested by joint task forces.

(35) Rules of engagement impede or preclude PLSS employment in certain geographical areas.

(36) Inadequate intelligence regarding adversary mining capabilities or techniques impairs OMD system utility.

(37) Neutral force or population use of OMD system frequencies in joint task force operating areas impairs OMD system capabilities.

(38) Adversaries use various means to counter OMD system detection capabilities.

(39) Adversary or neutral concerns make political or diplomatic case that RLSS represents militarization of space, forcing cessation of RLSS operations.

(40) Deliberate or accidental PLSS operations in neutral territory proximate to joint task force operations areas precipitate political or diplomatic pressure halting PLSS operations.

(41) OMD system optimization for clear-day surveillance limits system utility for nighttime operations.

(42) RLSS data feed system is degraded or inoperative.

(43) RLSS computing system is degraded or inoperative.

(44) RLSS processed data transmission system is degraded or lost.

(45) RLSS algorithms are not sufficiently robust to provide useful information regarding areas of operational interest.

(46) An insufficiently developed concept of operations (CONOPS) impairs RLSS utility.

(47) RAM (reliability, availability, and maintainability) issues impair RLSS utility.

(48) Inadequate maintenance personnel staffing of higher headquarters or other responsible organizations slows delivery of RLSS products requested by joint task forces.

(49) Inadequate training of higher headquarters or other responsible organization maintenance personnel slows delivery of RLSS products requested by joint task forces.

(50) PLSS UAV size and operating airspeed and altitude render it susceptible to adversary targeting.

(51) PLSS UAV airframe is vulnerable to adversary anti-aircraft weapons and tactics, including small arms fire.

(52) PLSS UAV launch and recovery parameters of wind speed and direction are difficult to attain or maintain under routine, host vessel operating conditions.

(53) Preprogrammed navigation restriction impairs PLSS utility.

(54) Four-hour PLSS UAV endurance insufficiently supports numerous combinations of missions and operating environments.

(55) PLSS deployment concept of one system per host vessel insufficiently supports operational needs.

(56) The PLSS ITR two-hour optical data storage capacity is insufficient for numerous combinations of missions and operating environments.

(57) Dependence on RLSS cuing jeopardizes PLSS utility.

(58) Competing priorities of host vessel slow transmission of joint task force requests for RLSS products.

(59) Inadequate operations personnel staffing of host vessels slows transmission of joint task force requests for RLSS products.

(60) Inadequate training of host vessel operations staffs slows transmission of joint task requests for RLSS products.

(61) Inadequate PLSS operations personnel staffing slows PLSS operations.

(62) Inadequate training of PLSS operations personnel slows PLSS operations.

(63) Inadequate operations personnel staffing of host vessels slow PLSS operations.

(64) Inadequate training of host vessel operations staffs slows PLSS operations.

(65) ITR-processed data link from PLSS UAV to host vessel is degraded or inoperative.

(66) PLSS host vessel post-mission processing capability is degraded or lost.

(67) Degraded or inoperative communication links render host vessel unable to transmit PLSS-processed data to joint task force planners.

(68) ITR algorithms are not sufficiently robust to provide useful information regarding areas of operational interest.

(69) An insufficiently developed concept of operations (CONOPS) impairs PLSS utility.

(70) RAM (reliability, availability, and maintainability) issues impair PLSS utility.

(71) Inadequate PLSS maintenance personnel staffing slows PLSS operations.

(72) Inadequate training of PLSS maintenance personnel slows PLSS operations.

(73) Inadequate host vessel maintenance personnel staffing slows PLSS operations.

(74) Inadequate training of host vessel maintenance personnel slows PLSS operations.

(75) PLSS UAV does not properly respond to return-to-host vessel command, impeding joint task force operations.

(76) PLSS UAV self-destruct does not occur when commanded and errant vehicle flies into enemy or neutral force airspace.

(77) PLSS UAV executes uncommanded self-destruct.

(78) Doctrine, operations, training, material, leadership and education, personnel, or facilities (DOTMLPF) change process will not accommodate OMD system fielding requirements.

(79) PLSS UAV platform is damaged during launch or recovery.

(80) Host vessel offensive or defensive posture impedes OMD-, and particularly PLSS-related operations.

(81) Adversary anti-satellite tactics disrupt RLSS operations.

(82) Adversary electronic attacks impair communications between PLSS UAVs and host vessels.

(83) Adversary electronic attacks impair PLSS navigation or surveillance functions.

(84) Friendly force electronic emissions impair PLSS UAV navigational or other flight-related functions.

(85) Friendly force electronic emissions impair PLSS optical sensing, optical data processing, processed data transmission, or other surveillance-related functions.

(86) When fielded, the mining threat for which the OMD system would be produced will no longer be of concern to joint military forces.

APPENDIX G

HIGH RISK PRIORITIZATION QUESTIONNAIRE

Operational Mine Detection
Advanced Concept Technology Demonstration

High Risk Prioritization Questionnaire

Participant Identifier: **A** ☐ **B** ☐ **C** ☐

Date: **December , 2006**

Your operations expert group has determined eight high risks evident in the hierarchical holographic model earlier developed to characterize the Operational Mine Detection Advanced Concept Technology Demonstration system deployed within a joint military operations metasystem of relevance. Moreover, your group used a DoD-Conventional Matrix of Risk Consequence and Likelihood to describe each of those eight high risks in terms of consequence and likelihood. The group assessed the (consequence, likelihood) components of two risks as (5, 4) and agreed that these two constituted the most serious of the eight:

DoD-Conventional Matrix of Risk Consequence and Likelihood

	LIKELIHOOD				
CONSEQUENCE	***Remote***	***Unlikely***	***Likely***	***Highly Likely***	***Frequent***
Unacceptable	Moderate (5, 1)	High (5, 2)	High (5, 3)	High (5, 4)	High (5, 5)
Minimally Acceptable	Low (4, 1)	Moderate (4, 2)	Moderate (4, 3)	High (4, 4)	High (4, 5)
Acceptable with Significant Utility Loss	Low (3, 1)	Low (3, 2)	Moderate (3, 3)	Moderate (3, 4)	High (3, 5)
Acceptable with Slight Utility Loss	Low (2, 1)	Low (2, 2)	Low (2, 3)	Moderate (2, 4)	Moderate (2, 5)
Little or None	Low (1, 1)	Low (1, 2)	Low (1, 3)	Low (1, 4)	Moderate (1, 5)

Risk: *PLSS deployment concept of one system per host vessel insufficiently supports operational needs.*

Risk: *Adversaries use various means to counter OMD system detection capabilities.*

The group assessed the (consequence, likelihood) components of four risks as (5, 3) and agreed that these constituted a high-risk grouping of intermediate significance, third through sixth most serious of the eight:

Risk: *Adversary electronic attacks impair PLSS navigation or surveillance functions.*

Risk: *OMD system yields false negative indications of mines or minefields.*

Risk: *Mines are concealed or camouflaged by natural or manmade objects expected to be seen within surf and beach zones.*

Risk: *OMD system yields false positive indications of mines or minefields.*

The group assessed the (consequence, likelihood) components of two other risks as (4, 4), agreeing these to be the least serious the eight high-risk scenarios identified:

Risk: *PLSS UAV airframe is vulnerable to adversary anti-aircraft weapons and tactics, including small arms fire.*

Risk: *RLSS algorithms are not sufficiently robust to provide useful information regarding areas of operational interest.*

A group preference regarding overall prioritization of the eight risks may now be achieved by soliciting individual (operations expert group member) prioritizations of risks associated with each of the (5, 4), (5, 3), and (4, 4) component categories of relative seriousness already determined.

Given each of the following eight pairings of risks, please check the block beside the risk you consider the more serious. You should check only one block per pairing and identify your preference for every pairing; no "ties" are allowed. Please also attempt to maintain ranking consistency; that is, if you identify risk *A* as more serious than risk ***B*** and risk ***B*** as more serious than risk ***C***, please attempt to ensure you have also identified risk *A* as more serious than risk ***C***.

Please check the block beside the risk you consider the more serious of the two:

☐ *PLSS UAV airframe is vulnerable to adversary anti-aircraft weapons and tactics, including small arms fire.*

☐ *RLSS algorithms are not sufficiently robust to provide useful information regarding areas of operational interest.*

Please check the block beside the risk you consider the more serious of the two:

☐ *PLSS deployment concept of one system per host vessel insufficiently supports operational needs.*

☐ *Adversaries use various means to counter OMD system detection capabilities.*

Please check the block beside the risk you consider the more serious of the two:

☐ *Adversary electronic attacks impair PLSS navigation or surveillance functions.*

☐ *OMD system yields false negative indications of mines or minefields.*

Please check the block beside the risk you consider the more serious of the two:

☐ *Adversary electronic attacks impair PLSS navigation or surveillance functions.*

☐ *Mines are concealed or camouflaged by natural or manmade objects expected to be seen within surf and beach zones.*

Please check the block beside the risk you consider the more serious of the two:

☐ *Adversary electronic attacks impair PLSS navigation or surveillance functions.*

☐ *OMD system yields false positive indications of mines or minefields.*

Please check the block beside the risk you consider the more serious of the two:

☐ *OMD system yields false negative indications of mines or minefields.*

☐ *Mines are concealed or camouflaged by natural or manmade objects expected to be seen within surf and beach zones.*

Please check the block beside the risk you consider the more serious of the two:

☐ *OMD system yields false negative indications of mines or minefields.*

☐ *OMD system yields false positive indications of mines or minefields.*

Please check the block beside the risk you consider the more serious of the two:

☐ *Mines are concealed or camouflaged by natural or manmade objects expected to be seen within surf and beach zones.*

☐ *OMD system yields false positive indications of mines or minefields.*

THANK YOU

For Participating as a Volunteer Member of the
Operations Expert Group

APPENDIX H

ACTD EXPERT REVIEW QUESTIONNAIRE

The final phase of five phases of research synthesized judgments of a group of 20 purposively selected volunteers collectively expert in ACTD management and MUA design. Research Phase 5 employed a single, single-stage, cross-sectional, primarily Likert scale survey instrument structurally similar to those used by Monroe (1997), Yeh (1998), Morgan (1999), and Chytka (2003) and topically related to survey structures used for related research in: (a) decision making (Yeh, 1998), (b) design performance evaluation (Sun, 2000); (c) risk and uncertainty assessment, including risk ranking (Chytka, 2003; Hampton, 2001; Monroe, 1997; Morgan, 1999; Wells, 1997); (d) technology adoption impact (Conway, 2003); and (e) evaluation of commercial product customer preferences (Liu, 1996). The instrument used to survey the ACTD expert group of 20 follows:

You are one of a group of advanced concept technology demonstration (ACTD) experts who have volunteered to judge the researcher's proposed methodology for ACTD military utility assessment (MUA) design. Your participation owes to your education as well as your experience with ACTD program management, ACTD management, or MUA design and conduct.

Please answer all questions of all sections as accurately and completely as possible. Unless otherwise indicated, please select only one response for questions prompting checkbox-type responses. For questions prompting free form responses, please answer using the (unlimited length) fields provided. The questionnaire should take no more than one hour to complete.

RESPONSES WILL REMAIN CONFIDENTIAL TO ALL BUT THE RESEARCHER.

SECTION 1. PROFESSIONAL AND EDUCATIONAL EXPERIENCE

(1) Select the description or descriptions (select all applicable) best characterizing your experience with advanced concept technology demonstrations:

ACTD Program Management ☐ ACTD Management ☐ MUA Design or Conduct ☐

Note that: program management indicates no less than one year of comprehensive responsibility for major military commands' or Department of Defense (DoD) agencies' ACTD policies possibly governing multiple ACTDs; ACTD management indicates no less than one year of experience as an ACTD operational or deputy operational manager, and MUA design or conduct indicates no less than one year of experience as an analyst designing or conducting ACTD military utility assessments.

(2) Identify your combined years of experience as an ACTD program manager, an ACTD operational manager or deputy operational manager, or an analyst pursuing ACTD MUA design or conduct.

1-2 Years ☐ 2-5 Years ☐ More Than 5 Years ☐

(3) Identify your highest level of education as:

Bachelor's Degree ☐ Master's Degree ☐ Ph.D. or Other Terminal Degree ☐

SECTION 2. ACTD GENERAL GUIDANCE

(1) ACTDs are intended as precursors to formal acquisition processes.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(2) ACTDs offer military users opportunities to "try before buy."

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(3) Concept of operations (CONOPS) development is an indispensable component of ACTDs.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(4) The most important aspect of ACTDs is user assessment of military utility.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(5) The most important aspect of ACTDs is transition to acquisition or fielding.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(6) User assessment of military utility is more important to the ACTD process than transition to acquisition or fielding.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(7) If you believe there to be some aspect (or aspects) of the ACTD process more important than either of (a) utility assessment; or (b) transition to acquisition or fielding, please identify and describe it (or them):

SECTION 3. ACTD MUA GUIDANCE

(1) Military utility assessments are intended as the principal mechanism by which ACTDs' potential value to military users may be gauged.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(2) Military utility assessments are intended to be highly dependent on user judgment.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(3) The ACTD MUA design process begins with the identification of critical operational issues (COI) the demonstration is intended to address.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(4) Appropriate, military users hold ultimate responsibility for approving COI.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(5) COI are "show stoppers" that must be addressed to users' satisfaction if ACTDs are to move to acquisition or fielding.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(6) COI are indispensable to MUA design.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(7) Measures of effectiveness (MOE) are derived from critical operational issues.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(8) MOE selection is a responsibility shared by appropriate military users and analysts charged with MUA design and conduct.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(9) ACTD program guidance intends MOE as primary indicators of whether or not ACTDs have satisfactorily addressed COI established for demonstrations.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(10) MOE are indispensable to MUA design.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

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SECTION 4. ACTD MUA DESIGN PRACTICE

(1) COI should be employed for all ACTD MUAs.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(2) MOE should be employed for every COI used for ACTD MUAs.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(3) ACTDs about which I have knowledge have employed COI as part of the MUA.

☐ Never ☐ Occasionally ☐ Often ☐ Always

(4) ACTDs about which I have knowledge have employed MOE as part of the MUA.

☐ Never ☐ Occasionally ☐ Often ☐ Always

(5) ACTDs about which I have knowledge have employed COI approved by military users.

☐ Never ☐ Occasionally ☐ Often ☐ Always

(6) ACTDs about which I have knowledge have employed MOE developed with cooperation of military users.

☐ Never ☐ Occasionally ☐ Often ☐ Always

(7) ACTDs about which I have knowledge have employed MOE developed with cooperation of analysts charged with MUA design and conduct.

☐ Never ☐ Occasionally ☐ Often ☐ Always

(8) ACTD MUAs about which I have knowledge have greatly depended on user judgment.

☐ Never ☐ Occasionally ☐ Often ☐ Always

(9) ACTDs about which I have knowledge have applied risk assessment methods to MUA design.

☐	☐	☐	☐
Never	Occasionally	Often	Always

(10) ACTDs about which I have knowledge have applied fuzzy set theory to MUA design.

☐	☐	☐	☐
Never	Occasionally	Often	Always

(11) ACTDs about which I have knowledge have applied Phases I-III of Haimes' Risk Filtering, Ranking and Management (RFRM) convention to MUA design.

☐	☐	☐	☐
Never	Occasionally	Often	Always

(12) ACTDs about which I have knowledge have applied the fuzzy prioritization method of Blin and Whinston to MUA design.

☐	☐	☐	☐
Never	Occasionally	Often	Always

SECTION 5. METHODOLOGY REVIEW

(1) There exists no rigorous methodology for ACTD MUA design.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(2) The Department of Defense has suggested no rigorous methodology for ACTD MUA design.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(3) There is a need for more rigor in ACTD MUA design.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(4) ACTD guidance endorsing demonstrations of minimum technical risk should be extended to include operational or other risks associated with demonstrations' intended uses.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(5) MUAs should emphasize user judgment.

☐	☐	☐	☐	☐
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(6) ACTDs about which I have knowledge have determined MOE by prioritizing user-perceived risks associated with fielding demonstrations or their derivatives.

☐ Never ☐ Occasionally ☐ Often ☐ Always

(7) ACTDs about which I have knowledge have determined MOE by developing metasystem models like that proposed with this methodology.

☐ Never ☐ Occasionally ☐ Often ☐ Always

(8) ACTDs about which I have knowledge have determined MOE using metasystem models to identify and assess risks in a manner like that proposed with this methodology.

☐ Never ☐ Occasionally ☐ Often ☐ Always

(9) ACTDs about which I have knowledge have determined MOE using risk prioritization schemes like that proposed with this methodology.

☐ Never ☐ Occasionally ☐ Often ☐ Always

(10) This methodology promotes a degree of MUA rigor appropriate for ACTDs.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(11) This methodology respects user judgment to a degree appropriate for MUAs.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(12) This methodology's treatment of joint military operations metasystems is appropriate for ACTDs

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(13) This methodology's treatment of risk is appropriate for ACTDs

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(14) This methodology's treatment of the ambiguities associated with human judgment is appropriate for ACTDs.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(15) This methodology could be applied by persons assigned to ACTD MUA design.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(16) The application of this methodology could be managed by ACTD operational managers or their deputies.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(17) This methodology could promote the identification of MOE used for ACTD MUAs.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(18) This methodology fills a gap in the ACTD MUA design process.

☐ Strongly Disagree ☐ Disagree ☐ Do Not Know ☐ Agree ☐ Strongly Agree

(19) Please conclude this questionnaire by submitting any additional thoughts you wish regarding the proposed methodology or its value to ACTD MUA design.

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE
and for
Your Participation as a Volunteer Member of the
ACTD Expert Group.

APPENDIX I

ACTD EXPERT REVIEW QUESTIONNAIRE RESPONSES

Nineteen of twenty ACTD experts who reviewed the methodology development and deployment responded to the questionnaire offered to capture their views of those proceedings and associated topics such as ACTD program intent and deficiencies. Responses are summarized below.

You are one of a group of advanced concept technology demonstration (ACTD) experts who have volunteered to judge the researcher's proposed methodology for ACTD military utility assessment (MUA) design. Your participation owes to your education as well as your experience with ACTD program management, ACTD management, or MUA design and conduct.

Please answer all questions of all sections as accurately and completely as possible. Unless otherwise indicated, please select only one response for questions prompting checkbox-type responses. For questions prompting free form responses, please answer using the (unlimited length) fields provided. The questionnaire should take no more than one hour to complete.

RESPONSES WILL REMAIN CONFIDENTIAL TO ALL BUT THE RESEARCHER.

SECTION 1. PROFESSIONAL AND EDUCATIONAL EXPERIENCE

(1) Select the description or descriptions (select all applicable) best characterizing your experience with advanced concept technology demonstrations:

ACTD Program Management **3** ACTD Management **8** MUA Design or Conduct **8**

Note that: program management indicates no less than one year of comprehensive responsibility for major military commands' or Department of Defense (DoD) agencies' ACTD policies possibly governing multiple ACTDs; ACTD management indicates no less than one year of experience as an ACTD operational or deputy operational manager, and MUA design or conduct indicates no less than one year of experience as an analyst designing or conducting ACTD military utility assessments.

(2) Identify your combined years of experience as an ACTD program manager, an ACTD operational manager or deputy operational manager, or an analyst pursuing ACTD MUA design or conduct.

1-2 Years **3** 2-5 Years **9** More Than 5 Years **7**

(3) Identify your highest level of education as:

Bachelor's Degree **4** Master's Degree **15** Ph.D. or Other Terminal Degree

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SECTION 2. ACTD GENERAL GUIDANCE

(1) ACTDs are intended as precursors to formal acquisition processes.

	1		**11**	**7**
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(2) ACTDs offer military users opportunities to "try before buy."

			9	10
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(3) Concept of operations (CONOPS) development is an indispensable component of ACTDs.

			7	12
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(4) The most important aspect of ACTDs is user assessment of military utility.

	3		2	14
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(5) The most important aspect of ACTDs is transition to acquisition or fielding.

	7		10	2
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(6) User assessment of military utility is more important to the ACTD process than transition to acquisition or fielding.

	3		11	5
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(7) If you believe there to be some aspect (or aspects) of the ACTD process more important than either of (a) utility assessment; or (b) transition to acquisition or fielding, please identify and describe it (or them):

Response summaries include:

(A) It would be nonsensical to transitioning ACTDs without adequate assessment opportunities and results.

(B) Transition assumes that military utility has been determined.

(C) They are both important but military utility is paramount.

SECTION 3. ACTD MUA GUIDANCE

(1) Military utility assessments are intended as the principal mechanism by which ACTDs' potential value to military users may be gauged.

			8	11
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(2) Military utility assessments are intended to be highly dependent on user judgment.

	6	1	8	4
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(3) The ACTD MUA design process begins with the identification of critical operational issues (COI) the demonstration is intended to address.

			10	9
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(4) Appropriate, military users hold ultimate responsibility for approving COI.

		2	11	6
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(5) COI are "show stoppers" that must be addressed to users' satisfaction if ACTDs are to move to acquisition or fielding.

	3		12	4
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(6) COI are indispensable to MUA design.

			7	12
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(7) Measures of effectiveness (MOE) are derived from critical operational issues.

			12	7
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(8) MOE selection is a responsibility shared by appropriate military users and analysts charged with MUA design and conduct.

	1		13	5
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(9) ACTD program guidance intends MOE as primary indicators of whether or not ACTDs have satisfactorily addressed COI established for demonstrations.

		2	14	3
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(10) MOE are indispensable to MUA design.

			12	7
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

SECTION 4. ACTD MUA DESIGN PRACTICE

(1) COI should be employed for all ACTD MUAs.

			6	13
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(2) MOE should be employed for every COI used for ACTD MUAs.

	3	1	9	6
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(3) ACTDs about which I have knowledge have employed COI as part of the MUA.

		4	15
Never	Occasionally	Often	Always

(4) ACTDs about which I have knowledge have employed MOE as part of the MUA.

		6	13
Never	Occasionally	Often	Always

(5) ACTDs about which I have knowledge have employed COI approved by military users.

	2	8	9
Never	Occasionally	Often	Always

(6) ACTDs about which I have knowledge have employed MOE developed with cooperation of military users.

1	4	9	5
Never	Occasionally	Often	Always

(7) ACTDs about which I have knowledge have employed MOE developed with cooperation of analysts charged with MUA design and conduct.

		9	10
Never	Occasionally	Often	Always

(8) ACTD MUAs about which I have knowledge have greatly depended on user judgment.

	2	12	5
Never	Occasionally	Often	Always

(9) ACTDs about which I have knowledge have applied risk assessment methods to MUA design.

1	11	5	2
Never	Occasionally	Often	Always

(10) ACTDs about which I have knowledge have applied fuzzy set theory to MUA design.

14	5		
Never	Occasionally	Often	Always

(11) ACTDs about which I have knowledge have applied Phases I-III of Haimes' Risk Filtering, Ranking and Management (RFRM) convention to MUA design.

15	**3**	**1**	
Never	Occasionally	Often	Always

(12) ACTDs about which I have knowledge have applied the fuzzy prioritization method of Blin and Whinston to MUA design.

15	**4**		
Never	Occasionally	Often	Always

SECTION 5. METHODOLOGY REVIEW

(1) There exists no rigorous methodology for ACTD MUA design.

2	**5**	**1**	**11**	
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(2) The Department of Defense has suggested no rigorous methodology for ACTD MUA design.

	2	**2**	**15**	
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(3) There is a need for more rigor in ACTD MUA design.

1			**14**	**4**
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(4) ACTD guidance endorsing demonstrations of minimum technical risk should be extended to include operational or other risks associated with demonstrations' intended uses.

	1	**4**	**14**	
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(5) MUAs should emphasize user judgment.

1	**3**	**1**	**11**	**3**
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(6) ACTDs about which I have knowledge have determined MOE by prioritizing user-perceived risks associated with fielding demonstrations or their derivatives.

2	**10**	**6**	
Never	Occasionally	Often	Always

(7) ACTDs about which I have knowledge have determined MOE by developing metasystem models like that proposed with this methodology.

11	**8**		
Never	Occasionally	Often	Always

(8) ACTDs about which I have knowledge have determined MOE using metasystem models to identify and assess risks in a manner like that proposed with this methodology.

12	6	1	
Never	Occasionally	Often	Always

(9) ACTDs about which I have knowledge have determined MOE using risk prioritization schemes like that proposed with this methodology.

12	5	2	
Never	Occasionally	Often	Always

(10) This methodology promotes a degree of MUA rigor appropriate for ACTDs.

	1	1	12	5
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(11) This methodology respects user judgment to a degree appropriate for MUAs.

		1	12	5
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(12) This methodology's treatment of joint military operations metasystems is appropriate for ACTDs

		1	14	4
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(13) This methodology's treatment of risk is appropriate for ACTDs

		1	13	5
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(14) This methodology's treatment of the ambiguities associated with human judgment is appropriate for ACTDs.

		3	13	3
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(15) This methodology could be applied by persons assigned to ACTD MUA design.

		2	11	6
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(16) The application of this methodology could be managed by ACTD operational managers or their deputies.

	1	1	13	4
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(17) This methodology could promote the identification of MOE used for ACTD MUAs.

		3	**10**	**5**
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(18) This methodology fills a gap in the ACTD MUA design process.

		5	**8**	**6**
Strongly Disagree	Disagree	Do Not Know	Agree	Strongly Agree

(19) Please conclude this questionnaire by submitting any additional thoughts you wish regarding the proposed methodology or its value to ACTD MUA design.

Response summaries include:

(A) Would like to see the process applied to an actual ACTD.

(B) This is a reasonable approach that addresses a gap in the current MUA process.

(C) This methodology has the potential to instill rigor in risk assessment processes that could influence MUAs.

(D) The methodology holds potential value for MUA design.

(E) This methodology could make more robust and otherwise greatly benefit the MUA design practices of ACTD sponsors.

(F) This methodology should be validated with application to actual ACTDs.

(G) There is very little science behind the MOE development processes used by ACTD and similar program agents. This methodology could provide that science.

(H) MOE development should be standardized in a fashion supported by this methodology.

(I) This methodology can provide a rigorous approach to the many ACTD MUA designs that lack rigor. It offers results with credibility.

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE
and for
Your Participation as a Volunteer Member of the
ACTD Expert Group.

APPENDIX J

ACTD ASSESSMENT GUIDE FOR PRACTITIONERS

Advanced concept technology and joint capability technology demonstration operational managers should understand the primary importance assigned military utility assessments under ACTD and JCTD program guidance, and those managers should pursue their demonstration's assessment designs in concert with supporting analysts and the supported community of potential users. Operational managers should ensure their assessment designs account for:

- risks derived from incorporating ACTD systems within larger systems of military systems and operational processes; and
- the ambiguities of human cognition and language used to identify risks associated with complex, military systems.

The following practitioner's guide should promote such accounting. It is intended to be a brief, non-prescriptive, and largely iterative guide for operational managers, assessment designers supporting operational managers, and others supporting MUA design. It should be used precisely as intended – as a guide to meeting the critical military needs that demonstrations can represent.

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(1) Operational managers must identify to MUA designers the critical operational need their demonstration is expected to satisfy.

(2) Operational managers must identify to MUA designers their demonstration's purpose or, equivalently, the capabilities it is expected to provide in satisfying some critical need.

(3) Operational managers must elicit from their demonstration's potential user community and provide to MUA designers the critical operational issues the user community wishes addressed with a military utility assessment.

(4) Operational managers must develop or elicit from their demonstration's potential user community an initial concept of operations for governing the demonstration's

deployment as part of relevant, existing military and possibly non-military systems and procedures. They must provide that concept of operations to MUA designers.

(5) Operational managers must elicit from their demonstration's system developers and provide to MUA designers an initial understanding of the demonstration's primary, technical elements.

(6) Operational managers must elicit from their demonstration's system developers and provide to MUA designers an initial understanding of the demonstration's primary, operational elements.

(7) Assessment designers must consider initial information provided them by the operational manager and draw from that information a recommendation regarding composition of an operations expert group of purpose like that pursued by the operations group of this research. Assessment designers should advance their recommendation to the operational manager, soliciting that individual's support in forming an operations expert group.

(8) Assessment designers must identify an analyst of their own group to serve as study leader of the operations expert group. The study leader should meet selection requirements criteria developed a priori by the assessment designers and comprising criteria regarding analytical skill and appropriate, operational experience.

(9) The operations experts should use Phases I-II of Haimes' (1998, 2004) Risk Filtering, Ranking, and Management method to develop a hierarchical holographic model of their demonstration of interest, together with relevant aspects of other systems and processes with which the demonstration systems and processes are to be incorporated. The HHM must include user-provided, critical operational issues together with system developer-provided information regarding a demonstration system's technical and operational attributes.

(10) In developing a HHM, the operations experts may wish to first identify its major category, perspectives and follow that by identifying perspective-subordinate domains and subdomains to whatever level of hierarchy the group believes needed.

(11) The HHM development process should conclude when operations expert group members agree upon a final model.

(12) The operations expert group should use Phase III of Haimes' (1998, 2004) Risk Filtering, Ranking, and Management method to identify the risks to military operations utility that the HHM represents to it. Risks should be understood as functions of consequence and likelihood.

(13) The group may find that they are able to transcribe directly as risks any subdomain or lower-level HHM constructs earlier identified.

(14) The risk identification process should conclude when operations expert group members agree upon a final set of risks.

(15) The experts should next again use RFRM Phase III procedures to categorize elements of their final risk set in terms of *high*, *moderate*, or *low*. Experts may identify high-moderate-low graduations based on analytical considerations of consequence and likelihood, but they should not be bound by a false sense of rigor assigned such a “risk as analysis” (Slovic et al., 2004, p. 311) approach. Experts may, instead, address “risk as feelings” (p. 311) by depending on their “experiential system” to guide them toward plausible, risk assessments.

(16) The experts should refine their high-moderate-low categorizations by associating with each risk an ordered pairing of consequence and likelihood, (consequence, likelihood), like that demonstrated with this research. These associations may be made in concert with or in lieu of the high-moderate-low categorizations described in (14). As with any broader categorizations pursued under the guidance of (15), operations experts should concede the equivalent credence of “risk as feelings” and “risk as analysis” (Slovic et al., 2004).

(17) Based on an assessment of resources available to pursue a demonstration, operational managers may request the operational expert group to assess in terms of (consequence, likelihood) only those risks identified by the group as high. Those most serious risks would then be the only ones subjected to an ensuing prioritization based on the fuzzy group preference method of Blin and Whinston (1973) and Blin (1974) and so the only ones from which would be derived the measures of effectiveness upon which a military utility assessment would be founded. Such a process could ensure that an assessment executed under conditions of limited resources would address user-prescribed COIs as optimally as possible.

(18) Operational managers may instead request that all identified risks (or, at least a set of risks larger than that comprising only of those considered as high) be associated with ordered pairings of consequence and likelihood. In that case the following prioritization process would remain the same as for the more restrictive case described in (17).

(19) Once the domain of prioritization is determined by the operational manager, the operations expert group must decide to pursue one of two prioritization schemes: (a) one that treats as equivalent all elements of sets of risks assigned to the three categories of high, moderate, or low; or (b) one that first prioritizes within each risk category the distinct groupings of (consequence, likelihood) and then prioritizes the risks within each grouping. The latter scheme will normally be easier to execute in terms of operations group deliberations needed and the fuzzy mathematics computations to follow those deliberations.

(20) Once a particular prioritization scheme is determined, the leader of the operations expert group leader must develop a questionnaire to portray to group members the

pairwise comparisons of risks of interest required for the Blin and Whinston (1973) and Blin (1974) method.

(21) Operations expert group members must individually complete the questionnaire developed by their study leader. The study leader may participate in the survey but must most importantly ensure the completeness and accuracy of all questionnaire responses. Completeness and accuracy may be ensured by measures addressed in this research

(22) Observing the prioritization scheme selected from the two options of (19), the study leader must apply the Blin and Whinston (1973) and Blin (1974) fuzzy group preference method to determine from independent, operations group member responses: (a) a single group preference of prioritized risks; and (b) the level of agreement associated with that single preference.

(23) The group leader must then apprise the operational manager of the operations expert group preference regarding identified risks. The group leader must also apprise the operational manager of the level of agreement associated with that preference.

(24) The operational manager and operations group leader should together analyze the implications of the group preference and level of agreement determined. Given the analysis, they may determine that the preference and agreement level support the immediate development of MOEs from identified risks. They might alternately determine that the operations expert group should reconsider certain elements of their proceedings before a transition from identified risks to MOEs is made.

(25) Whatever the implications of the group preference and agreement level to the operational manager and operations expert group study leader, neither should consider MUA design complete until the demonstration's end. The entire or elements of the process described by (1) through (24) can and should be repeated whenever during the course of a demonstration such repetition seems of value to the MUA.

VITA

Thomas James Meyers
Department of Engineering Management and Systems Engineering
Old Dominion University
Norfolk, Virginia 23529

Thomas J. Meyers earned a Bachelor of Science degree in Physics and Mathematics from Jacksonville University, Jacksonville, Florida, in 1975. He earned the degree of Master of Science in Operations Research from the Naval Postgraduate School, Monterey, California, in 1989. In 2000 he concluded 25 years of active duty in the United States Marine Corps and has since been employed as a research analyst by The Johns Hopkins University Applied Physics Laboratory. He is a member of the Institute of Electrical and Electronics Engineers (IEEE), the International Council on Systems Engineering (INCOSE), the Military Operations Research Society (MORS), the International Test and Evaluation Association (ITEA), and the Epsilon Mu Eta engineering management honor society.