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MONTEREY, CALIFORNIA

THESIS

**TACTICAL DECISION MAKING
UNDER CATEGORICAL UNCERTAINTY WITH
APPLICATIONS TO MODELING AND SIMULATION**

by

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December 2008

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WITH APPLICATIONS TO MODELING AND SIMULATION**

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requirements for the degree of

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ABSTRACT

The Network Centric Warfare approach to command and control emphasizes decentralized decision making. Consequently, decision makers must comprehend and evaluate information to determine the optimal course of action. This study examines how different categories of uncertainty (ambiguous/missing, conflicting, baseline) and individual differences affect response time in decision making tasks. The researchers elicited real-world tactical scenarios from veterans of Operation Enduring Freedom and Operation Iraqi Freedom in which uncertainty was present. Nine scenarios were given to 28 participants at the Command General Staff College, FT Leavenworth, KS. The participants were asked to make a decision; their responses were recorded and analyzed. The results indicate that the category of uncertainty and scenario difficulty are significant factors in determining response time. No individual difference factors were found to be significant. These findings have the potential to improve human behavior modeling, tactical simulations, and representations of complex task environments.

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TABLE OF CONTENTS

I.	INTRODUCTION.....	1
A.	THE HISTORICAL PREMISE OF UNCERTAINTY	1
B.	UNCERTAINTY IN WARFARE.....	2
C.	HUMAN SYSTEMS INTEGRATION	4
D.	RESEARCH QUESTIONS.....	5
E.	RESEARCH OBJECTIVES.....	5
F.	THESIS ORGANIZATION.....	6
II.	LITERATURE REVIEW	7
A.	DECISION MAKING AND COMMAND AND CONTROL.....	7
	1. Network-Centric Warfare.....	7
	2. The Cognitive Domain.....	8
B.	DECISION-MAKING MODELS.....	9
	1. Naturalistic Decision Making.....	9
	2. Perception	11
C.	DYNAMIC MODEL OF SITUATION COGNITION.....	12
	1. Principles of DMSC	12
	2. Uncertainty Emergence.....	13
	a. Oval 1.....	13
	b. Oval 2.....	13
	c. Oval 3.....	14
	d. Oval 4.....	14
	e. Oval 5.....	14
	f. Oval 6.....	15
	g. Amorphous Shapes	15
	3. Feedback Loops.....	15
D.	DEFINITION OF UNCERTAINTY	17
E.	CATEGORIES OF UNCERTAINTY.....	18
	1. Ambiguous/Missing Information.....	18
	2. Conflicting Information.....	18
	3. Unreliable Information.....	18
	4. Baseline Information	18
	5. Distinguishing the Definitions.....	19
F.	UNCERTAINTY TAXONOMY.....	20
	1. Information Flow	21
	a. Information Flow Interaction	21
	2. Individual Difference Factors	22
	a. Operational Experience	23
	b. NEO-FFI.....	24
	c. Coping with Uncertainty.....	26
G.	CRITICAL DECISION MAKING METHOD	27
H.	HYPOTHESES	28

III.	METHOD	31
A.	PILOT STUDIES	31
1.	Pilot #1 - Ambiguous Words	31
a.	Participants.....	31
b.	Method.....	32
c.	Results.....	32
d.	Discussion.....	32
2.	Pilot #2 - Operational Intelligence.....	33
a.	Participants.....	33
b.	Method.....	34
c.	Results.....	35
d.	Discussion.....	35
3.	Pilot #3 - Tactical Decision Environments.....	36
a.	FT Leavenworth, KS.....	36
b.	Naval Postgraduate School.....	37
B.	CGSC EMPIRICAL STUDY	39
1.	Independent Variables.....	39
2.	Dependent Variables.....	39
3.	Participants.....	39
4.	Materials and Apparatus	40
a.	Demographic Survey.....	40
b.	NPS Decision-Making Study.....	40
c.	Uncertainty Response Scale (URS) Survey.....	42
d.	Operational Experience	42
5.	Design and Procedure.....	43
IV.	RESULTS	47
A.	SUMMARY STATISTICS FOR CATEGORICAL UNCERTAINTY	47
1.	Descriptive Statistics for Categorical Uncertainty.....	47
2.	Inferential Statistics for Categorical Uncertainty.....	48
a.	Decision Time.....	48
b.	Adjoined Times.....	50
c.	Interrelated Times.....	52
d.	Within Category Times	53
B.	SUMMARY STATISTICS FOR UNCERTAINTY RESPONSE SCALE	53
1.	Descriptive Statistics for URS.....	53
2.	Inferential Statistics for URS.....	54
C.	SUMMARY STATISTICS FOR EXPERIENCE	54
1.	Descriptive Statistics for Operational Experience	54
D.	SUMMARY STATISTICS FOR VARIABLE ASSOCIATIONS.....	56
V.	DISCUSSION	57
A.	IMPLICATIONS OF ANALYSIS.....	57
1.	Hypothesis One	57
a.	Ambiguous/Missing Overall Total Time and Baseline Overall Total Time	59

	b.	<i>Ambiguous/Missing Overall Total Time and Conflicting Overall Total Time</i>	<i>62</i>
	c.	<i>Conflicting Overall Total Time and Baseline Overall Total Time</i>	<i>64</i>
	2.	2nd Hypothesis.....	65
	a.	<i>Cognitive Uncertainty and Overall Total Time.....</i>	<i>66</i>
	b.	<i>Emotional Uncertainty and Overall Total Time</i>	<i>66</i>
	3.	3rd Hypothesis.....	67
B.		CONSTRAINTS AND LIMITATIONS OF THE RESEARCH	68
C.		CONCLUSIONS AND RECOMMENDATIONS.....	68
	1.	Conclusions.....	69
	2.	Future Research.....	69
	a.	<i>Additional Research on Decision-Making Response to Uncertainty.....</i>	<i>69</i>
	b.	<i>Application to Modeling and Simulation for Human Behavior</i>	<i>70</i>
	c.	<i>Expansion to the Military Services.....</i>	<i>70</i>
	d.	<i>Application to Civilian Occupations</i>	<i>71</i>
	3.	Summary.....	71
APPENDIX A.		UNCERTAINTY RESPONSE SCALE TEST	73
APPENDIX B.		MODIFIED CDM INTERVIEW SHEET	81
APPENDIX C.		NPS PILOT STUDY # 1 SCREEN SHOTS	83
APPENDIX D.		NPS PILOT STUDY # 2 SCREEN SHOTS	85
APPENDIX E.		CGSC TACTICAL VIGNETTES	87
APPENDIX F.		CGSC STUDY INSTRUCTIONS	93
		LIST OF REFERENCES.....	95
		INITIAL DISTRIBUTION LIST	101

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LIST OF FIGURES

Figure 1.	Klein's Recognition Primed Decision Model (1993).	10
Figure 2.	Wickens et al. Integrated Model (2004)	11
Figure 3.	Dynamic Model of Situated Cognition (Shattuck & Miller, 2006).	13
Figure 4.	Dynamic Model of Situated Cognition Feedback System (Shattuck & Miller, 2006).	16
Figure 5.	Uncertainty Association Taxonomy.	21
Figure 6.	Pilot Study #2 Situational Display.	34
Figure 7.	Photograph of CGCS Study.	42
Figure 8.	Tactical Decision-Making Assumptions.	43
Figure 9.	Tactical-Decision-Making Assumptions.	44
Figure 10.	Participant Mean Overall Total Time for the Categories of Uncertainty.	49
Figure 11.	Regression Plot for Inter-Rater Reliability Difficulty and Overall Total Time.	50
Figure 12.	Regression Plot for Scenario Difficulty for Adjoined Times.	51
Figure 13.	Participant Mean Time to Decision for the Categories of Uncertainty.	52
Figure 14.	Participants Months of Operational Experience by Theatre.	55
Figure 15.	Distribution of Total Operational Experience in Months.	55
Figure 16.	Diagram of Statistical Inferences for Differences between Ambiguous/Missing Information and Baseline Information.	58
Figure 17.	Diagram of Statistical Inferences for Differences between Ambiguous/Missing Information and Conflicting Information.	63
Figure 18.	Low Resolution Ambiguity Slide.	83
Figure 19.	Medium Resolution Ambiguity Slide.	83
Figure 20.	High Resolution Ambiguity Slide.	84
Figure 21.	Conflicting Information Slide.	85
Figure 22.	Missing Information Slide.	85
Figure 23.	Ambiguous Information Slide.	86
Figure 24.	Baseline Information Slide.	86
Figure 25.	Conflicting Information Slide.	87
Figure 26.	Ambiguous/Missing Information Slide.	87
Figure 27.	Baseline Information Slide.	88
Figure 28.	Conflicting Information Slide.	88
Figure 29.	Ambiguous/Missing Information Slide.	89
Figure 30.	Baseline Information Slide.	89
Figure 31.	Conflicting Information Slide.	90
Figure 32.	Ambiguous/Missing Information Slide.	90
Figure 33.	Baseline Information Slide.	91

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LIST OF TABLES

Table 1.	Sign Test for Categories of Uncertainty.	35
Table 2.	Scenario Difficulty Means for the Categories of Uncertainty.	41
Table 3.	Categorical and Time Segment Means and Standard Deviations for CGSC Study (seconds).....	48
Table 4.	Wilcoxon Sign-Rank Analysis for Overall Total Time.	48
Table 5.	Descriptive Statistics for URS.	54
Table 6.	CDM Uncertainty Elicitation Interview Sheet.....	81

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EXECUTIVE SUMMARY

The Information Age has revolutionized command and control in the tactical environment. The advent of Network Centric Warfare has led to an emphasis on decentralized decision making in real-time. The warfighter is expected to evaluate and analyze large quantities of information to produce a logical, rational decision at a moment's notice. However, warfare often is neither rational nor logical. Although military commanders attempt to plan fail-safe operations, uncertainty often will create havoc or "fog" in the battle space. This fog forces commanders to adjust their plans in real time by using the information available to them.

To apply their best judgment, commanders must utilize various inputs, including machine and human agents, to achieve an accurate awareness of the situation. This reliance on both human and machine agents strongly suggests a Human Systems Integration (HSI) approach - an approach that emphasizes the symbiotic, interdependent nature of human and machine agents to solve difficult and uncertain problems.

During this study, U.S. Army officers, with recent experience in Operation Enduring Freedom and Operation Iraqi Freedom, were interviewed. The purpose of these interviews was to elicit real-world, tactical situations where uncertainty affected the decision making process. These scenarios were then crafted into nine vignettes representing the categories of uncertainty (i.e., ambiguous/missing, conflicting, and baseline). The vignettes were presented to 28 U.S. Army officers at FT Leavenworth, KS. The participants were asked to determine what decision they would make for each situation. Their decisions and response times were recorded and analyzed. Additionally, the participants completed a demographic survey and the Uncertainty Response Scale (e.g., emotional uncertainty & cognitive uncertainty). The researchers hypothesized that there would be a difference between the categories of uncertainty with respect to response time. Additionally, it was believed that emotional uncertainty, cognitive uncertainty, operational experience, and response time would be significantly correlated.

The results suggest that the category of uncertainty coupled with scenario difficulty were significant factors in determining response time. Moreover, ambiguous/missing scenario response times were significantly greater than conflicting and baseline scenario response times. Operational experience, cognitive uncertainty, emotional uncertainty, and response time were not significantly correlated.

In conclusion, the findings have implications for advancing the state of the art in modeling and simulation. This research provides insights into human behavior under uncertain conditions. These insights can aid researchers in more accurately modeling human behavior in tactical environments. The findings also extend to civilian and military decision making under complex tasking.

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I. INTRODUCTION

History is captured by moments of uncertainty. From the ancient and mythical battlefields of the Peloponnese to the rugged and unpredictable terrain of the War on Terror, statesmen, politicians, and military commanders have made critical decisions with uncertain information. This is the nature of the world we live in; very few things are certain, and most things are uncertain.

This natural phenomenon has prompted many philosophers and theorists to address and pontificate on uncertainty's role in the natural world. Consequently, psychologists, historians, and researchers have approached uncertainty from cognitive, historical, and sociologists' perspectives. More importantly, they have attempted to define uncertainty, determine the effects, and discover its origins. Their research has yielded varying and numerous results. Regardless, their research has established a great foundation for future inquiry, and for this study, the effects of uncertainty on decision-making.

A. THE HISTORICAL PREMISE OF UNCERTAINTY

Commentary on uncertainty can be traced back to the greatest thinkers in Western literature and philosophy. Although the constructions of their arguments do not attempt to study uncertainty, they do make reference, and find its presence important in their works. In *Discourse of Method*, Rene Descartes (1637) addressed the importance of discovery and truth through science. To accomplish this, he asked man to "reject all previous knowledge, opinion, and customs" (Descartes, 1637, p. 21). He writes:

The first was never to accept anything as true which I did not clearly know to be such, that is to say, carefully to avoid haste and prejudice, and to accept nothing as true except what was presented to my mind so clearly and distinctly as to exclude all possibility of doubt.

Descartes was arguing two points. First, knowledge, and therefore truth, cannot, and must not, be concluded without a thorough investigation of the question posed. Second, a statement cannot be considered true unless all uncertainty (i.e., doubt) is

removed. The latter of the two is most important for this debate, because Descartes is advocating that doubt (i.e., uncertainty) naturally exists in any, and all, scientific and intellectual arguments.

Moreover, Thomas Hobbes (1651) discussed this innate uncertainty through the nature of man. In *The Leviathan*, the Englishman examined the relationship between knowledge, opinion, judgment, and faith. Hobbes writes, “no discourse whatsoever can end in absolute knowledge of fact, past, or to come...no man can know by discourse, that this, or that, is, has been, or will be; which is to know absolutely” (p. 511). Therefore, the search for understanding can never conclude in concrete truth, because man cannot adequately predict the future or what is to come. More importantly, his judgment and reason can be clouded by personal conscious and faith.

However, there is something more important to be learned from the writings of Descartes and Hobbes. The philosophers articulate the symbiosis of the natural state of man and the events of history. Although this may seem trivial, it supports the premise of uncertainty in the modern world; because man is naturally flawed, favored by opinion and prejudice, unable to grasp all possible knowledge, and his affairs dynamic, uncertainty will always be present in all of man’s institutions. Thus, economics, politics, and for this study, warfare, by nature, will be laced with uncertainty. Consequently, it must be studied and understood.

B. UNCERTAINTY IN WARFARE

The role of uncertainty in warfare has been documented throughout history. Recently, Secretary of Defense Donald Rumsfeld, trying to explain the clouded future of the War on Terror, delivered a set of shrouded words that left the media confused and hysterical. In under a minute, the battle-hardened patriot described the innate characteristics of war.

There are things that we know. There are known unknowns. That is to say, there are things that we know we don't know. But there are also unknown unknowns. There are things we don't know we don't know (Rumsfeld, 2002).

Although many scoffed, laughed, and viewed his uncanny remarks as mysterious, the proposed message was intended to prepare and warn the American public of the complex, dynamic nature of warfare. Like Hobbes' interpretation of human nature, Rumsfeld viewed uncertainty as an inherent attribute of warfare.

However, Rumsfeld's often criticized, yet sometimes revered, speech was not the first to describe the assumptions, estimates, and uncertain nature of armed-conflict. More than two millennia earlier, military philosopher Sun Tzu (650) argued that the factors of war can be controlled; therefore uncertainty and chaos can be spawned, developed, and adjusted to confuse an opponent. Victory, therefore, can be achieved by creating a specific amount of uncertainty that both paralyzes and strikes fear in one's adversary.

Conversely, in the 19th century, military theorist Carl von Clausewitz (1805) argued that uncertainty is not a variable that can be manipulated in armed-conflict. Instead, he argued uncertainty to be a powerful and uncontrollable force that man is incapable of harnessing. Clausewitz described the climate of war using four distinct characteristics: danger, exertion, uncertainty, and chance. He wrote, "war is the realm of uncertainty; three quarters of the factors on which action in war is based are wrapped in a fog of greater or lesser uncertainty" (Clausewitz, 1805, p. 102). Consequently, uncertainty creates "friction" that makes the simplest movements difficult. To Clausewitz, war is not solely an act of pure intellect or intuition, but rather a delicate congruence of fate, luck, and skill.

Interestingly, Sir Jilian Corbett (1911) may have best expressed the unique nature of man and uncertainty in war. A student of Clausewitz and Jomini, the British historian disagrees with the idea that war is an art vice a science with "no fixed laws or rules" (Corbett, 1911, p. 8). Instead, Corbett argues that history shows "certain lines of conduct produce certain effects" (p. 8). However, Corbett later suggests that "strategic analysis can never give exact results...only at approximations..." and will always "leave much to judge" (p. 83).

His statements give more credence to Clausewitz's views; that war is not an equation of set variables, but rather an open system of ever changing inputs and outputs. Therefore, uncertainty will always find a place among the commander's sure plans or the infantryman's charge.

C. HUMAN SYSTEMS INTEGRATION

To explore the role of uncertainty in military decision making, our study will address the topic from the perspective of Human Systems Integration (HSI). The definition of HSI continues to be the subject of debate. However, two definitions best describe the essence of the discipline. First, HSI is "the interdisciplinary approach that makes elicit the underlying tradeoffs across the domains, facilitating optimization of total system performance," (Miller & Shattuck, 2006). Second, HSI is "a human centered approach to the design, development, and acquisition of systems from cradle to grave," (Read, 2007, p. 3). In simpler terms, HSI aims to incorporate the human system in the "systems of systems" architecture; it attempts to remedy an individual's weaknesses and highlight their strengths. In order to do so, HSI focuses on the eight domains and the tradeoffs within each. The following are the eight domains of HSI:

- Manpower
- Training
- Personnel
- Survivability
- Habitability
- Human Factors Engineering
- Health Hazards
- System Safety

By incorporating these eight domains early in the acquisition cycle, the U.S. Department of Defense hopes to reduce costs, human survivability, and system lifespan. Further explanation of these terms can be found in *Department of Defense Instruction 5000.2* (U.S. Department of Defense, 2003) or *Handbook of Human Systems Integration* (Booher, 2003).

For the scope of this study, the exploration of uncertainty in tactical decision making will be focused on modeling and simulation. Therefore, close attention will be paid to the domains of human factors engineering, personnel, and training. The researchers' hope is to create algorithms for decision making under uncertainty in tactical simulations, thus providing a more realistic interpretation of the *actual* events of the battle space.

D. RESEARCH QUESTIONS

The historical presence of uncertainty and its influence on military history has prompted several important questions. While these questions provide an adequate foundation for research in the field of uncertainty, we must remind ourselves that the problem reaches far into the battle space. When addressing the problem from the perspective of HSI, the machine and human must be discussed in integrated, symbiotic terms. The following research questions were not mutually exclusive of the human being, but instead created to better understand the human's cognitive abilities in combat.

- What is uncertainty? What is its origin? What is its definition?
- How does uncertainty affect the man and machine symbiosis?
- What models and taxonomies can aid in the understanding of uncertainty in HSI?
- What are the relationships between uncertainty, data, and individual difference factors?
- Does an individual's emotional or cognitive response to uncertainty affect his/her ability to cope with uncertainty?
- Do decision makers delay their decisions when faced with uncertainty?

E. RESEARCH OBJECTIVES

With the premise properly stated and research questions posed, the objectives for the study can be outlined:

- Create a methodology for examining uncertainty in the tactical environment.
- Emphasize the importance of HSI in exploring uncertainty across the battle space.
- Begin to identify the individual difference factors that influence decisions under uncertain conditions.

- Develop of algorithms for modeling and simulation.
- Provide a clear direction for future research in tactical decision making under uncertainty.

F. THESIS ORGANIZATION

The organization of this thesis follows a traditional format. In accordance with APA standards, it documents a literature review, methodology, results chapter, and discussion. Chapter II uses a top-down approach to examine decision-making under uncertainty through the perspective of HSI. Literature regarding command and control (C2), decision-making models, uncertainty, personality characteristics, and experience are analyzed and discussed to better explain their role in the realm of the uncertainty.

Chapter III focuses on the previous pilot studies performed at NPS, along with the methodology used to conduct the final study. The pilot studies provide an interesting and important tale when addressing the nature of uncertainty. Additionally, “lessons learned” are documented and translated into future success. Moreover, a detailed description of the methodology is provided for future replication.

Chapter IV and Chapter V provide statistical analysis and a discussion of the results. Additionally, conclusions based on previous research will be documented, along with opportunities for future research in the field of uncertainty.

II. LITERATURE REVIEW

A. DECISION MAKING AND COMMAND AND CONTROL

1. Network-Centric Warfare

To remedy the effects of uncertainty, militaries have established means of communications and procedures to relay plans, monitor execution, and provide assessment (or assess results). These means of command and control (C2) remain central and increasingly important to all military operations and allow commanders to issue explicit and implicit orders when executing simple and complex operations.

The theory of C2 has evolved over the course of military history. However, the Industrial Age forever altered its essence. The 20th century ushered in the use of machines in the battle space. Ships, aircraft, and tanks greatly increased the range, distance, lethality, and speed of battle. Additionally, radio and radar allowed commanders to view the enemy at great distances and communicate over thousands of miles of terrain and ocean. Consequently, platform-centric warfare became the preferred method of C2 operations (i.e., the commander makes a centralized decision and communicates his direction to subordinate platforms who then execute the commanders' orders) (Alberts, Garstka, & Stein, 1999; Alberts, 2003; Cebrowski & Garstka, 1998). More importantly, the warfighters were no longer autonomous in their own thought or action, but rather guided, and sometimes aided or instructed by mechanized technology (i.e., the integration of the human and machine system were vital to operational success).

The evolution of technology (e.g., satellite communication, AEGIS, and simulation) soon gave new capabilities to commanders and operators. For the first time in warfare, the human possessed the capability to share, analyze, disseminate, and internalize distant battle space information in near real-time. Consequently, a new vision of military C2 operations emerged, and Cebrowski and Garstka's (1998) Network Centric Warfare (NCW) theory changed the direction of C2 and military decision-making.

The NCW concept has revolutionized military operations. The centralized information and decision-making environment of the past is being replaced by a shared network, focused on decentralized decision-making. Consequently, DeLange (2006) argues that NCW is merely a named process and the underlying, important message is “Decision Centric Warfare” (DCW) (i.e., improved decision-making is the most important aspect behind the NCW revolution). But while the particulars and details of NCW operations are fascinating and intriguing, the most important concepts lie in its four domains (cognitive, social, physical, and information) outlined by its creators (Cebrowski & Garstka, 1998). More importantly, for this study, how the cognitive domain impacts Network Centric Operations (NCO) when clouded by uncertainty

2. The Cognitive Domain

The cognitive domain is the mind of the decision maker (Alberts, Garstka, Hayes, & Signori, 2001). It serves as the most important element in NCO. While automation in complex systems has increased over the last quarter century, the decision maker continues to play the most important role in the system. Consequently, the ultimate success of NCW relies on the integration of human cognition and technological capability (Read, 2007, & Baker, 2002).

To better understand the capabilities and limitations of human cognition in NCO, Garstka and Alberts (2004) have described the human’s thought process as “sensemaking,” while also placing an emphasis on “shared sensemaking” or “collaboration.” The latter articulates two fundamental ideas: (1) the cognitive domain is influenced by the social domain (i.e., culture, organization, politics), and (2) the decision makers share their evaluation of the situation with their peers (Garstka & Alberts, 2004). Consequently, an individual decision maker can have a major impact, through a pseudo-social medium, on the course of action at both the micro and macro level due to the ability to share and analyze information in real time. Additionally, Caneva (1999) suggests NCW has the potential to not only increase military operations spatially, but also temporally. Therefore, the cognitive domain can expand the battlefield beyond our own expectations and imagination.

While these points are important to recognize, it is outside the scope of our research. Instead, our goal is to focus on the “sensemaking” occurring at the individual cognitive level prior to peer-sharing. To describe the aforementioned, Garstka and Alberts (2004) explain the development of mental models to facilitate decision-making. Additionally, the researchers argue, “over time and with experience, people build up a repertoire of mental models that apply across a range of situations” (Garstka & Alberts, 2004, p. 30). Their researcher implicitly hints at the various thought processes applied to decision-making.

B. DECISION-MAKING MODELS

To describe how individuals make or should make decisions, researchers have developed three models: (1) normative, (2) descriptive, and (3) naturalistic. Although all three models describe the human thought process in unique and explicit terms, the naturalistic model, or naturalistic decision-making model (NDM), has been widely accepted in recent years due to its utility in operational settings (Shattuck, 2007). More importantly, the NDM characteristics outlined by Orasanu and Connolly (1993) (e.g., ill-structured problems, uncertain dynamic environments, multiple players, and organizational norms and goals) describe the situations and context of military exercises and engagements (e.g., the recent 2008 military showdown between the United States and Iranian naval forces in the Straits of Hormuz).

1. Naturalistic Decision Making

In examining the utility of NDM in operational settings, Zsombok and Klein’s (1997), *Naturalistic Decision Making*, cites several real-world, research studies. For example, Hutchins (1997) addresses human error and situation awareness in U.S. Navy Littoral Anti Air Warfare (AAW) operations, while Serfaty, MacMillan, Entin, and Entin (1997) examined the importance of expertise in military tactical decision-making.

Coincidentally, the AEGIS training center’s Tactical Decision Making under Stress (TADMUS) program focused on decision-making in stressful and time-sensitive environments (Cannon-Bowers & Salas, 1998). Additionally, Kaempf and Klein (1993)

examined the decision-making strategies of naval officers aboard U.S. Navy AEGIS Cruisers. The aggregate research illustrates the complex, uncertain environments in which decision makers must operate.

Consequently, NDM researchers have developed overlapping theories on how decision makers formulate and select their courses of action. For example, Klein's (1993) Recognition Primed Decision-Making (RPD) model argues that decision makers rely on past experiences to select their courses of action (i.e., individuals do not select from several different outcomes, but rather choose their course of action based on past experience) (see Figure 1). He describes the model as consisting of two fused parts: (1) situational assessment and (2) mental simulation (Klein, 1993). Klein argues mental situational assessment generates a plausible course of action (COA) and mental simulation evaluates that COA. However, it is important to note, that Klein (1989, as cited in Wickens, Lee, Liu, and Becker, 2004) describes the RPD model as a "more refined description" of the various components of Rasmussen's (1983, 1986, 1993) Skill, Rule, and Knowledge (SRK) model (p. 173). However, while the aforementioned models describe the process behind decision making, they do not adequately add the important aspect of perception.

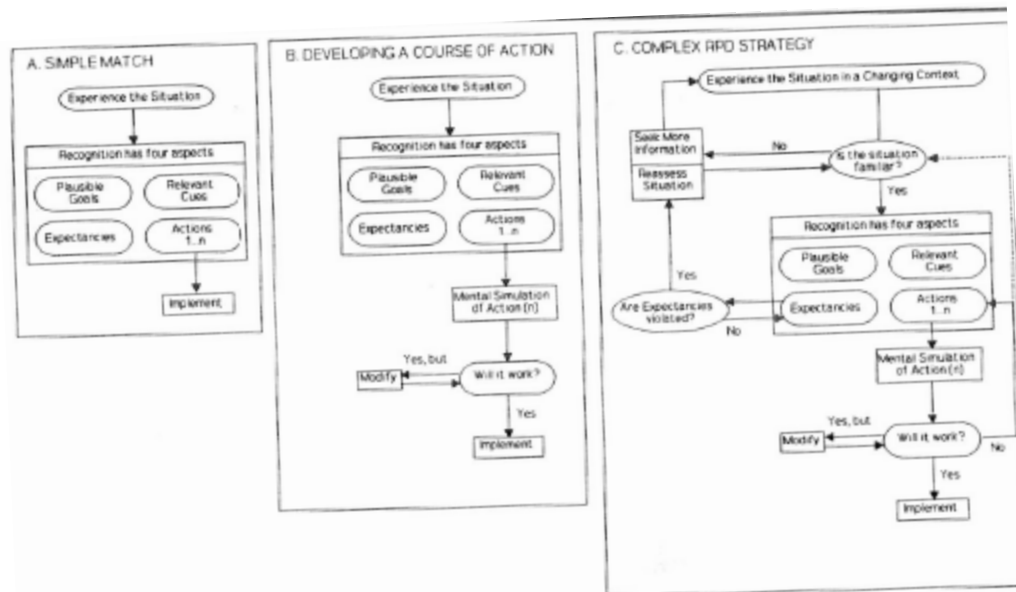


Figure 1. Klein's Recognition Primed Decision Model (1993).

2. Perception

Endsley (1995) discusses perception in terms of situation awareness (SA). She defines SA as the “perception of the elements of in the environment within a volume of time and space, the comprehension of their meaning and the projection their status to the near future” (Endsley, 1995, p. 36). Consequently, the information presented to the commanders can be radically altered by their situational perception.

To remedy this gap, Wickens et al. (2004) offers an integrated, adaptive decision making model (see Figure 2). Although the model effectively integrates RPD, SA, and SKR, it fails to address the symbiosis of man and machine in the battle space (i.e., the advent of technology discussed in Chapter II.A.1 has made the two parties mutually dependent of each other). Consequently, when discussing the role of the warfighter in “sensemaking,” one must apply a model that incorporates both man and machine. The model that best portrays this necessary relationship is the Dynamic Model of Situation Cognition (DMSC) (Shattuck & Miller, 2006; Miller & Shattuck, 2006).

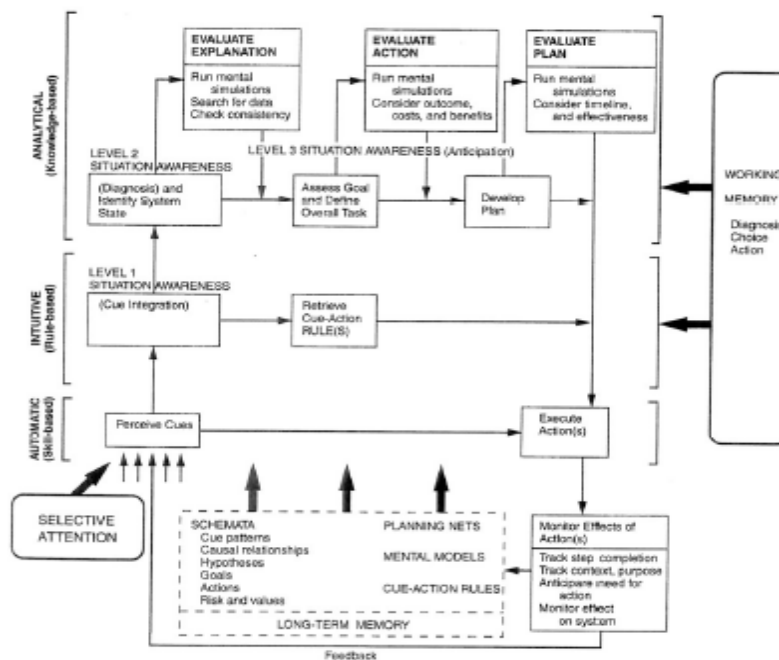


Figure 2. Wickens et al. Integrated Model (2004) .

C. DYNAMIC MODEL OF SITUATION COGNITION

The DMCS represents the integration of man and machine in the battle space (see Figure 3). It shows the processes associated with human-machine interaction when operating in complex, fast-paced, and uncertain environments. Additionally, it describes the perception, or lens, of the warfighter when making critical, tactical decisions. As described in Chapter I.A, because individuals are flawed and unable to grasp all knowledge they may naturally interpret information differently. Lastly, it addresses the inherent uncertainty involved in cognitive reasoning when conducting real-world operations.

1. Principles of DMSC

DMSC contains two distinct and important principles: (1) ground truth will never be completely realized or recognized by the decision maker and (2) the machine or system cannot identify or articulate uncertainty through its medium. Both principles are the curse of the information technology age. Because society is obsessed with the idea of perfection, we strive to create no doubt or uncertainty in our world. We have been conditioned to assume the technology cannot be wrong; it is the antidote to fix our inherent flaws. Consequently, we allow ourselves to be drawn into the perfect storm, or as Miller and Shattuck (2006) profoundly call it, “the seduction of technology.”

This is no more evident than in the military, where we often struggle to remedy the effects of uncertainty in the tactical, operational environment. Even worse, the physical representation of uncertainty continues to present an enormous challenge in the modeling and simulation discipline. Regardless, before we can study the effects of uncertainty on decision making, we must first identify how the uncertainty manifests in both the technology and human systems. Fortunately, DMSC answers this critical question.

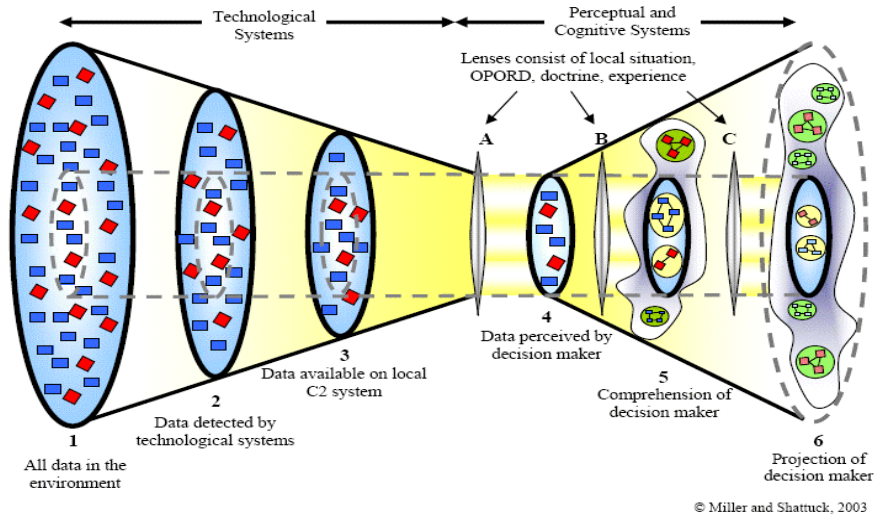


Figure 3. Dynamic Model of Situated Cognition (Shattuck & Miller, 2006).

2. Uncertainty Emergence

The DMSC shows the presence of uncertainty throughout the model. It appears as early as Oval 2, and influences the decision making process. As Shattuck and Miller (2006) note, “the specific comprehension achieved by the decision maker is a function of the data that have propagated through the model and the contents of the lens,” (p. 998). Consequently, Oval (5) and Oval (6) show uncertainty’s effect on the decision maker’s comprehension and projection. However, before we can discuss uncertainty in the context of the model, we must explore the ovals where it manifests.

a. Oval 1

Oval 1 represents ground truth; ground truth being the absolute, unequivocal truth as described by Descartes (1637).

b. Oval 2

Oval 2 is how accurately technology depicts ground truth. *Technological accuracy* is determined by the efficiency of applied sensors (e.g., if the sensors do not detect various units in the battle space, then the unequivocal representation of ground truth is lost) (Shattuck and Miller, 2006). Additionally, the data can be misidentified.

Shattuck and Miller suggest that in a perfect world Ovals 1 and 2 would be mirror images, thus allowing for the decision maker to view the world from “God’s eye.”

c. Oval 3

Oval 3 describes the transition from the sensors to the display. Shattuck and Miller (2006) note that current C2 systems (Blue Force Tracker, Tactical Tomahawk Weapons Control System) allow for decision makers to tailor their displays to view perceived important information. Consequently, some information may not be seen or processed. Additionally, faulty algorithms may misinterpret what is ground truth, thus depicting an inaccurate picture.

d. Oval 4

The transition from Oval 3 to Oval 4 represents the bridge between technology and the operator (hence, human systems integration). Oval 4 shows the data perceived by the decision maker. Shattuck and Miller (2006) describe this process in terms of passive or active input. Active input is a result of the decision maker requesting or “pulling” information, where passive involves the information that is not requested or “pushed” upon the decision maker (Shattuck & Miller, 2006).

e. Oval 5

Oval 5 represents the comprehension of the decision maker. Endsley (1995) (as cited in Shattuck and Miller, 2006) describes comprehension as multiple processes, including integration, analysis, and interpretation. Additionally, Oval 5 is the result of Lens B in the model. Lens B articulates several factors including personality states and traits, experience, and social culture that influence the comprehension of the decision maker (Shattuck & Miller, 2006). Elements of Lens B will be discussed in Chapter II.F.2.

f. Oval 6

Oval 6 embodies the idea of projection. Shattuck and Miller (2006) define projection as “the prediction of the decision maker,” (p. 998). At this point, decision makers have ascertained what they believe to be true, and in some cases, have transmitted their depiction or beliefs about the situation to other decision makers in the battle space.

g. Amorphous Shapes

The amorphous shapes surrounding Oval 5 and Oval 6 represent the various organizations or interpretations of the information (Shattuck & Miller, 2006). Although the same information may be presented to two different decision makers, their interpretation of the information may be slightly or very different. Consequently, the decision makers may formulate different mental models of the situation (Shattuck & Miller, 2006). Additionally, the enlarging of the amorphous shapes from Oval 5 to Oval 6 depicts the idea that there is more uncertainty involved in projection vice comprehension. A prediction of the future is merely one possible outcome of numerous possibilities for the future; the farther an individual predicts into the future, the more uncertainty will be present (Shattuck & Miller, 2006).

3. Feedback Loops

To curtail uncertainty in the DMSC, Shattuck and Miller (2006) emphasize the iterative, dynamic process inherent in the model. Feedback loops depict decisions or reorientations by the decision maker (see Figure 4). Thus, the individual can mitigate uncertainty by constantly updating their cognitive approach or the technologies’ output. Unfortunately, in most cases, the operator cannot simply “tag” an object as uncertain or ambiguous. However, they can inform other operators of the incorrect information being displayed. This leads to the next important point in terms of uncertainty.

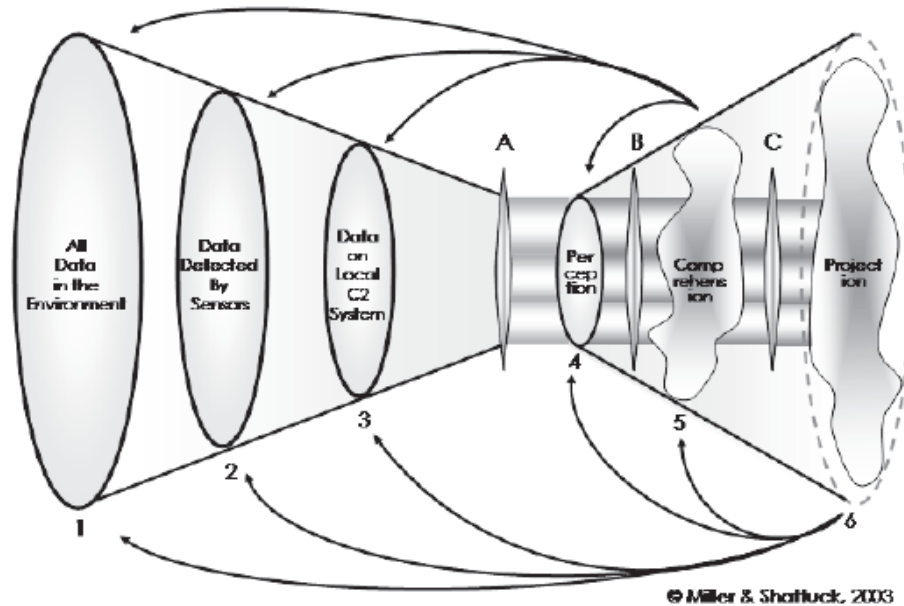


Figure 4. Dynamic Model of Situated Cognition Feedback System (Shattuck & Miller, 2006).

Because NCW relies on a shared picture, or common operating picture (COP), the propagation of uncertainty in the battle space can be disastrous regardless of the echelon of command (i.e., uncertainty experienced by a flag officer or junior enlisted soldier can have equal effect). This is why the recent wars in Afghanistan and Iraq have focused on young soldiers making real time decisions with significant consequences. However, the impact of uncertainty up and down the chain of command is a pervasive issue and will need to be explored in future research.

The present research examined tactical decisions made by middle echelons commanders (e.g., company commanders (CO CDR)). By doing so, the researchers established a basic understanding of the role of uncertainty in their decisions. More importantly, they examined how uncertainty influences the time it takes to make a decision and how individual differences help or hinder their responses.

But before we can begin to study uncertainty, we must (1) define uncertainty, and (2) describe the individual differences that influence our decisions under uncertain conditions. While these tasks seem simple the answer is as ambiguous as the word being examined.

D. DEFINITION OF UNCERTAINTY

Researchers continue to argue the definition of uncertainty. In capturing the mood of the debate, Downey and Slocum (1975, p. 562, quoted in Milliken, 1987, p. 134) state the overabundant use of the term “uncertainty” has made it “all too easy to assume that one knows what he or she is talking about.” Regardless, Lipshitz and Strauss (1997) propose uncertainty “in the context of action is a sense of doubt that blocks or delays action” (p. 150). Additionally, Lipshitz and Strauss distinguish uncertainty from ambiguity. Paraphrasing Hogarth (1987), the researchers describe ambiguity as “lacking precise knowledge about the likelihood of events” (Lipshitz and Strauss, p. 150).

Conversely, Cohen and Freeman (1996) use a quantitative approach to characterize uncertainty. The researchers define uncertainty as “probabilities other than zero” (Cohen & Freeman, p. 179). Additionally, Conrath (1967) constructed a one-dimensional scale using the terms “certainty” and “uncertain” as the two extreme opposite points along the continuum. However, McCloskey and Klein (1996) go beyond defining the term, and identify four categories of uncertainty: (1) missing information, (2) unreliable information, (3) complex information, and (4) ambiguous/conflicting information.

McCloskey and Klein (1996) define information as ambiguous or conflicting “if there is more than one reasonable way to interpret it” (p. 195). However, the researchers advocated a different approach. Rather than keeping ambiguous/conflicting information as a pair, they separated them into two different entities; ambiguous and conflicting. Then, from the pilot studies outlined in Chapter III.A, they adjoined missing and ambiguous. Additionally, the researchers viewed complex information as product of the other defined categories of uncertainty (i.e., the more uncertain a situation becomes, the more complexity involved). The modification of the categories of uncertainty reduced the number of categories to three. Finally, the researchers added the category of baseline to establish situations where little or negligible uncertainty appeared. Thus, the researchers viewed the categories of uncertainty as the following: (1) ambiguous/missing information, (2) conflicting information, (3) unreliable information, and (4) baseline information.

E. CATEGORIES OF UNCERTAINTY

The categories of uncertainty provide structure for examining its affects in the natural world. However, before we can adequately study the levels of uncertainty, we must explicitly define the four terms. However, this research will only address three of the categories of uncertainty (ambiguous/missing, conflicting, and baseline). Examples are used to illustrate the differences between the aforementioned terms.

1. Ambiguous/Missing Information

Ambiguous/Missing data represents information that may be unavailable, but if available may be unclear or not critical to the decision. In other words, the decision maker may have information that is unnecessary to make an adequate decision, or may possess information that is very muddled and not explicit. Furthermore, the data may result in a choice between numerous alternatives. This last statement coincides with McCloskey and Klein's (1996) interpretation of complex information.

2. Conflicting Information

Conflicting data represents multiple sources of information that is contradictory in nature. Mathematically this is expressed by x is true, y is true, but x equals y is not true. An example is provided later in this chapter.

3. Unreliable Information

Unreliable data consists of information where the source possess very little or no credibility (McCloskey & Klein, 1996). The decision maker does not trust the source, or feels the source contains low fidelity. This type of information is the link between the technological and warfighter sides of the DMSC, because it is dependent on whether the operator views the system or the human as reliable (Shattuck & Miller, 2006).

4. Baseline Information

Baseline data represents information that is available, understood, and possesses negligible uncertainty.

5. Distinguishing the Definitions

Crafting understandable and distinguishable definitions for the categories of uncertainty was not a trivial task. Crafting suitable definitions involved discussions, much iteration, and multiple pilot studies to truly capture the essence of each category. Historical examples that illustrate the differences are provided below.

Ambiguous/missing information was presented to French General Napoleon Bonaparte at the Battle of Waterloo. On June 18th, 1815, the French army prepared to destroy the Duke of Wellington's English force. Days earlier, Napoleon defeated the Prussian Armies at Ligny. However, his victory over the Prussians came with a price. The Prussians headed east, away from French scouts. Without intelligence on important information such as location, heading, speed of advance, casualties, or intentions of the Prussian armies, the French general was placed in a difficult and frustrating position. Napoleon wanted to attack the left flank of the British forces, but the idea of the Prussian Army somewhere to his right flank was not only dangerous but unnerving (Keegan, 1978). The reality of the ensuing battle left the "genius" of Napoleon marginalized. The ambiguous nature of the Prussian whereabouts led Napoleon to conclude that a frontal attack was his best option (Keegan, 1978). Consequently, he was defeated, and forced to surrender.

In contrast, on October 1962, conflicting information was presented to President John F. Kennedy. On October 14, 1962, U.S. intelligence took photographs of Soviet Union nuclear, ballistic missiles in Cuba. The placement of nuclear weapons just hundreds of miles off the coast of Florida placed U.S. national security at grave risk. President Kennedy chose not to inform the Soviets of his discovery. Instead, the President and his advisor debated over alternatives for an appropriate response. However, on October 18th, President Kennedy met with the Soviet Minister of Foreign Affairs, Andrei Gromyko. When asked about the nature of Soviet weapons in Cuba, Soviet Minister Gromyko told President Kennedy that the Soviet Union weapons were of a defensive nature (Brugioni, 1991; Hilsman, 1996). While President Kennedy most likely immediately dismissed Gromyko's claim, the Soviet Minister of Foreign Affairs provided

the President with a classic example of conflicting information; either the Soviet Union did or did not have offensive weapons in Cuba. Consequently, President Kennedy had two alternatives that were contradictory in nature.

F. UNCERTAINTY TAXONOMY

The *uncertainty taxonomy* was developed to better understand the factors that create and reason with uncertainty in the battle space. Like the DMSC, the *uncertainty taxonomy* examines the factors that influence decision making under uncertainty (see Figure 5). While human cognition is responsible for comprehension and projection of uncertainty, multiple factors, including technological systems, communication, and individual differences shape the conditions in which uncertainty can arise. Consequently, the *uncertainty taxonomy* provides means for classifying uncertainty types and for suggesting viable areas of research to determine the impact of the uncertainty types on performance. In order to better explain the relevance of the *uncertainty taxonomy*, the researchers divided into two parts: (1) information flow (IF) and (2) individual difference factors (IDF).

Like the DSMC, information flow focuses on the projection of information or sources of information in the battle space. This structure parallels McCloskey and Klein's (1996) levels of uncertainty. The IF is not just limited to humans, but also machines. Conversely, IDFs focus solely on the human's abilities and cognition. This coincides with Shattuck and Miller's (2006) Lens A and Lens B in the DMSC. However, it is important to note, trust is the interlinking variable (unreliable information) in both the IF and IDF branches (i.e., how well does an individual trust one's self, in addition to, trusting the technology?).

The ultimate goal of the *uncertainty taxonomy* is to analyze these associations with respect to their influence on decision making. Consequently, the IDF section discusses the influence of experience and personality, and examines how individuals cope with uncertainty.

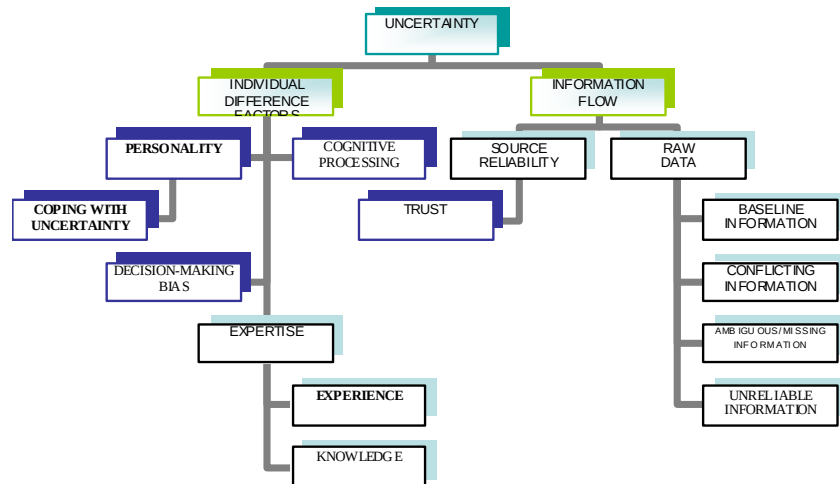


Figure 5. Uncertainty Association Taxonomy.

1. Information Flow

IF is critical in military operations. Whether at the team performance level or individual performance level, the efficiency and speed of IF can determine the outcome of the engagement. Without adequate IF, a unit or commander may be paralyzed or unable to make critical, time-sensitive decisions due to the inconsistency or unavailability of information. Consequently, the interactions of several factors contribute to the aggregate effectiveness of IF in conducting continuous operations.

a. Information Flow Interaction

The interaction of trust, data, sources, uncertainty, and communication is complex. Instead of viewing these terms as abstract, independent ideas, the research addressed them using a systems approach (i.e., rather than considering these terms individually, the present research addressed their interaction). First, uncertainty can result from the interaction of data and communication. Data can be in the form of ambiguous/missing information, conflicting information, unreliable information, or baseline information. Additionally, the communication of data can be the aforementioned categories of uncertainty. For example, if an Officer of the Deck (OOD) witnesses on radar two contacts off the starboard bow, and a sailor looking at the same input from a

different display reports three contacts off the starboard bow, then the *communication* of the data, not the *raw* data itself, is uncertain. Conversely, if the sailor witnesses three contacts off the starboard bow from a different input source on a different screen, then the *raw* data, not the *communication* of the data are uncertain.

Second, sources can be uncertain (i.e., a source, whether a system or human can be conflicting, unreliable, or ambiguous/missing). In addition to being uncertain, sources can possess the characteristic of trustworthiness. Kramer (1999) defines trust as “a state of perceived vulnerability or risk that is derived from individual’s uncertainty regarding the motives, intentions, and prospective actions of others on whom they depend” (p. 571). In other words, trust is an individual’s acceptance of the consequences for another’s (man or machine) actions.

Zand (1997) describes IF as a characteristic of trust. He discusses the effects of “[predisposed] beliefs” and “short-cycle feedback” loops (p. 94). He suggests that “people build a data bank, gathering impressions of other’s trustworthiness...these impressions are short-cycle feedback loops; they confirm or disconfirm” an individual’s trustworthiness (p. 94). Additionally, Yanik and Kleinberger (2000) suggest that decision makers are constantly correlating the quality of the advice given to the individual who gave them the advice.

Even in the absence of feedback loops, decision makers, as reflected in their advice weighing policies, are aware of the quality of the advice received (Yanik & Kleinberger, 2000). The researchers offer two suggestions for the phenomena: (a) decision makers “relied on ranges of estimates” to determine accuracy, and (b) decision makers may have performed “plausibility checks,” and “recognized that a particular estimate was out of bounds” (Yanik & Kleinberger, pg. 270). Not only does this suggest that trust relies on the acceptance of the consequences for another’s actions, but it also shows that prior knowledge or experience often guides decision makers.

2. Individual Difference Factors

While IF is critical to C2 at the operational level, IDFs translate into individual performance. IDFs consist of several elements, including both intrinsic and extrinsic

factors. Personality characteristics, knowledge, cognitive processing, social interaction, training, and experience all contribute to a decision maker's ability to perform (Miller, N.L., Crowson, J.J., & Narkevicius, J.M., 2003). Consequently, researchers must examine human behavior under various, unpredictable conditions to fully grasp and eventually predict human behavior (Miller et al., 2003).

How an individual responds to adversity, risk, or uncertainty may play a vital role in their choice of alternatives. This was the key question of the researchers' work, and for the scope of the study, they examined how individuals cope with uncertainty and how it related to their decision times. In the present study, the researchers focused on three aspects of specific IDFs: (a) operational experience, (b) personality characteristics (as measured by NEO Five Factor Indicator (NEO-FFI)), and (c) the ability to cope with uncertainty (as measured by Uncertainty Response Scale (URS)).

a. Operational Experience

An individual's competence is derived from his or her ability to transform prior experience to decisive action. Klein's (1997) research using the Recognition Primed Decision (RPD) model (Klein, Calderwood, & Clinton-Cirocco, 1985) supports this claim. Klein (1997) found that decision makers, in dynamic environments, mostly rely on past experience when deciding on their course of action. Kaempf, Wolf, Thordsen, and Klein (1992, as cited in Klein, 1997, p. 289) examined 78 cases of decision making on U.S. Navy AEGIS Cruisers, and estimated that in 78% of the cases the "decision maker adopted the course of action (COA) without any deliberate evaluation" (p. 289). This suggests that decision makers do not weigh alternatives, but rather choose based on prior experience (Kaempf et al., 1992; Klein, 1997).

St. John, Callan, Proctor, and Holste (2000) used Tactical Decision Games (TDG) to measure how uncertainty affects decision making among U.S. Marines. The researchers found that when facing increased uncertainty, the majority of less experienced Marine officers chose a "wait and see" option, while the more experienced officers did not (St. John et al., 2000). This study coincides with the findings of Serfaty, MacMillan, Entin, and Entin (1997), who found that participants with greater expertise in

a given field provided a more detailed COA compared to participants with less expertise. They concluded their findings “[were] consistent with the idea that experts are able to draw on previous experience to generate a more complete schema for the tactical situation” (Serfaty et al., p. 242).

In this study, experience is defined as operational experience. Operational experience is defined as months in an operational theatre (e.g., Iraq & Afghanistan). However, the researchers are confident that while all the participants received specialized training for their occupations, they also received common basic training. Consequently, each participant had enough training and experience to be evaluated in the study.

b. NEO-FFI

Experience is the most obvious extrinsic factor, but personality is also important when examining decision making under uncertainty. The NEO Personality Inventory has been the standard for research in personality traits and characteristics. However, unlike the NEO Personality Inventory, the NEO-Five Factor Indicator (NEO-FFI) only addresses the five major elements of personality, and not the different facets that accompany each (Costa & McCrae, 1992, & Hannon, 2007). For this study, the NEO-FFI was used to look at the relationship between personality and uncertainty. The five major elements of the NEO-FFI are the following:

- Openness (O)
- Agreeableness (A)
- Conscientious (C)
- Neuroticism (N)
- Extraversion (E)

(1) **Openness (O)** refers to individuals who are “open to experience” and “curious about both inner and outer worlds,” (Costa & McCrae, 1992, p. 15). Additionally, individuals who score high on O are not usually conservative in thought, but rather unorthodox thinkers with creative imaginations (Costa & McCrae, 1992). Under uncertainty, the researchers would expect a decision maker to not necessarily respond slower or faster, but rather adopt a clever, inventive decision.

(2) **Agreeableness** (A) refers to individuals who are “fundamentally altruistic” and “sympathetic to others and eager to help them,” (Costa & McCrae, 1992, p. 15). However, Costa and McCrae (1992) are quick to note, that agreeableness is not a preferred characteristic in occupations where one’s own self-interests may be at risk (e.g., military, police, firefighter). Consequently, in a sample pool involving military service members, one would not expect respondents to score high on A. Under uncertain conditions, the researchers would expect individuals who score high on A to respond quickly with sometimes irrational, if not brash, decisions.

(3) **Conscientiousness** (C) examines whether an individual is “purposeful, strong-willed, and determined,” (Costa & McCrae, 1992, p. 16). Additionally, Costa and McCrae (1992) suggest conscientiousness is somewhat analogous with character (i.e., individuals who possess high C scores are usually considered credible and in high moral stature). The researchers would expect individuals who score high on C would not necessarily respond faster or slower, but be very aware of both ethical and moral elements of their decisions, not to mention, self-reflective.

(4) **Neuroticism** (N) refers to the emotional stability of an individual (Costa & McCrae, 1992). Moreover, an individual who possess low N scores will usually be “calm, even-tempered, and relaxed,” (Costa & McCrae, 1992, p. 15). More importantly, they are able to deal with stressful environments (Costa & McCrae, 1992). Military officers often perform in complex, operational environments, therefore they would be expected to score low on N.

(5) **Extroversion** (E) examines whether or not an individual is “assertive, talkative, or active,” (Costa & McCrae, 1992, p. 15). Additionally, it explores whether an individual socializes in larger groups or even likes people in general (Costa & McCrae, 1992). Faced with uncertainty, individuals who score high on E would be quick, even aggressive, to make a decision. However, it is unknown whether their decision would be ill-thought or carefully calculated.

In conclusion, the NEO-FFI may provide insight into decision making under uncertainty. The different elements of personality may lend to increased

resolve when faced with uncertainty in a time-sensitive, stressful environment. However, we must explore whether these characteristics are congruent with the methods or techniques used to cope with uncertainty.

c. Coping with Uncertainty

Although experience and personality characteristics may influence a decision maker's choice of alternatives, perhaps another important measure may lie in how a commander responds emotional and cognitively to uncertainty. To explore this question, the Uncertainty Response Scale (URS) explores the effects of uncertainty from three, different perspectives: (1) emotional uncertainty (EU), (2) desire for change (DFC), and (3) cognitive uncertainty (CU) (Greco & Roger, 2001) (see Appendix A).

EU is defined as “the degree to which an individual responds to uncertainty with maladaptive behavior” (Sutton, Cosenzo, & Pierce, 2004). Higher scores on EU indicate an individual does not adapt well to uncertain situations (Thomas, 2005). Interestingly, Greco and Roger (2001) found a significant correlation between N and EU ($r = 0.56, p < 0.01$). Additionally, EU correlated significantly with Kirton's (1981) Tolerance to Ambiguity (TOA) ($r = 0.18, p < 0.01$). Consequently, we suggest individuals who score high on EU and N erratic response times in an uncertain, tactical environment.

DFC is classified as “the enjoyment of uncertainty, novelty, and change,” (Greco & Roger, 2001, p. 525). Higher scores on DFC indicate that an individual enjoys uncertainty or the unknown (Thomas, 2005). Greco and Roger (2001) found significant correlations between sub-elements of E (e.g., impulsivity and sociability). The researchers found a moderate association between DFC and impulsivity ($r = 0.37, p < 0.01$) and DFC and sociability ($r = 0.23, p < 0.01$). Unfortunately, these results give no insight into whether individuals with high E scores will perform adequately under uncertain conditions.

CU is described as the “degree to which an individual prefers order, planning, and structure in an uncertain environment,” (Thomas, 2005, p. 35). Higher scores on CU indicate that an individual desires control or organization in uncertain

situations (Thomas, 2005). Greco and Roger (2001) found a significant correlation between CU and TOA ($r = 0.37, p < 0.01$). Additionally, the researchers discovered a significant correlation between CU and N ($r = -0.20, p < 0.05$). Moreover, the E sub-element of impulsivity was significantly correlated to CU ($r = -0.25, p < 0.01$). As previously mentioned, military officers often operate in highly structured, yet complex, environments. Consequently, these results suggest officers scoring high in cognitive uncertainty may perform well when faced with uncertainty.

These significant correlations provide evidence of the important relationship between personality characteristics and an individual's method for coping with uncertainty. The URS has both high internal consistency reliability (EU = 0.91, CU = 0.87, DFC = 0.87) and test-retest reliability (EU = 0.79, CU = 0.80, DFC = 0.86), thus procuring credibility for future research. More importantly, Greco and Roger (2001) provide an excellent basis for inferring a relationship between uncertainty and personality characteristics. Their work has implications for the present research in tactical decision-making under uncertainty.

G. CRITICAL DECISION MAKING METHOD

Although the decision maker's choice of alternative is important to understanding his or her cognitive reasoning, it is not the focal point of this study. Instead, research efforts were directed toward discovering the impact of uncertainty on the commander's decision. This paradigm shift is the result of two objectives. First, the study of uncertainty was undertaken to determine "why and how" uncertainty affects the commander's lens. Secondly, the study was focused in discovering where uncertainty occurs in the tactical environment.

Until this point, this literature review has explored the "why" and "how" question, but not adequately addressed the "where." Consequently, before we can develop a methodology to test uncertainty in decision making, we must expose and unearth uncertainty in the battle space, (i.e., in the ovals in the DMSC) (Shattuck and Miller, 2003). In simpler terms, we must find a process to elicit uncertain situations in the operational world.

Klein et al. (1989) developed the elicitation process of Critical Decision Method (CDM). The techniques of examining cases based on non-routine events by cognitive probes and maintaining a semi-structured approach allow researchers to uncover the methods and reasoning behind an individual's decision. These techniques follow a top-down approach to determine how and why a decision maker chose an alternative. More importantly, as Klein et al (1989) points out, CDM provides a method for evaluating performance to better assist in identifying training requirements. Consequently, CDM is a powerful tool in reconstructing naturalistic events in the hopes of creating more realistic and efficient models for training simulations.

While Klein's interest lies in the decision maker's cognitive reasoning, CDM was modified in this study to elicit the presence of uncertainty in the battle space. Developed by Dr. Lawrence Shattuck, the modified CDM follows the outline presented by Klein et al (1989), but instead uses cognitive probing techniques to unearth the presence (i.e., the "where") of uncertainty in the participant's recollection of events (see Appendix B). Consequently, the decision becomes secondary in the process. This alteration allows the researchers to categorize the witnessed uncertainty using the definitions provided in Chapter II.F. Moreover, it enables a clear examination of the chronological events prior to and after uncertainty appears in the equation.

H. HYPOTHESES

This literature review has uncovered many important questions in the field of tactical decision-making under uncertainty. The questions have been narrowed to those deemed most important. The alternative hypotheses generated from those questions are listed below.

- H_{a1} : There is a significant difference in the overall total time with respect to the three categories of uncertainty.
- H_{a2a} : There is a significant, positive correlation between emotional uncertainty and overall total time for ambiguous/missing information and conflicting information.
- H_{a2b} : There is a significant, negative correlation between cognitive uncertainty and overall total time for ambiguous/missing information and conflicting information.

- Ha₃: There is a significant, negative correlation between operational experience and overall total time for ambiguous/missing information and conflicting information.

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III. METHOD

Research began in January 2007. Over the past 18 months three small scale pilot studies were conducted. The results shaped the methods used in the main study. This section contains short, concise descriptions of the three pilot studies, in addition to, lessons derived from their results. Finally, the main study method will be outlined.

A. PILOT STUDIES

This section addresses the pilot studies conducted by the researchers. Each pilot study focused on the research questions outlined in Chapter II.C. It is important to note, the latter pilot studies built off the successes and failures of the preceding studies. Consequently, they will be discussed in chronological order.

1. Pilot #1 - Ambiguous Words

In the first pilot study, a research team, consisting of Naval Postgraduate School (NPS) students, attempted to: (1) operationally define ambiguity, and (2) design a study to test its effects on decision-making with respect to the time it takes to make a decision. After a review of the literature, the team began developing models to understand uncertainty. The team considered the research of McCloskey and Klein (1996) as the most robust definition of ambiguity and uncertainty. Their work provided the basis to design an experiment examining uncertainty at the fundamental level.

a. Participants

Thirty-two NPS students (30 male, 2 female) volunteered to participate in the initial pilot study. All participants were commissioned officers, who were in the process of earning their master's degree. Of the group, twenty-nine participants had 20/20 vision, while only three reported being colorblind. The colorblind participants were omitted from the results. No compensation was given for their participation.

b. Method

The participants were shown numerous Microsoft PowerPoint slides with a word in pink letters (see Appendix C). The words were drawn from the American National Standards Institute (ANSI) Standard S3.2-1989, *Method for Measuring the Intelligibility of Speech over Communications System* (2005). Transposed over the pink letters was a rectangular pink square, which was adjusted for resolution to create different severities of ambiguity (high, medium, low). The participants were given four choices and asked to match the word shown on the slide to a word on their answer sheet. Confidence was measured by survey using a Likert scale. Time to decision (time to decision) was measured by an electronic timer embedded in the software. Participant accuracy was determined by grading the correctness of their responses.

c. Results

The researchers analyzed three separate aspects of the data using a within subjects design. First, using ANOVA, the researchers found a significant difference between the three severities of ambiguity (high, medium, low) with respect to time to decision ($F(2, 320) = 76.20, p < 0.001$). Next, the researchers used non-parametric measures (contingency analysis) to determine the relationship between confidence and ambiguity severity level. As expected, they found a higher percentage of “less confident” participant responses when presented with the “high” severity of ambiguity compared to medium and low severities. Finally, the researchers analyzed the accuracy rates of the three severities of uncertainty. They discovered the following: High = 85.6%, Medium = 96.9%, Low = 99.7%.

d. Discussion

Overall, the study provided an initial approach to the topic of uncertainty and ambiguity. The results suggest that ambiguity severity affects response time. Additionally, the results infer that accuracy and confidence are degraded by the presence of ambiguity. Unfortunately, the study did not address whether ambiguity and uncertainty

were, in fact, synonymous terms. If ambiguity and uncertainty are not synonymous, then how are they different (or differentiated)? Is one subsumed by the other? Are there other categories that are separate but related?

While these questions were important to answer, another need slowly emerged from the study. When the results from the first pilot were presented to military officers and civilian officials, they questioned the relevance and realism of the stimuli (i.e., how does the study link to the ambiguity seen by commanders on the battlefield?). Consequently, the researchers returned to the NDM literature to find examples (solutions) of real-world, operational environments. Additionally, the results and conclusions from the first pilot study moved the researchers to develop two distinct goals for the subsequent pilot study: (1) to develop a better operational definition of uncertainty, and (2) to design a study that incorporates a relevant military setting.

2. Pilot #2 - Operational Intelligence

For the second pilot study, the research team expanded the scope of research. McCloskey and Klein (1996) suggest that four categories of uncertainty in the realm of uncertainty. They described them as follows: (1) missing information, (2) complex information, (3) ambiguous/conflicting, and (4) unreliable information (McCloskey and Klein, 1996).

However, the researchers' experience in tactical environments led them to believe ambiguous/conflicting were two separate categories. Additionally, the idea of complex information seemed too abstract to operationally define given a relatively short timeline. Moreover, complexity seemed inherent in uncertainty (i.e., complexity was proportional to uncertainty). Consequently, the research team opted to evaluate three categories: (1) missing information, (2) conflicting information, and (3) ambiguous information.

a. Participants

Thirty-four participants from NPS, which included 14 naval officers, 5 Marine Corps officers, 6 army officers, 5 foreign military officer, and 4 civilians

participated in the second pilot study. They ranged from two to twenty years of military service and were not compensated for their participation.

b. Method

The participants were placed in an operational situation. They were briefed on a hostage crisis involving several senior U.S. State Department officials, including the Secretary of State. The experimenters explained that intelligence agents had placed three GPS transmitters on key hostage personnel in preparation for a hostage rescue mission. The three GPS transmitters each displayed a single shape (circle, triangle, square) on a 3 x 3 targeting grid (see Figure 6).

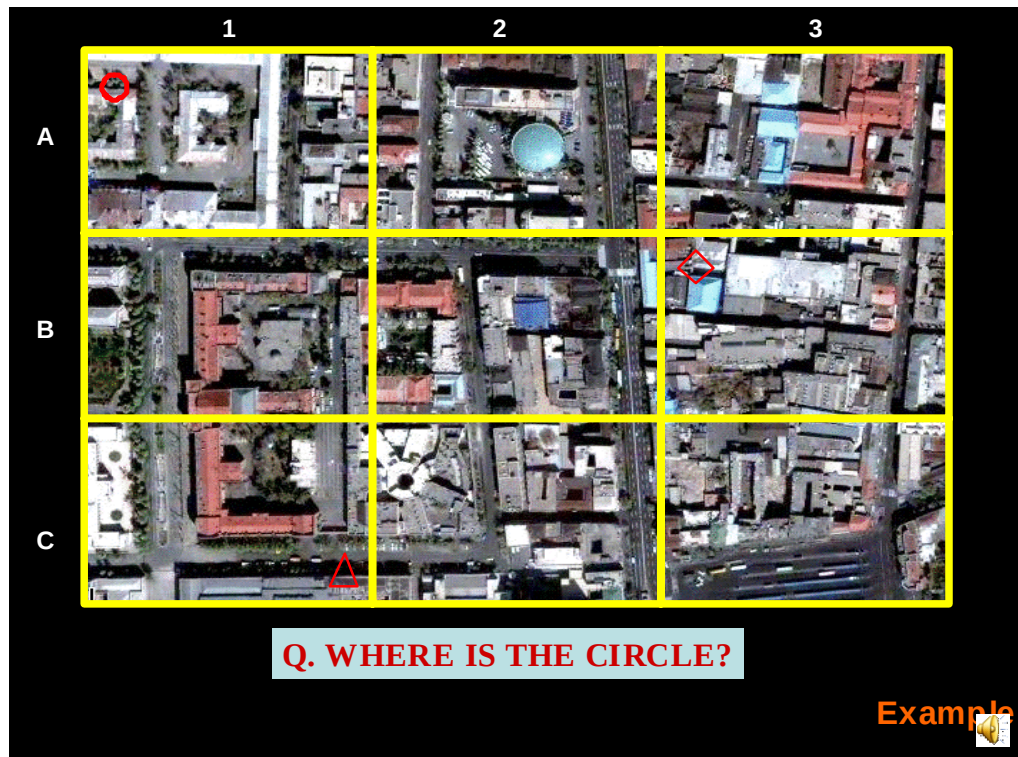


Figure 6. Pilot Study #2 Situational Display.

Each participant was shown 20 slides that contained the shapes under the four categories of uncertainty (conflicting information, baseline information, ambiguous information, missing information) (see Appendix D). Each slide asked a question relating to the location of a shape. Each scenario was displayed for a total of twenty seconds, and

the question appeared with ten seconds remaining. The participant was then required to analyze the scenario and answer the question to the best of his or her ability. A ten second interstitial slide was displayed to allow the individual to indicate his or her certainty response level on a corresponding Likert scale. The Likert Scale ranged 1 to 9 with 1 corresponding to “not at all certain” and 9 corresponding to “100% certain.”

c. Results

The researchers collected three sets of data: (1) certainty response level (Likert Scale), (2) grid location choice, and (3) NEO-FFI. Non-parametric statistics were used to analyze the certainty response levels, while Pearson correlation coefficient was used for the NEO-FFI and response time data. The researchers found a significant difference between the four categories of uncertainty (see Table 1), but did not find a significant correlation to any of the five factors of the NEO-FFI.

	Miss - Base	Con - Base	Amb - Base	Con - Miss	Amb – Miss	Amb - Con
Z	-5.388	-4.773	-5.127	-5.127	-4.874	-3.359
Asymp. Sig. (2-tailed)	.000	.000	.000	.000	.000	.001

Table 1. Sign Test for Categories of Uncertainty.

The study suggests that individuals differ in their degree of certainty with respect to the category of uncertainty. Individuals appear to be less certain when faced with ambiguous information than with conflicting information (i.e., individuals would rather have a choice between two alternatives vice a choice amongst many or unknown alternatives).

d. Discussion

The results from Pilot Study #1 and Pilot Study #2 produced another important question. If the categories of uncertainty contribute to significant differences in certainty response levels and if different severities for ambiguity lead to significant

differences in time (see Chapter III.A.1), then will different categories of uncertainty cause significant differences in time? To answer this question the research team developed realistic tactical vignettes for each category of uncertainty.

3. Pilot #3 - Tactical Decision Environments

a. FT Leavenworth, KS

(1) **Participants.** Interviews were conducted at Command General Staff College (CGSC), FT Leavenworth, KS, using the modified version of Klein's (1996) CDM (see Chapter I.G.). The participants consisted of 20 U.S. Army officers (2 females and 18 males with a mean age of 36.9 years). Nineteen participants held the rank of O-4 or Major, while one participant held the rank of O-3 or Captain. The participants had an average of 16.0 years of military service and 13.1 years of commissioned service. These averages suggest many participants served in the enlisted ranks prior to earning a commission. Additionally, the participants had an average of 15.5 months of deployment time post September 11th, 2001 (i.e., the participants had a creditable amount of operational experience in the War on Terror)

(2) **Method.** To begin the knowledge elicitation, the researchers used the following paragraph as their primary inquiry:

Recall a tactical situation during a recent deployment to a combat zone in which you were confronted with uncertainty and had to make a decision. Uncertainty can be described simply as a sense of doubt that blocks or delays action. There are no right or wrong answers and we are in no way evaluating your performance or the decisions you made.

Each participant was asked to provide two situations or scenarios. Additional follow-on questions used for data elicitation can be found in Appendix B. These questions were used to explore the uncertainty in the described situation.

The researchers analyzed the scenarios described by the participants. The majority of the incidents of uncertainty recalled were categorized as ambiguous. Two scenarios were selected and modified for the data collection at NPS. The researchers created four versions of each scenario (i.e., conflicting, missing, ambiguous, and baseline) for a total of eight situations.

b. Naval Postgraduate School

(1) **Participants.** The participants at NPS consisted of 17 officers, including one female and sixteen males with an average age =32.5 years. Nine participants were U.S. Navy officers, three were U.S. Army officers, one was a U.S. Air Force officer, one was a Canadian Air Force officer, and three participants were Turkish Air Force officers. Six participants held the rank of O-4, 10 held the rank of O-3, and one participant held the rank of O-2. None of the participants were compensated.

(2) **Method.** Each participant saw a total of eight slides. They were given two pieces of information: (1) operational order (OPORD) information and (2) additional information (AI). The OPORD provided data on the situation, enemy forces, friendly units, terrain, and tactical situation. The additional data provided real time intelligence, including enemy movement, enemy killed, and situational reports (SITREPS).

The OPORD first appeared followed by the AI. All the information was present within 24 seconds of scenario commencement; thus, the participant had direct access to all information available to make a decision. Once a decision was made, the participant pressed the space bar, which recorded the total time from beginning to end. However, the total time was then subtracted by 24 seconds to produce time to decision.

After the participant pressed the space bar, the interviewer, located in the same room, asked the participant to: (1) provide a brief description of the decision, and (2) list any contributing factors to the decision? The researchers took written notes of the participant's responses. Digital voice recorders (DVRs) recorded each session. The quality and accuracy of their answers were not analyzed.

(3) **Results.** The researchers analyzed the difference scores of time to decision for each category of uncertainty. The distributions of the difference scores of time to decision for each category of uncertainty violated the normality assumption, thus non-parametric tests were conducted for analysis.

First, the researchers conducted an analysis to determine whether or not a learning effect occurred between Situation 1 and Situation 2. Due to the small sample size, the researchers set alpha (α) at 0.10. They discovered a significant learning effect between Situation 1 and Situation 2 ($p = 0.09$). Consequently, the researcher did not analyze Situation one data. Instead, they analyzed Situation two data by taking the difference scores from each category of uncertainty and subtracting it from the baseline for each participant (e.g., ambiguous information time to decision – baseline information time to decision = delta (ambiguous information, baseline information)).

The researchers found a significant difference between the difference scores for ambiguous information compared to conflicting information ($p = 0.097$). Additionally, they discovered a significant difference for conflicting information compared to baseline ($p = 0.073$). The researchers did not find a significant difference between missing and ambiguous information ($p = 0.52$).

(4) **Discussion.** The pilot study identified issues that needed reconciliation prior the final empirical study. First, the learning effect discovered between Situation 1 and Situation 2 revealed the need for several different, independent situations along with randomization. Consequently, the researchers incorporated this approach into their final study. Secondly, although “jointness” is often emphasized in the conduct of U.S. military operations, many of the participants were naval officers vice army officers, thus some terms were unfamiliar to the Naval officers. Therefore, the researchers determined that they needed a sample group that shared a common language and experience. Additionally, a list of acronyms was necessary to properly identify terms. Thirdly, the OPORD and AI was found to be too broad and generalized, thus being interpreted as “not real enough.” The researchers enlisted the help of a group of active duty or retired Army personnel to craft better, more detailed vignettes.

Finally, and most importantly, the data suggested that ambiguous information and missing information were statistically the same, thus the researchers (as discussed in Chapter II.E) crafted new definitions and categories of uncertainty. These definitions became the final definitions for the CGSC empirical study.

B. CGSC EMPIRICAL STUDY

1. Independent Variables

- Category of Uncertainty – ambiguous/missing information, conflicting information, baseline information.
- Block Number (Randomization) – Block 1, Block 2, and Block 3.
- Difficulty – mean difficulty rating calculated through inner rater reliability testing.

2. Dependent Variables

- Overall Total Time (OTT) – the elapsed time from commencement of scenario to end of scenario.
- Situation time (ST) – the elapsed time from the commencement of the scenario to the when the participant requests the additional information.
- Additional time (AT) – the elapsed time from the time the participant requests additional information to when they finish reading the additional information.
- Situation/Additional Total Time (SATT) – the elapsed time from the commencement of the scenario to when the participant finishes reading the additional information.
- Time to Decision (TTD) – the elapsed time from when the participant finishes reading the additional information to when they inform the researcher they have made a decision.
- Time to Decision/Additional Total Time (TTDAT) – the elapsed time from when the participant requests additional information to when they inform the researcher they have made a decision.
- Uncertainty Response Scale Scores – the scores for the three categories of the URS (emotional uncertainty, cognitive uncertainty, desire for change uncertainty).

Overall total time, cognitive uncertainty, and emotion uncertainty scores are the primary metrics of the study. The other variables are secondary metrics used to discover and explain differences in the outlined hypotheses.

3. Participants

The participants consisted of 28 students attending the CGSC, FT Leavenworth, KS. There were 28 males with an average age of 37 years and an average commissioned service time of 13 years. Twenty-seven participants held the rank of Major (O-4), and one

participant held the rank of Lieutenant Colonel (O-5). With respect to their branch type, 14 served in Combat Arms (CA), 9 served in Combat Support (CS), and 5 served in Combat Service Support (CSS).

Participants were treated in accordance with the “Ethical Principles of Psychologists and Code of Conduct” (American Psychological Association, 1992). The NPS Institutional Review Board (IRB) and CGSC Quality Assurance Office Survey Control approved the research methods used for the experiment; all participants signed voluntary consent forms and audio/video consent forms prior to participation.

4. Materials and Apparatus

a. Demographic Survey

The demographic survey asked for information on age, military service, commissioned service, branch, and operation deployment time. Because the study focused entirely on U.S. Army officers, the questions were limited to the specified service.

b. NPS Decision-Making Study

From the lessons learned in the pilot study and the situations depicted by the CDM interviews, ten vignettes were crafted by members of U.S. Army Training and Doctrine Command, FT Leavenworth (TRAC-FLVN), and U.S. Army Training and Doctrine Command, Monterey (TRAC-MTY). The ten vignettes consisted of three ambiguous/missing information vignettes, three conflicting information vignettes, and four baseline information vignettes (see Appendix E).

The vignettes were given to retired U.S. Army service members working at TRAC-FLVN for reliability screening. Each evaluator was given the definitions listed in Chapter II.E, and the ten vignettes. The evaluators were instructed to answer three questions: (1) what category best describes the uncertainty in scenario, (2) how difficult would it be to make a decision in this scenario, and (3) how difficult was it to classify the category of uncertainty?

After several iterations, the researchers achieved 90% reliability for 9 out of the 10 vignettes. Consequently, the researchers used those 9 vignettes for the study (e.g., (3) ambiguous/missing vignettes, (3) conflicting vignettes, and (3) baseline vignettes). Additionally, the researchers achieved high inter-rate reliability for the level of difficulty ($\kappa = 0.81$). The level of difficulty was different for each scenario (see Table 2), and discussed and analyzed in Chapter IV. The vignettes were counter-balanced and given randomly to the participants.

<i>Category</i>	<i>Difficulty Mean</i>
<i>Ambiguous/Missing 1</i>	3.4
<i>Ambiguous/Missing 2</i>	4.7
<i>Ambiguous/Missing 3</i>	3.6
<i>Baseline 1</i>	2.5
<i>Baseline 2</i>	2.3
<i>Baseline 3</i>	1.4
<i>Conflicting 1</i>	4.1
<i>Conflicting 2</i>	2.9
<i>Conflicting 3</i>	4.2

Table 2. Scenario Difficulty Means for the Categories of Uncertainty.

Each slide contained two segments of information: (1) situation information, and (2) additional information. The situation information contained information on mission, enemy size, friend forces, and environment. The additional data provided real-time, battle space intelligence. For all vignettes, the situation information and additional information possessed approximately the same amount of data (see Appendix E).

The researchers collected data on five different time intervals: (1) overall total time, (2) time to decision, (3) situation time, (4) additional time, (5) situation time/additional time, and (6) time to decision/additional time. Further explanation of these times is discussed in Chapter III.B.2.

Stopwatches were used as the primary means of recording the times. The secondary means were DVRs. Training “clickers” were used to make distinguishable sounds for data analysis. The vignettes were presented using Microsoft PowerPoint, and

displayed on a 52 inch flat, plasma screen television. The study was conducted in Lewis and Clark Memorial Hall, 2nd floor, at CGSC FT Leavenworth, KS (see Figure 7).



Figure 7. Photograph of CGCS Study.

c. *Uncertainty Response Scale (URS) Survey*

As described in Chapter II.F.2, the URS explored the various ways individuals cope with uncertainty. The URS data were used to help explain differences in performance across participants.

d. *Operational Experience*

Operational experience was collected by the aforementioned surveys. Operational experience was measured by months in Afghanistan, months in Iraq, and total number of months in Iraq and Afghanistan. Participants with no operational experience in both theatres were omitted from the study.

5. Design and Procedure

The study was a within subjects design. Upon entering the room, participants signed an Informed Consent Form and an Audio/Visual Consent Form. The participants were seated at a desk approximately five feet from the television screen. Next, they were asked to read an instruction sheet aloud (see Appendix F). Then, the participants were shown a slide with various assumptions about the tactical environment (see Figure 8). Subsequently, the participants completed an example slide. Lastly, the participants were shown 9 slides and times were recorded as mentioned previously. Each scenario proceeded in the following manner:

IMPORTANT

- You will given a total of 10 scenarios; 1 example scenario and 9 evaluated scenarios.
- For all scenarios, the following is true:
 - 1) Your units are properly equipped and capable of accomplishing the mission.
 - 2) If you are an advisor, consider your advice equal to decision.
 - 3) Your command climate allows you to make decisions at your level.
 - 4) The scenarios are not connected in any way. They are independent, so consider every decision made in each scenario as separate and distinct from any other scenario.

Figure 8. Tactical Decision-Making Assumptions.

First, the participants were shown the situation information and the time started. The participants read the situation data aloud. When they were ready to receive the additional data, they snapped the training clicker. The training clicker was used to facilitate the analysis of the DVR data after the experiment (i.e., the training clicker created a sound with greater amplitude than a normal speaking voice, thus making it easier to identify the various dependent variables associated with time).

When the participants snapped their clicker for the additional data two events occurred: (1) the experimenter logged their time (situation time) and (2) the additional data was presented to the participants. However, it is important to note, that the situation data remained displayed, so the participant had access to all presented information.

Second, when the additional data appeared, the participant read the additional data aloud. When the participants finished reading the last word of the additional data, the experimenter logged their time.

Third, when the participants were ready to make a decision, they were asked to snap their training clicker. Upon snapping their training clicker, the experimenter logged their time. Thus, a total of three times were logged, and used to calculate the various times noted (see Figure 9).

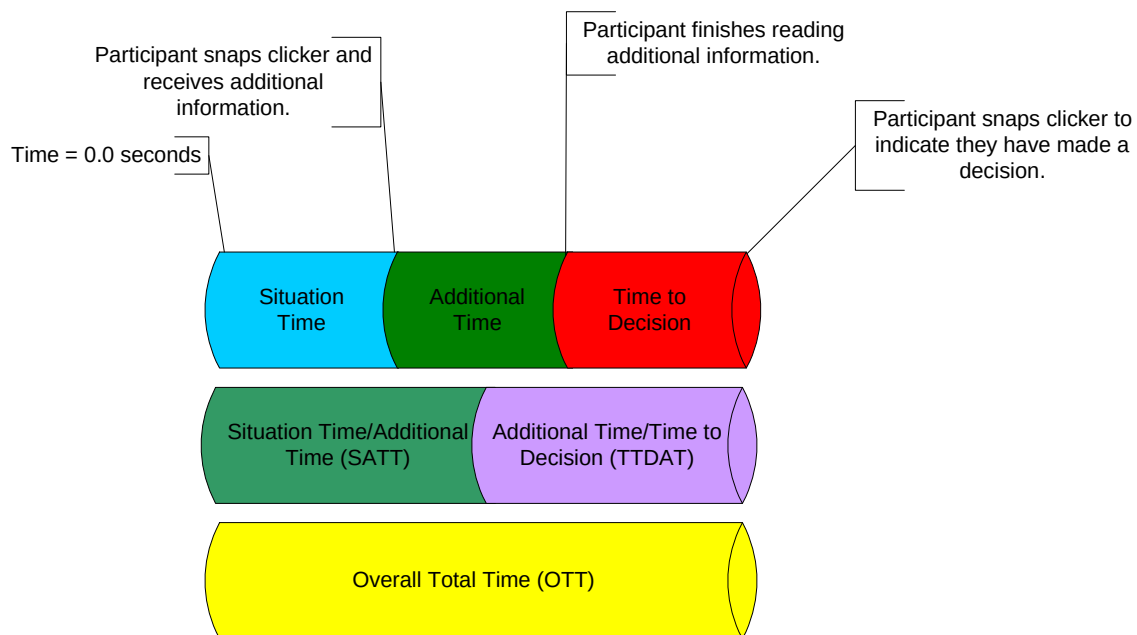


Figure 9. Tactical-Decision-Making Assumptions.

Finally, the participant was asked to answer two questions: (1) what is your decision, and (2) how did you arrive at your decision? The participants' answers were recorded on DVRs, and later transcribed for evaluation.

Upon completion of the NPS tactical decision-making study, the participants completed two surveys. First, they completed the URS. The title of the survey was not listed on the paper. Next, the participant completed the demographics survey explained in Chapter II.C.4. To ensure all documents and exercises were completed, the experimenter completed and signed an interviewer checklist.

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IV. RESULTS

The results consist of four parts: (a) summary statistics for categorical uncertainty, (b) summary statistics for URS, (c) summary statistics for operational experience, and (d) statistical analysis for the associations between categorical uncertainty, URS, and operational experience. Descriptive statistics are provided in parts a, b, and c. Inferential statistics are used in all parts to analyze differences across the categories of uncertainty with respect to time, along with appropriate correlations between variables where necessary. Due to discovered differences in the recorded times, between the stopwatches and DVRs, the researchers opted to use the DVR times for statistic analysis.

A. SUMMARY STATISTICS FOR CATEGORICAL UNCERTAINTY

For description purposes, additional time, situation time, and time to decision will be referred to as the *adjoined times*. *Adjoined* emphasizes that these times follow a chronological order (i.e., they are linked by one ending and the next beginning). Consequently, situational time is followed by additional time which is followed by time to decision. Additionally, situation time/additional time and time to decision/additional time will be referred to as the *interrelated times*. *Interrelated* emphasizes that these times overlap, and that they both use additional time in their calculation. Moreover, overall total time will be referred to as the *decision time*. The decision time is the total summation of the adjoined times. This terminology was developed to simplify reporting the results. Overall total time serves as the variable of primary analysis. The interrelated and adjoined times are supplementary analysis that will be used to better explain the differences in overall total time.

1. Descriptive Statistics for Categorical Uncertainty

For the adjoined times, ambiguous/missing information had the largest mean for situation time and time to decision, while conflicting information had the largest mean for additional time (see Table 3). Additionally, ambiguous/missing had the largest standard deviation (SD) across all the adjoined times. For overall total time, ambiguous/missing had the largest mean along with the largest SD.

	Ambiguous/Missing	Baseline	Conflicting
<i>ST</i>	51.7 (SD = 12.2)	36 (SD = 8.6)	35.4 (SD = 8.3)
<i>AT</i>	25.2 (SD = 2.7)	24.2 (SD = 3.5)	27.1 (SD = 3.7)
<i>SATT</i>	76.9 (SD = 13.3)	60.2 (SD = 10.8)	62.5 (SD = 9.9)
<i>TDDAT</i>	43.1 (SD = 16.7)	38.5 (SD = 15.6)	41.2 (SD = 11.7)
<i>TTD</i>	18 (SD = 15.9)	14.3 (SD = 13.5)	14.1 (SD = 9.4)
<i>OTT</i>	94.8 (SD = 25.6)	74.8 (SD = 21.6)	76.4 (SD = 17.9)

Table 3. Categorical and Time Segment Means and Standard Deviations for CGSC Study (seconds).

2. Inferential Statistics for Categorical Uncertainty

The data violated the normality assumption, thus non-parametric analysis was conducted to compare the categories of uncertainty with respect to time. To evaluate the times for each participant, the researchers calculated the means for each participant in each category of uncertainty. Each participant had mean times for each category of uncertainty for each segment of time. The researchers used the times and difficulty scores to determine whether difficulty was a significant factor in determining response time.

a. Decision Time

For overall total time, the researchers discovered significant differences amongst two of the categorical pairs of uncertainty: (1) ambiguous/missing information was significantly greater than conflicting information ($p < 0.01$), and (2) ambiguous/missing information was significantly greater than baseline information ($p < 0.01$). Conversely, the researchers did not find a significant difference between conflicting information and baseline information ($p = 0.06$) (see Table 4).

	Mean(OTT, Baseline)- Mean(OTT, Ambiguous/Missing)	Mean(OTT, Conflicting)-Mean(OTT, Ambiguous/Missing)	Mean(OTT, Conflicting)- Mean(OTT, Baseline)
<i>Test Statistic</i>	-181	-184	80
<i>Prob > z </i>	<.0001	<.0001	0.0674

Table 4. Wilcoxon Sign-Rank Analysis for Overall Total Time.

The researchers found a significant, positive correlation between all the categories of uncertainty for overall total time: (1) ambiguous/missing information and conflicting information ($r = 0.87, p < 0.01$), (2) ambiguous/missing information and baseline information ($r = 0.84, p < 0.01$), and (3) conflicting and baseline information ($r = 0.8, p < 0.01$) (see Figure 10). Hence, if a participant responded quickly to one category of uncertainty, he/she would respond quickly to the other categories of uncertainty.

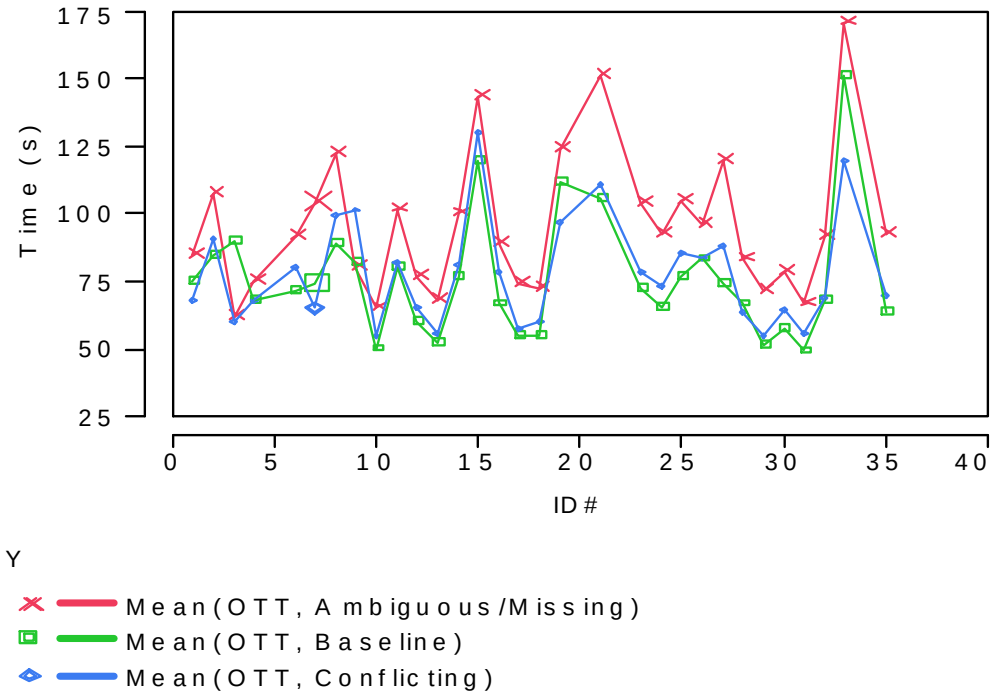


Figure 10. Participant Mean Overall Total Time for the Categories of Uncertainty.

Regression analysis revealed that scenario difficulty was a significant predictor for ambiguous/missing overall total time ($p < 0.01$), but not a significant predictor for conflicting overall total time ($p = 0.99$) and baseline overall total time ($p = 0.95$) (see Figure 11).

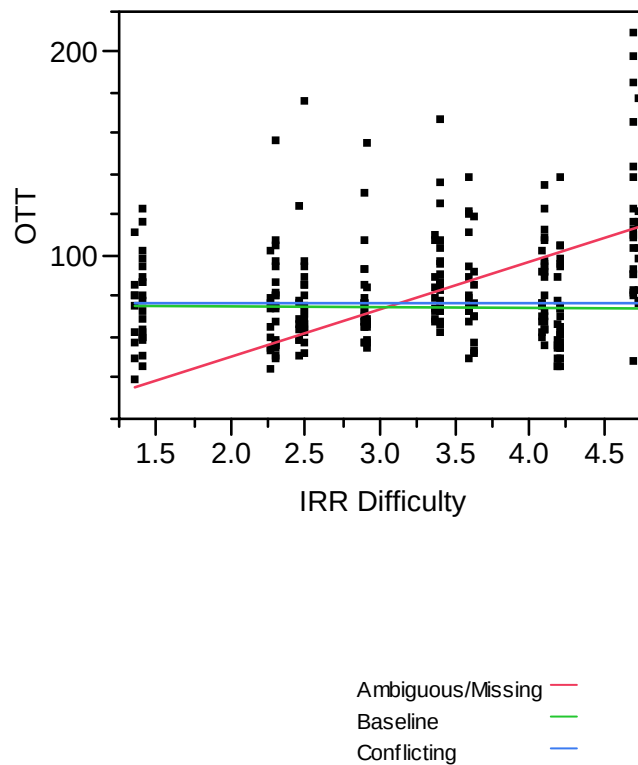


Figure 11. Regression Plot for Inter-Rater Reliability Difficulty and Overall Total Time.

b. Adjoined Times

For situation time ambiguous/missing information was significantly greater than conflicting information ($p < 0.01$), and significantly greater than baseline information ($p < 0.01$). However, there was no significant difference between conflicting information and baseline information ($p = 0.45$). Furthermore, scenario difficulty was a significant predictor for ambiguous/missing situation time ($p < .01$), but not a significant predictor for conflicting situation time ($p = 0.12$) and baseline situation time ($p = 0.33$) (see Figure 12).

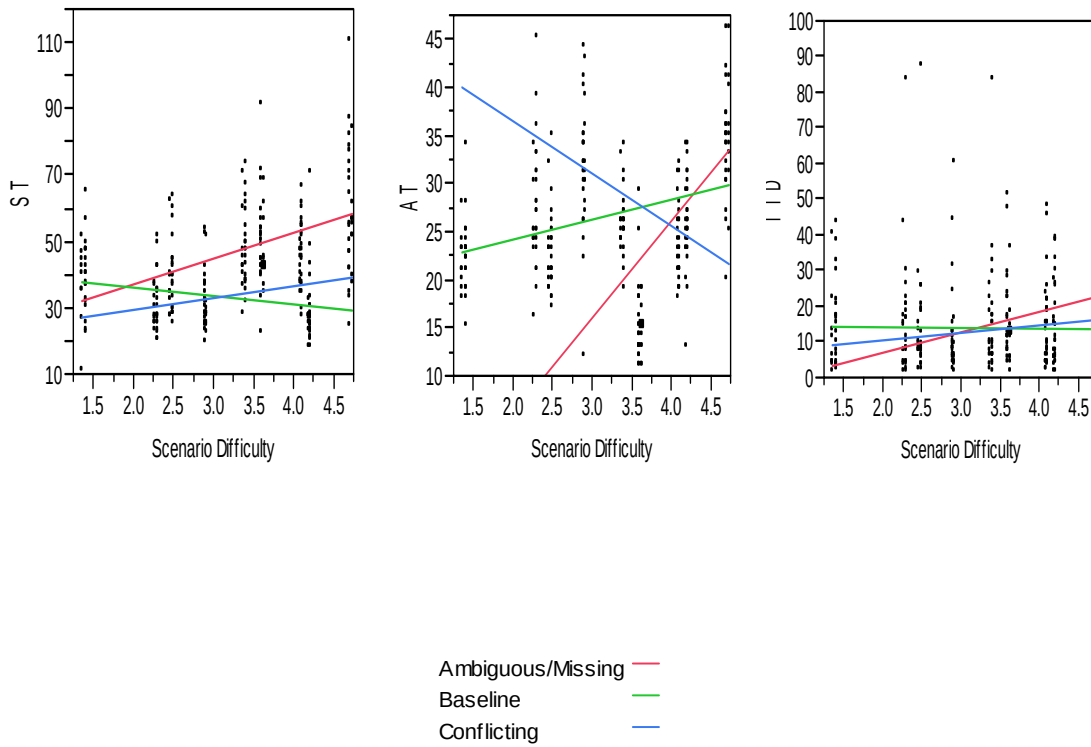


Figure 12. Regression Plot for Scenario Difficulty for Adjoined Times.

For additional time, baseline information was significantly less than conflicting information ($p < 0.01$), in addition to, ambiguous/missing information being significantly less than conflicting information ($p < 0.01$). However, there was no significant difference between ambiguous/missing information and baseline information ($p = 0.10$). Furthermore, scenario difficulty was a significant predictor for ambiguous/missing additional time ($p < 0.01$) and conflicting additional time ($p < 0.01$), but not a significant predictor for baseline additional time ($p = 0.07$).

For time to decision, ambiguous/missing information was significantly greater than baseline information ($p < 0.01$). Conversely, there was no significant differences between ambiguous/missing information and conflicting information ($p = 0.10$) or conflicting information and baseline information ($p = 0.32$) (see Figure 13). Interestingly, scenario difficulty was not a significant predictor for time to decision.

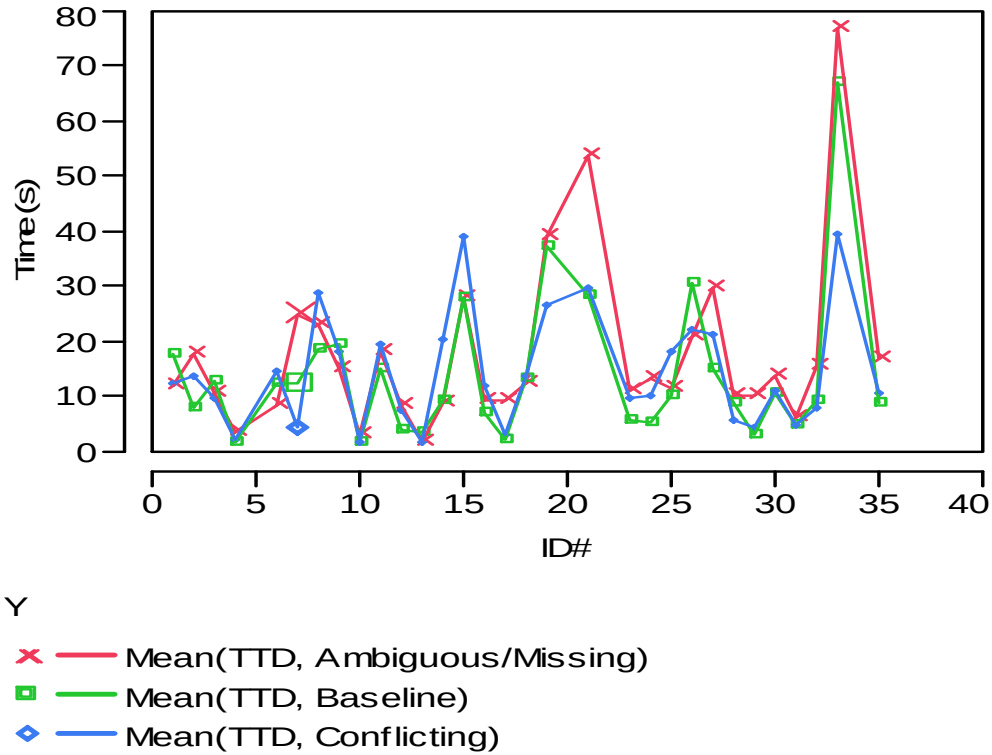


Figure 13. Participant Mean Time to Decision for the Categories of Uncertainty.

c. *Interrelated Times*

For situation time/additional time, the researchers found significant differences between all three categories of uncertainty: (1) ambiguous/missing information was significantly greater than conflicting information ($p < 0.01$), (2) ambiguous/missing information was significantly greater than baseline information ($p < 0.01$), and (3) conflicting information was significantly greater than baseline information ($p < 0.01$). For time to decision/additional time, the researchers found two significant differences: (1) ambiguous/missing information was significantly greater than baseline information ($p < 0.01$) and (2) conflicting information was significantly greater than baseline information ($p < 0.01$). Additionally, scenario difficulty was a significant predictor for both ambiguous/missing information situation time/additional time and ambiguous/missing information time to decision/additional time. However, it was not a

significant predictor for conflicting information situation time/additional time, conflicting information time to decision/additional time, baseline information situation time/additional time, and baseline information time to decision/additional time.

d. Within Category Times

For ambiguous/missing information, the researchers found a significant, positive correlation between situation time and time to decision ($r = 0.54, p < 0.01$). However, there were no significant correlations between situation time and additional time ($r = 0.34, p = 0.08$) and between additional time and time to decision ($r = 0.22, p = 0.24$).

For conflicting information, the researchers found two significant correlations: (1) situation time and time to decision ($r = 0.64, p < 0.01$) and (2) additional time and time to decision ($r = 0.50, p < 0.01$). However, no significant correlations were found between additional time and situation time ($r = 0.26, p = 0.17$).

For baseline information, the researchers found significant, positive correlations between all three time segments: (1) situation time and additional time ($r = 0.49, p < 0.01$), (2) situation time and time to decision ($r = 0.53, p < 0.01$), and (3) additional time and time to decision ($r = 0.51, p < 0.01$).

B. SUMMARY STATISTICS FOR UNCERTAINTY RESPONSE SCALE

URS data was produced through a scoring system on a Likert Scale, thus non-parametric tests (Spearman's Rho) were used to determine correlation. Additionally, descriptive statistics provide means, medians, and standard deviations for each category of the URS. For this study, EU served as the primary metric of analysis. CU and DFC were recorded for supplementary analysis and future research.

1. Descriptive Statistics for URS

CU had the highest mean score of 62 ($SD = 8$), while EU had the lowest mean score of 32 ($SD = 7$). Additionally, DFC produced a mean score of 59 ($SD = 7$). The median score for CU was 64, while the median score for EU was 33. DFC had a median

score of 58. The small standard deviations coupled with the medians being relatively close to the means suggest a small amount of variance amongst the URS scores (see Table 5).

Category	EU	DFC	CU
<i>Mean</i>	32	59	62
<i>Standard Error</i>	1	1	2
<i>Median</i>	33	58	64
<i>Standard Deviation</i>	7	7	8
<i>Sample Variance</i>	50	55	65
<i>Kurtosis</i>	0	2	0
<i>Skewness</i>	0	-1	0
<i>Range</i>	29	37	31
<i>Minimum</i>	19	37	45
<i>Maximum</i>	48	74	76

Table 5. Descriptive Statistics for URS.

2. Inferential Statistics for URS

The researchers found no significant correlations between the categories of the URS: (1) CU and EU ($\rho = 0.15$, $p = 0.44$), (2) CU and DFC ($\rho = -0.22$, $p = 0.25$), and (3) EU and DFC ($\rho = -0.30$, $p = 0.12$). These findings suggest that the URS measures distinct characteristics or variables, and are not associated or related to one another.

C. SUMMARY STATISTICS FOR EXPERIENCE

Operational experience was discussed in Chapter II.C.3. However, a more detailed analysis is warranted due to the inclusion of experience as a hypothesis. Consequently, descriptive statistics will be provided in this section.

1. Descriptive Statistics for Operational Experience

The participants had a mean of 12 ($SD = 6$) months of operational experience in Iraq and a mean of 3 ($SD = 5$) months of experience in Afghanistan. However, the median months in Afghanistan are 0, while the median months in Iraq are 12. The highest number of months of operational experience in either theatre is 25 months. The variance for experience in each theatre can be seen in Figure 14.

Nineteen of the 28 participants did not serve in Afghanistan. Three participants had not served in Iraq, and 6 participants served in both theatres. Overall operational experience had a mean of 14 months ($SD = 7$), and a median of 12.5 months (see Figure 15).

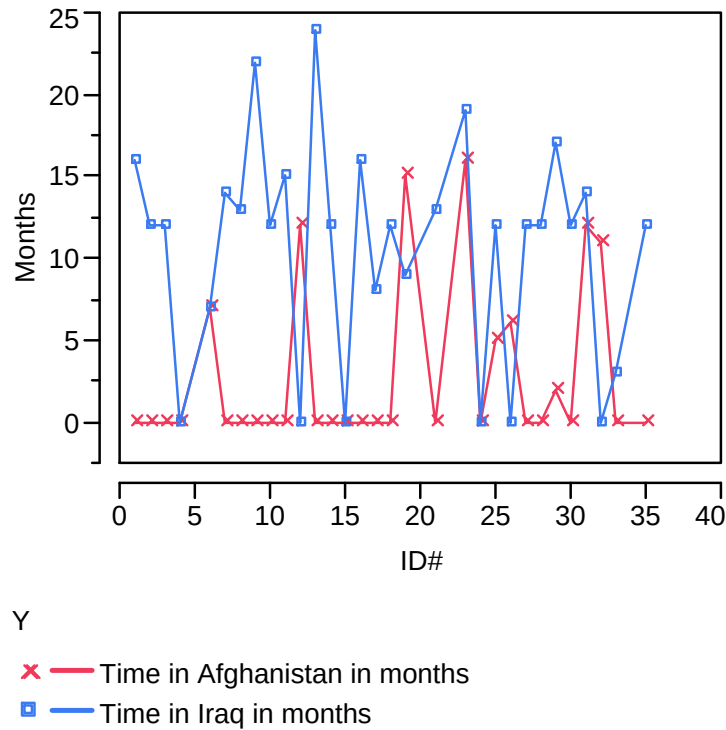


Figure 14. Participants Months of Operational Experience by Theatre.

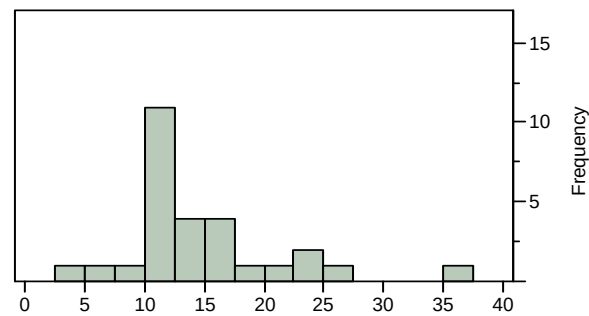


Figure 15. Distribution of Total Operational Experience in Months.

D. SUMMARY STATISTICS FOR VARIABLE ASSOCIATIONS

The researchers found no significant correlations between categories of uncertainty for overall total time, the categories of the URS, and operational experience.

V. DISCUSSION

The discussion is divided into three parts: (a) implications of analysis, (b) constraints and limitations, and (c) conclusions and recommendations. Part A will the implications of the statistical findings presented in IV. Additionally, it will outline where and possibly why those statistical findings emerged. Part B will discuss the constraints and limitations of the research based on the data from Chapter III and Chapter IV. It will discuss important observations obtained from the entire body of the researchers' work. Additionally, it will describe how our research relates to the prior work described in Chapter II and Chapter III. Finally, Part C will discuss the short-term and long-term vision of research in decision making under uncertainty.

A. IMPLICATIONS OF ANALYSIS

1. Hypothesis One

H_{a1} : There is a significant difference in the overall total time with respect to the three categories of uncertainty.

The results support the alternative hypothesis that there are significant differences between the categories of uncertainty with respect to overall total time. The results suggest that decision makers respond slower to situations with ambiguous/missing information compared to baseline information or conflicting information. Decision makers respond in statistically the same amount of time when faced with conflicting information or baseline information. These findings produced a subsequent set of questions concerning the nature of these differences.

The differences between ambiguous/missing information and baseline information were found in situation time, time to decision/additional time, time to decision, and scenario difficulty. The results suggest that decision makers spent more time in the situation time and time to decision segments for ambiguous/missing information compared to baseline information. As expected, ambiguous/missing situation time and ambiguous/missing time to decision were positively correlated. Thus, if a decision maker spent a large amount of time on situation time, then he/she would spend a

large amount of time on time to decision, and visa versa (see Figure 16). Finally, the results suggest that scenario difficulty was a determining factor in response time (i.e., the higher the level of difficulty, the slower the individual responded to ambiguous/missing scenarios). The level of difficulty was not a significant factor for baseline overall total time.

Ambiguous-Missing Information > Baseline Information

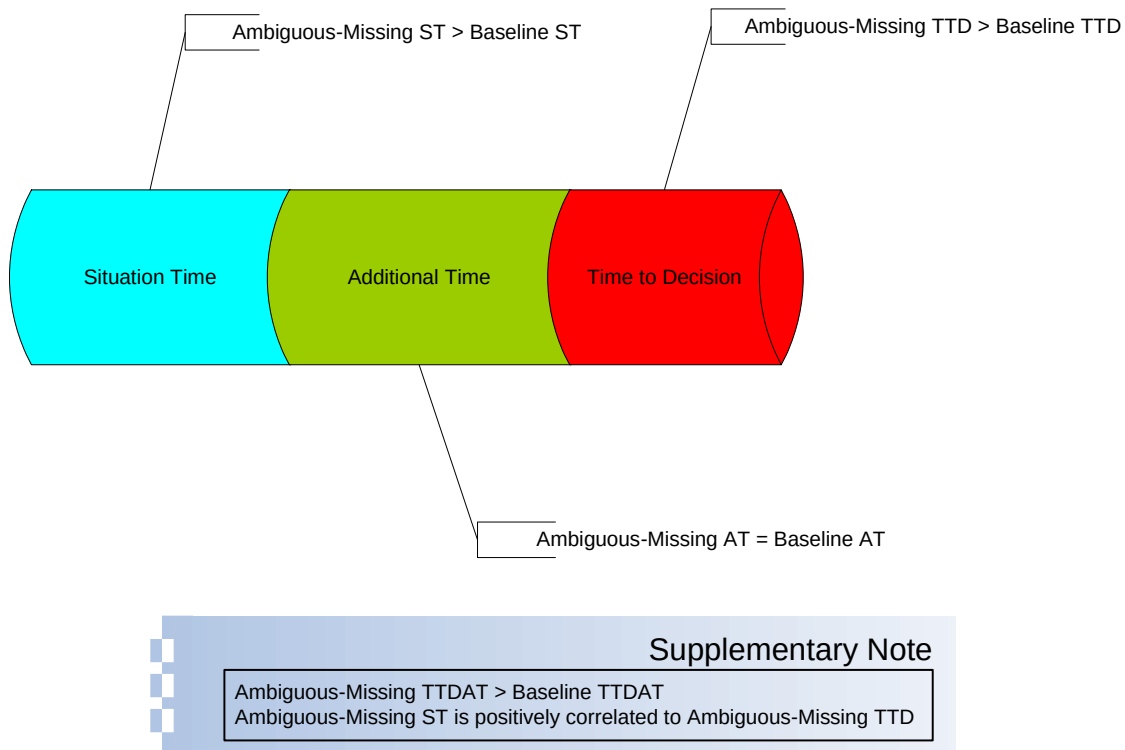


Figure 16. Diagram of Statistical Inferences for Differences between Ambiguous/Missing Information and Baseline Information.

The differences between ambiguous/missing information and conflicting information for decision time and scenario difficulty are additional time and situation time. The results suggest that decision makers spend more time on ambiguous/missing additional time compared to conflicting additional time. Additionally, the results suggest that decision makers spend more time on ambiguous/missing situation time compared to

conflicting situation time. Furthermore, both conflicting situation time and additional time were positively correlated to time to decision. Thus, if a decision maker spends a large amount of time on either conflicting situation time or additional time, he/she would spend a large amount of time on time to decision. And as in the previous paragraph, scenario difficulty was a predictor for ambiguous/missing overall total time, but not a predictor for conflicting overall total time (i.e., scenario difficulty had no effect on conflicting overall total time, but did have an effect on ambiguous/missing overall total time).

Finally, the results suggest that if a decision maker is slow to respond on any of the three categories of uncertainty, then he/she will be slow on the others. Thus, the researchers can infer that the response time to any of the categories of uncertainty is correlated with a decision maker's response time to others.

a. Ambiguous/Missing Overall Total Time and Baseline Overall Total Time

While the four preceding paragraphs describe “where” the differences lie, an explanation of “why” is needed. To address the differences in ambiguous/missing overall total time and baseline overall total time, the researchers offer three possibilities: (1) the differences are a result of the relationship between uncertainty and difficulty, (2) the ambiguous/missing information presented in the additional information (AI) did not have any effect because the decision maker had thoroughly evaluated the situation information (SI) and produced multiple COAs, and (3) the ambiguous/missing information in the AI acted as a retarding agent when merged with the situation information (SI).

As noted, the researchers attempted to evenly distribute the information in both the additional time and situation time sections. Thus, one portion of the slide would not possess more or less information than another section of the slide. The researchers did conduct reliability analysis to determine the difficulty of each scenario (see Chapter III.B.4). They did not conduct reliability analysis on the complexity. This is where the discussion about the relationship between complexity and difficulty becomes relevant.

Because our reliability inquired about the difficulty of the situation, and the not complexity, these results can only address the former. With that said, difficulty is created by numerous factors, including context, uncertainty, task, and mission type.

It is not clear whether uncertainty produces difficulty or difficulty produces uncertainty. As previously stated, conflicting information emerges when two or more sources or information contradict one another. Conversely, ambiguous/missing information can be available or unavailable to the decision maker. If available it may be unclear to its meaning or relevance to the mission; if unavailable the decision maker is unable to access it.

To create an ambiguous/missing situation, the researchers had to draft a scenario with detailed information or an abundance of resources, which produced numerous alternatives for the decision maker to compare and contrast. The decision maker may spend more time reasoning about the situation, comprehending the facts, and gaining SA (hence, the difficulty previously noted). In terms of this study, SI was clear and concise, providing a context in which actors were defined and environments understood. The AI provided the uncertainty. Thus, the main contributor to the differences in situational time, time to decision, and overall total time could be the nature of the AI.

A second possibility is that if a decision maker spent a large amount of time reasoning about the SI (understanding his overarching mission and how it relates to the situation), then he/she may have spent a large amount of time producing a COA, regardless of the AI, in the time to decision segment. This may account for why additional time was not statistically significant between ambiguous/missing information and baseline information (i.e., the decision maker had already begun reasoning about the situation information). Thus, the decision maker had already developed COAs, and the ambiguous/missing information presented reinforced the rationale of at least one of the COAs, or possibly, the uncertainty had little or no impact on his decision-making process.

This argument has implications for Klein's (1993) RPD model, where a decision maker relies on past experience when choosing a COA. Because our sample contained individuals who had operational experience in Iraq, Afghanistan, or both, they may have experienced similar situations and missions. Thus, they executed what they knew.

A third possibility arises when SI and AI are combined. Because the ambiguous/missing information was not presented until the decision maker requested the AI, and SI remained present on the slide, the AI drastically impacted time to decision. This is supported by the finding that ambiguous/missing time to decision/additional time is significantly greater than baseline time to decision/additional time ($p < 0.01$), and there was no significant difference between ambiguous/missing additional time and baseline additional time. The findings suggest that the ambiguous/missing AI acted as a much more effective retarding agent when merged with the SI compared to baseline information. That is, even if the situation time between ambiguous/missing and baseline were equal, the ambiguous/missing information in the AI would slow the decision maker's response when compared to baseline information. More importantly, scenario difficulty was a predictor variable in ambiguous/missing situation time. This suggests that the more difficult the scenario, the longer time the decision maker's situation time. This is not true for conflicting situation time or baseline situation time. Consequently, the researchers believe the decision maker had to re-evaluate all their previous assumptions and beliefs, and produce new COAs or iterate previous plans for ambiguous/missing scenarios.

The third argument has implications for the DMSC. As previously discussed, Shattuck and Miller (2006) stress the importance of promulgation of information and feedback loops in DMSC. Consequently, the emergence of ambiguous/missing information in AI may alter the lens of the decision maker. Thus, his/her interpretation of ground truth is no longer valid, and the decision maker must recalibrate his/her lens to achieve effective SA. In many ways, the third argument lends

itself to the cliché, “the calm before the storm,” (i.e., the commander assumes his lens is properly calibrated to the environment only to be rattled by the emergence of uncertainty in the tactical battle space).

b. Ambiguous/Missing Overall Total Time and Conflicting Overall Total Time

While the differences described above are difficult to express, the disparity in ambiguous/missing overall total time and conflicting overall total time is even more muddled. The most straightforward way to discuss the differences between ambiguous/missing overall total time and conflicting overall total time was to examine why conflicting overall total time was significantly less than ambiguous/missing overall total time.

Once again, the idea of difficulty arises when discussing the differences in additional time. It appears that, situation time is significantly different between the categories mostly due to the predictor variable of difficulty. While this reason may seem somewhat simplistic, it follows from the data analysis reported in the previous chapter (see Figure 17).

Ambiguous-Missing Information > Conflicting Information

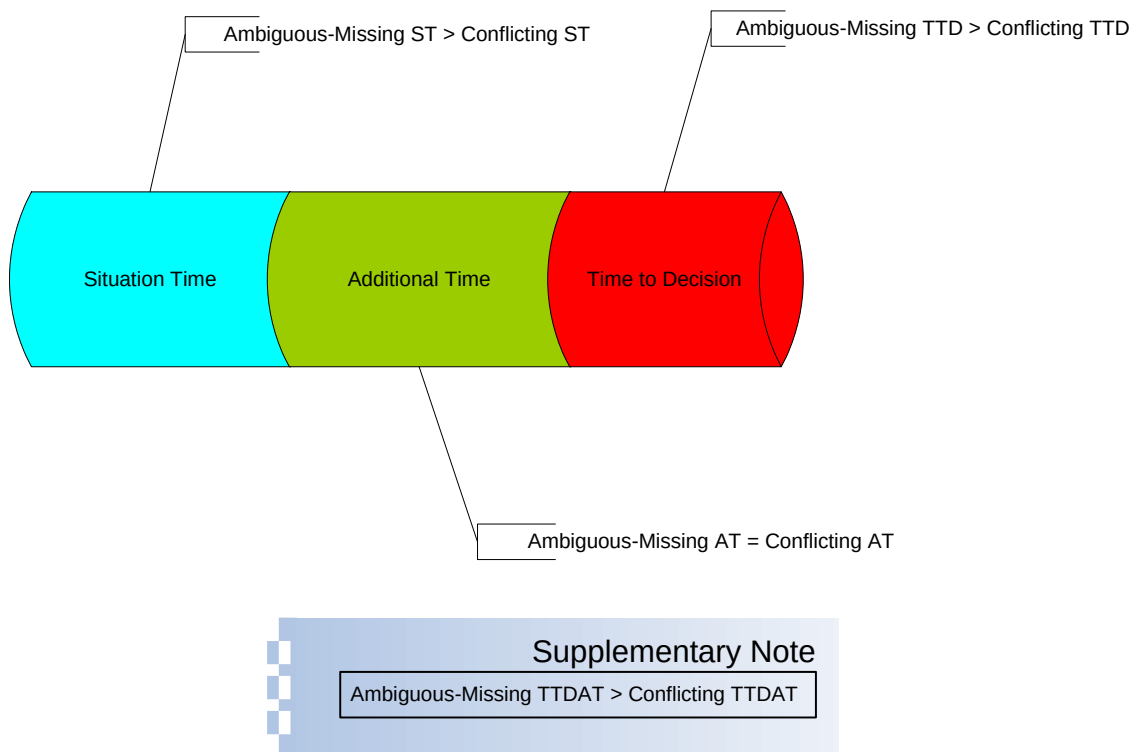


Figure 17. Diagram of Statistical Inferences for Differences between Ambiguous/Missing Information and Conflicting Information.

Scenario difficulty was a predictor for both conflicting additional time and ambiguous/missing additional time. At a qualitative level, the researchers noticed the decision makers re-reading the lines due to confusion or disbelief (i.e., the contradictory information prompted the decision maker to ensure the knowledge previously acquired was accurate). The decision maker spent a great deal of time re-reading and reinterpreting his previous beliefs.

Unfortunately, this does not adequately explain why conflicting situation time and additional time were significantly, positively correlated to conflicting time to decision. The results suggest that because additional time and situation time were not

significantly correlated, there was no association between the two variables (i.e., just because a decision maker was fast in situation time, does not imply he/she was fast in additional time).

The researchers support the findings concerning time to decision/additional time. Unlike ambiguous/missing time to decision/additional time and baseline time to decision/additional time where the results were not significantly different, the findings indicate that time to decision/additional time for ambiguous/missing information was significantly greater than time to decision/additional time for conflicting information. Contrary to the third possibility discussed in Chapter V.A.1., the researchers suggest that the *true* difference lies in the SI (i.e., the uncertainty introduced in AI retarded both situations equally, thus the time differential is created from the aforementioned difficulty element). The significant difference for additional time between the categories is diminished by the time to decision between the categories (i.e., the time differential that favored conflicting additional time was mitigated by the time differential favoring ambiguous/missing additional time). This is further supported by the times to decision for ambiguous/missing information and conflicting information. Consequently, the researchers suggest that situation information and scenario difficulty were the determining factors on whether or not the decision maker responded faster to ambiguous/missing or conflicting information.

c. Conflicting Overall Total Time and Baseline Overall Total Time

In this section the researchers explain why conflicting overall total time and baseline overall total time are not statistically different. Situation time between the two categories is statistically different, but additional time was not. Moreover, time to decision between the categories was not significant, but conflicting time to decision/additional time was significantly greater than baseline time to decision/additional time.

While examining the differences between the categories of uncertainty is necessary, it is also important to analyze where they are similar. For example, there was no statistical difference between conflicting situation time and baseline situation time.

Additionally, scenario difficulty was not a predictor for overall total time for either category. These two findings are very important. The researchers can suggest that uncertainty alone does not determine the rate of response, but rather uncertainty must be placed in the context of the situation.

The differential between baseline additional time and conflicting additional time can be explained in a manner similar to ambiguous/missing information and conflicting information. When the decision maker is presented with contradictory information, the researchers often observed many participants re-reading the given information to reinforce or reconsider their previous assumptions. This would account for the statistical significance across the categories of uncertainty found in additional time.

By definition, ambiguous/missing information presents the decision maker with more alternatives to consider compared to conflicting. However, an argument can also be made that baseline information is not much different than conflicting information (i.e., having an explicit understanding of the information may be the same as having two explicit understandings). Consequently, if a decision maker believes both to be equally valid interpretations, then either interpretation is adequate and could be assumed to be true. This may explain why there is no statistical difference for time to decision when comparing baseline and conflicting information. Moreover, the researchers suggest that the time to decision/additional time difference found is not large enough to account for the non-significant situation time difference. Thus, time differentials in additional time were mitigated by situation time and time to decision. Interestingly, the findings in this section support the findings of the third pilot study (see Chapter III.A.3).

2. 2nd Hypothesis

Ha_{2a}: There is a significant, positive correlation between emotional uncertainty and overall total time for ambiguous/missing information and conflicting information.

Ha_{2b}: There is a significant, negative correlation between cognitive uncertainty and overall total time for ambiguous/missing information and conflicting information.

The results refute the alternative hypothesis that cognitive uncertainty is significantly, negatively correlated with ambiguous/missing overall total time or conflicting overall total time. Additionally, the results refute the alternative hypothesis that emotional uncertainty is significantly, positively correlated with ambiguous/missing overall total time or conflicting overall total time.

a. *Cognitive Uncertainty and Overall Total Time*

The findings for cognitive uncertainty are interesting. The characteristics of environments in which naturalistic decision making occurs (Orasanu and Connolly, 1993) are prevalent in the military. However, this does not imply that structure does not exist. Instead, the researchers suggest that at the beginning of most military operations there is structure, but uncertainty can still exist in the battle space. Consequently, it is not uncommon for structure and uncertainty to coexist for the decision maker.

This relationship leads to anomalies when examining cognitive uncertainty and response time. Because the military places a great deal of emphasis on C2, commanders will strive to avoid organizational chaos. They will more than likely have an organizational structure that is accustomed to or designed to mitigate uncertainty. This may explain why cognitive uncertainty had the largest average score compared to the other categories of the URS. It may well be that the participants were accustomed to operating within a structured environment. Thus, the presence of uncertainty is not unexpected or foregone to their cognitive performance. Instead, it is assumed to be a part of everyday operation.

b. *Emotional Uncertainty and Overall Total Time*

The lack of statistical significance for emotional uncertainty and overall total time can be explained in a manner similar to the previous discussions. However, it is important to note some characteristics of the emotional uncertainty data prior to proceeding to the aforementioned case. Emotional uncertainty had the smallest range ($R = 29$) and variance ($v = 50$) compared to the other URS categories. This was expected

because the sample pool consisted of military officers who often operate in dynamic, uncertain environments. Regardless, the researchers were somewhat surprised by the findings.

Maladaptive behavior toward uncertainty does not necessarily lead to a failure to respond quickly. Although a decision maker may experience anxiety or sadness when faced with uncertain conditions, he/she may still be able to make a quick decision due to other factors overriding their emotional response. Future research must be conducted to better understand why emotional uncertainty does not directly affect the response time of the decision maker.

3. 3rd Hypothesis

Ha₃: There is a significant, negative correlation between operational experience and overall total time for ambiguous/missing information and conflicting information.

The results refute the alternative hypothesis that operational experience is negatively correlated with ambiguous/missing overall total time and conflicting overall total time. This research does not support the research conducted by St. John et al. (2000). However, it is important to note St. John et al. (2000) used senior and junior ranks to conduct their study, and not years of service. However, their overarching assumption was that higher ranks equal more experience.

Once again, the researchers were surprised by this finding. The absence of a relationship suggests that operational experience does not increase the speed of battle under uncertainty (i.e., more operationally experienced decision makers do not make faster decisions under uncertain conditions, nor as the data suggest, do they make slower decisions).

Other than one participant, all the participants had at least six months of operational experience. The researchers omitted all participants without any operational experience. Consequently, the participants operated in Afghanistan, Iraq, or both. The data did not provide the researchers with the ability to discriminate performance based on level of experience.

B. CONSTRAINTS AND LIMITATIONS OF THE RESEARCH

The researchers experienced two challenges during the study. First, defining the relationship or association between complexity and difficulty is necessary to understanding uncertainty. Second, branch participant selection is important due to the tasks assigned by the scenario. As discussed previously, the relationship between complexity and difficulty is important in terms of their influence on uncertainty. The researchers' reliability survey inquired only about difficulty and not complexity. These terms are most likely related but not necessarily synonymous. Scenario difficulty has contributed greatly to our work by influencing decision time across the categories of uncertainty.

While the relationship of complexity and difficulty is important, participant selection based on combat branch is equally vital to achieving better results. While participants were procured from all three branch categories of the U.S. Army, the scenarios were constructed from a CA perspective (i.e., the situations resembled the types of tasks and mission executed by infantry, armor, and artillery officers). This is not to say that the CS officers or CSS officers cannot accomplish the missions evaluated by the study. In fact, the combination of smaller, lighter forces along with the tactics of post September 11, 2001 insurgents have placed many CS and CSS officers in direct contact with the enemy. Our suggestion points out that the branches associated with CS and CSS receive different training and, for the most part, do not perform enemy engagement missions as frequently as their CA counterparts. Consequently, the exclusion of CS and CSS officers would bring greater validity to the results.

C. CONCLUSIONS AND RECOMMENDATIONS

The conclusion and recommendations section contains three parts: (1) conclusions, (2) future research, and (3) summary. The conclusion will discuss the important information ascertained from the study, while future research will offer suggestions for future work in the field of uncertainty. Finally, the summary discusses the researchers' final thoughts on the study.

1. Conclusions

First, the evidence suggests that decision makers respond differently when confronted with various categories of uncertainty. Additionally, scenario difficulty was a significant factor in ambiguous/missing information response time, but not a significant factor in determining conflicting or baseline information response time. These findings suggest that the categories of uncertainty coupled with scenario difficulty determine response time. However, whether or not these differences are mostly due to the categories of uncertainty, scenario difficulty, or both could not be determined by this study. Consequently, future research must focus on teasing out these differences to determine what role each one of these factors plays in response time.

Second, the absence of an association between operational experience and response time is dubious. However, this study did not look at the quality of decisions, but focused on response time. The *true* differences may be found in the quality or type of decision vice the response time. This theory is being explored by TRAC-FLVN in an adjacent study. Third, because there was no association between the analyzed categories of the URS and overall total time, the researchers believe calibration may have been the cause (i.e., because military officers operate in uncertain environments, they have learned how to mitigate its effects to remain efficient). However, future research is needed to determine if this theory is correct.

2. Future Research

The conclusions provide a wealth of questions for future research. These questions can be grouped into four areas of study: (a) additional research on decision-making response to uncertainty, (b) application to modeling and simulation for human behavior in software agents, (c) expansion to military services, and (d) application to other fields of occupation.

a. Additional Research on Decision-Making Response to Uncertainty

This study explores the categories of uncertainty in terms of response time. However, response time is just one of many performance measures that can be

examined to determine how individuals respond under uncertainty in tactical situations. TRAC-FLVN will be publishing an adjacent report on this study that classifies the decisions made by the participants in terms of passive, cautious, and decisive action. This analysis will help determine what types of decisions individuals make when faced with the different categories of uncertainty. Additionally, research is needed to explore the relationship between complexity and difficulty and their impact on uncertainty. By doing so, researchers will be able to develop methods that can tease out the influence of these constructs and provide more conclusive findings.

b. Application to Modeling and Simulation for Human Behavior

This study provides the foundation for creating software agents that better model individual behavior under conditions of uncertainty. Modeling human behavior is a difficult task, but it is vital to understanding decisions made at the tactical level. While various types of uncertainty lead to differences in response time, research must focus on other factors that may also affect decision makers. The injection of harsh weather or unbearable heat may drastically affect an individual's ability to reason under uncertainty. Acute or chronic fatigue may also affect a decision maker's ability to reason about uncertainty. Data that result from the interactions of these factors may produce more robust algorithms to better model human behavior.

c. Expansion to the Military Services

The scenarios used in this study were crafted for U.S. Army personnel. However, uncertainty is not only found in U.S. Army operations, but in other military services as well. Scenario generation should be developed in other tactical environments, including continuous operations at sea and air defense operations at home and abroad. For example, U.S. Navy carrier strike groups' operations routinely deal with uncertainty when coordinating organic and non-organic assets. Additionally, combat operations, and in particular, amphibious operations, conducted by the U.S. Marine Corps parallel the tactical and operational environments experienced by those in the U.S. Army. The challenge is to develop scenarios that provide tactical realism and meet the specific

human behavior modeling needs of the services. An even more challenging approach would be to inject categorical uncertainty into staff operations to determine how it affects team, staff planning operations, and both at the single service and joint levels.

d. Application to Civilian Occupations

While modeling military operations and decision makers was the central focus of this research, examining the impact of uncertainty on occupations outside the military may also prove beneficial. Businesses routinely operate with uncertainty at all levels. For example, commodity speculators attempt to determine the future price of oil based on complex, dynamic demand and supply issues in the near and long term. Additionally, transportation and logistics companies face uncertain conditions in weather, prices, and interruptions in supply lines when making critical operational decisions that have long term consequences. Developing software agents that mimic human behavior may help us understand these uncertainties by properly modeling how they influence human decision making. Such research could provide additional insights into modeling and simulation techniques and how decision makers outside the military cope with uncertain conditions.

3. Summary

Research in decision making under uncertainty has great potential. The study of human reasoning under uncertain conditions is critical to understanding the dynamic and unpredictable nature of war. The researchers are confident that the findings in this study will add to the body of knowledge in this field of decision making under uncertainty and lead to improved comprehension of the battle space. Additionally, these proposed research areas will provide a more robust understanding of uncertainty in modeling and simulation. The results of the research coupled with the improved modeling and simulation will allow commanders to eventually view the battle before it is fought. These improvements have the potential to revolutionize the manner in which military leaders train for, reason about, and conduct military operations at all levels of war.

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APPENDIX A. UNCERTAINTY RESPONSE SCALE TEST

1. I tend to give up easily when I don't clearly understand a situation.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

2. When I go shopping, I like to have a list exactly of what I need.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

3. I feel better about myself when I know that I have done all I can to accurately plan my future.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

4. Sudden changes make me feel upset.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

5. When making a decision, I am deterred by the fear of making a mistake.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

6. When uncertain, I act very cautiously until I have more information about the situation.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

7. I like to have things under control.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

8. When the future is uncertain, I generally expect the worst to happen.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

9. Facing uncertainty is a nerve-wracking experience.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

10. I get worried when a situation is uncertain.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

11. Thinking about uncertainty makes me feel depressed.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

12. I find the prospect of change exciting and stimulating.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

13. Uncertainty frightens me.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

14. There is something exciting about being kept in suspense.

<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Never	Sometimes	Now and Then	Often	Always

15. The idea of taking a trip to a new country fascinates me.

<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Never	Sometimes	Now and Then	Often	Always

16. I like going on holidays with nothing planned in advance.

<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Never	Sometimes	Now and Then	Often	Always

17. I think you have to be flexible to work effectively.

<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Never	Sometimes	Now and Then	Often	Always

18. Taking chances is part of life.

<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Never	Sometimes	Now and Then	Often	Always

19. When I feel uncertain about something, I try to rationally weigh up all the information I have.

<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Never	Sometimes	Now and Then	Often	Always

20. Before making any changes, I need to think things over thoroughly.

<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Never	Sometimes	Now and Then	Often	Always

21. I prefer to stick to tried and tested ways of doing things.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

22. I like to have my weekends planned in advance.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

23. I feel curious about new experiences.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

24. I like to think of a new experience in terms of a challenge.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

25. A new experience is an occasion to learn something new.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

26. When I feel a situation is unclear, I try to do my best to resolve it.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

27. I like to know exactly what I'm going to do next.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

28. When facing an uncertain situation, I tend to prepare as much as possible, and then hope for the best.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

29. I feel relieved when an ambiguous situation suddenly becomes clear.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

30. When I feel uncertain, I try to take decisive steps to clarify the situation.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

31. When I can't clearly discern situations, I get apprehensive.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

32. I enjoy finding new ways of working out problems.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

33. When I'm not certain about someone's intentions towards me, I often become upset or angry.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

34. New experiences can be useful.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

35. When uncertain about what to do next, I tend to feel lost.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

36. I feel anxious when things are changing.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

37. New experiences excite me.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

38. I think variety is the spice of life.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

39. I try to have my life and career clearly mapped out.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

40. I think a mid-life career change is an exciting idea.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

41. When a situation is unclear, it makes me feel angry.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

42. I enjoy unexpected events.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

43. I like things to be ordered and in place, both at work and at home.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

44. I really get anxious if I don't know what someone thinks about me.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

45. I easily adapt to novelty.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

46. I am hesitant when it comes to making changes.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

47. I like to plan ahead in detail rather than leaving things to chance.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

48. Before I buy something, I have to view every sample I can find.

1	2	3	4	5
Never	Sometimes	Now and Then	Often	Always

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APPENDIX B. MODIFIED CDM INTERVIEW SHEET

Participant Name:	Event #
Recall a tactical situation during a recent deployment to a combat zone in which you were confronted with uncertainty and had to make a decision. Uncertainty can be described simply as a sense of doubt that blocks or delays action. There are no right or wrong answers and we are in no way evaluating your performance or the decisions you made.	
Critical incident summary (Location, Date/Time, Key Personnel, General Description)	
Detailed Incident timeline (Sequence of key incidents, activities)	
Identify uncertainty (uncertainties) in the timeline	
Describe the specific nature of the uncertainty (what was known by whom, what was not known by whom, what the participant wanted/needed to know in that context)	
Describe the actions that were undertaken to overcome the uncertainty (e.g., asked for additional data or Intel, relied on previous experiences, etc.)	
Describe the effect of the uncertainty on the decision that was made	
Describe what you would do differently if faced with the same situation	

Table 6. CDM Uncertainty Elicitation Interview Sheet.

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APPENDIX C. NPS PILOT STUDY # 1 SCREEN SHOTS

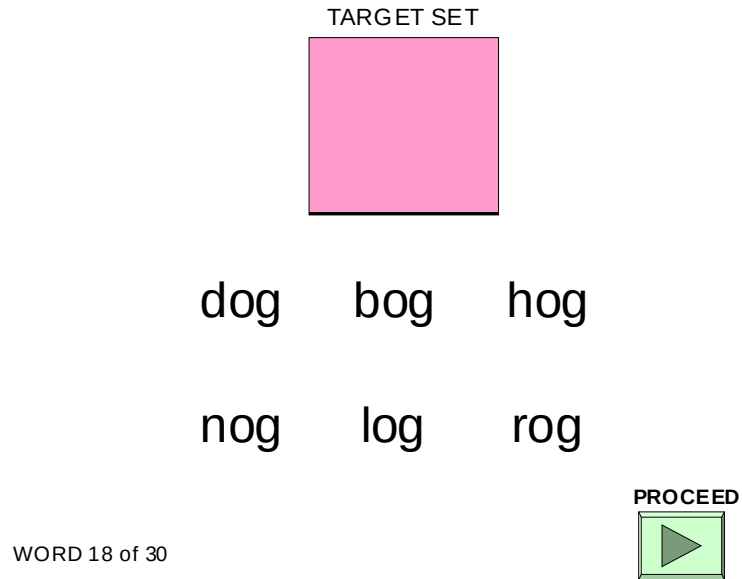


Figure 18. Low Resolution Ambiguity Slide.

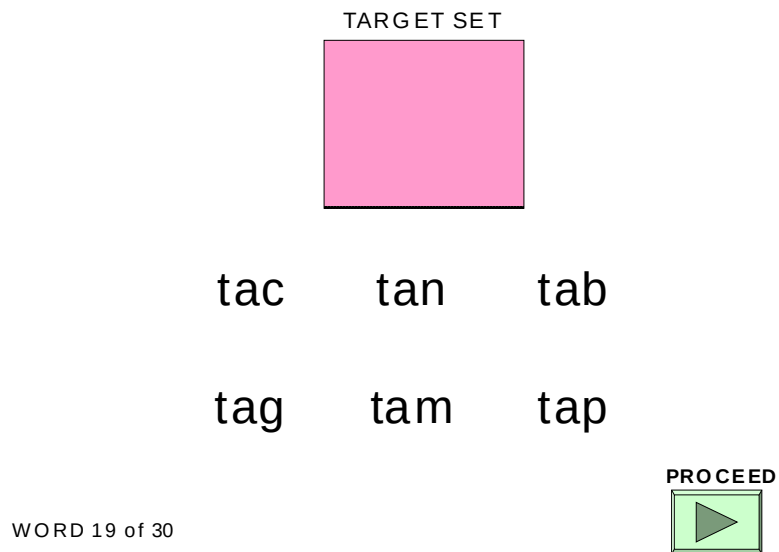
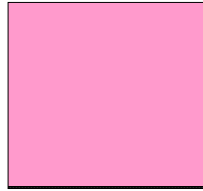


Figure 19. Medium Resolution Ambiguity Slide.

TARGET SET



rake rate rare

raze race rave

WORD 17 of 30

PROCEED



Figure 20. High Resolution Ambiguity Slide.

APPENDIX D. NPS PILOT STUDY # 2 SCREEN SHOTS

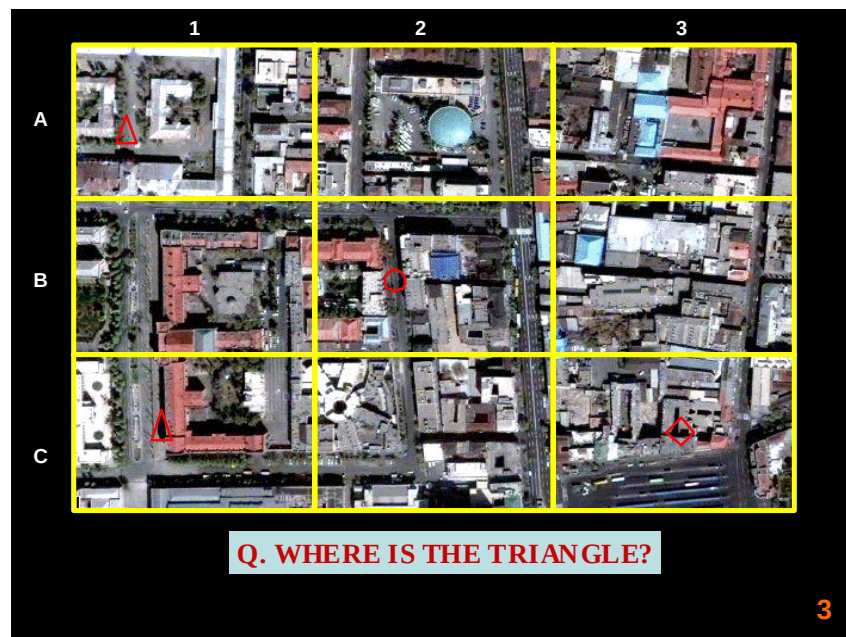


Figure 21. Conflicting Information Slide.

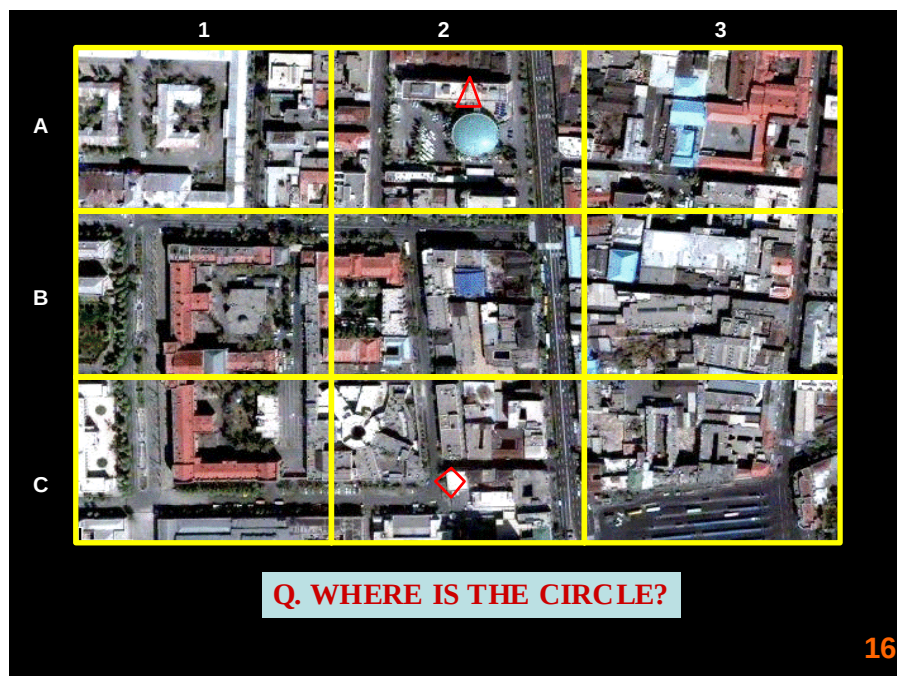


Figure 22. Missing Information Slide.

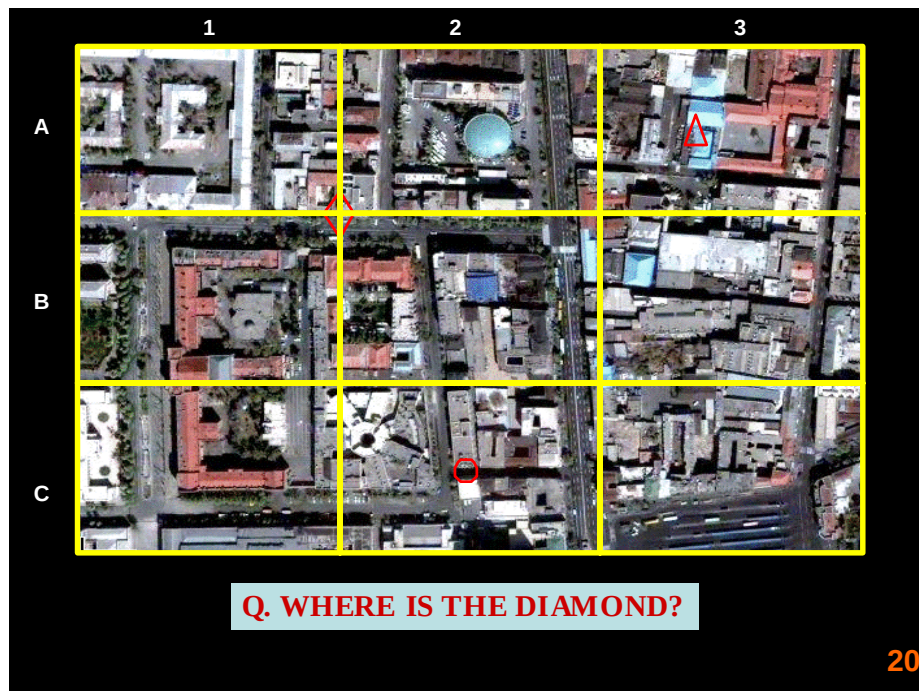


Figure 23. Ambiguous Information Slide.

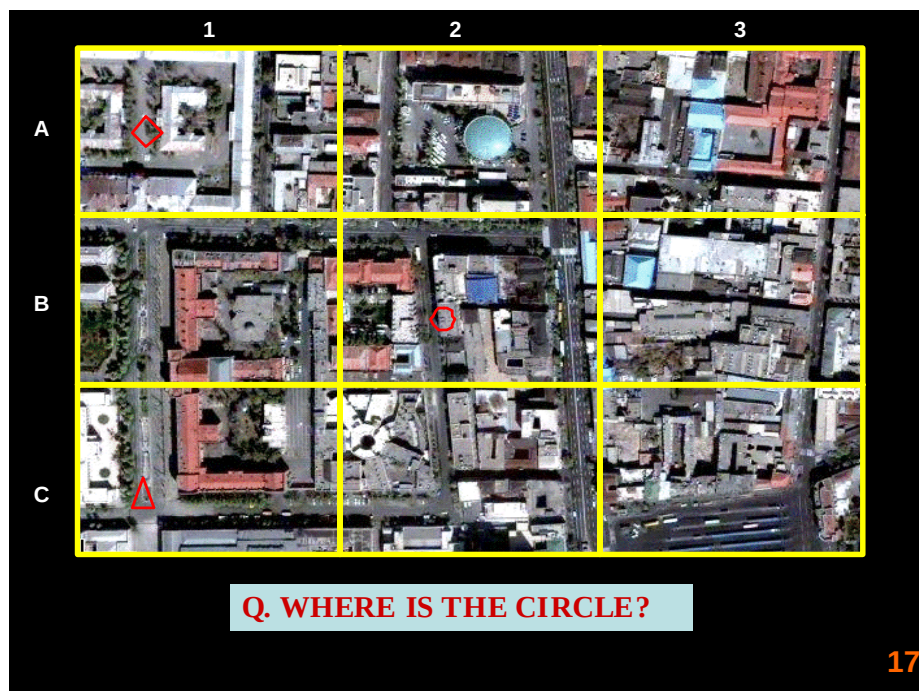
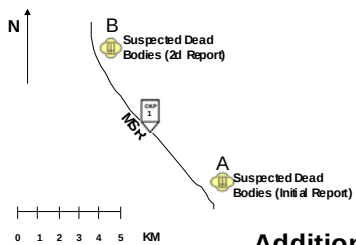


Figure 24. Baseline Information Slide.

APPENDIX E. CGSC TACTICAL VIGNETTES



Situation

- You are a MITT team leader advising an Iraqi BN.
- Insurgents have been operating in the area to include emplacement of IEDs and ambush sites.
- The MSR has been swept for IEDs within the last (2) hours and there is no evidence of IEDs or ambush.

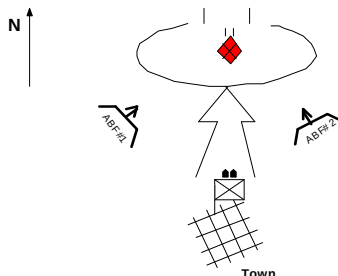
Additional Information

- Near dark, the Iraqi BN Commander receives a report of (5) dead bodies along the MSR at Point A.
- You accompany the Iraqi CDR and a heavily armed Iraqi Police (IP) escort south along the MSR to Point A.
- While enroute, in the vicinity of CKP 1, you receive a radio report directly from your higher HQ that the dead bodies are located on the MSR at Point B, to your rear, in a location you have already driven past.

PLEASE SNAP YOUR CLICKER WHEN YOU HAVE MADE A DECISION

SLIDE 1

Figure 25. Conflicting Information Slide.



Situation

- You are a Special Forces ODA team leader operating with (50) freedom fighters. Your split ODA teams (mounted) are occupying the (2) ABF positions.
- Your mission is a coordinated daylight attack against the remnants of a light infantry BN (minus) with a approximately (200) entrenched on a hillside.
- The enemy BN has mortars and small arms capability.
- Prior to the attack, an air strike will reduce the enemy BN strength to an acceptable attack/defense ratio.

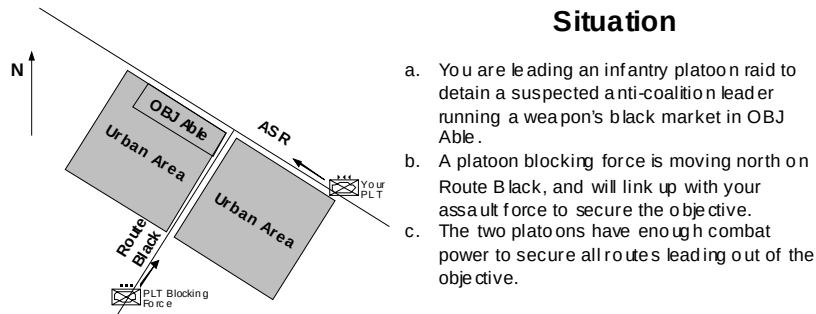
Additional Information

- You observe several rounds "off target" during the air strike.
- The adjacent units report they started their attacks.
- You do not have any information about the remaining enemy strength.

PLEASE SNAP YOUR CLICKER WHEN YOU HAVE MADE A DECISION

SLIDE 2

Figure 26. Ambiguous/Missing Information Slide.



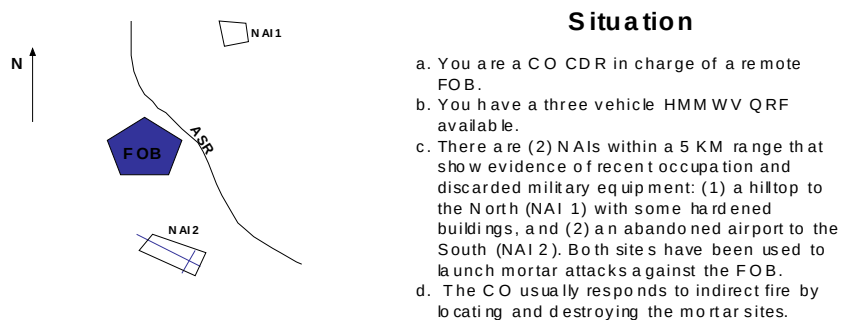
Additional Information

- The blocking force reports being set in position to the South and all escape routes are secured.
- You continue to OBJ Able, enter crowded market conditions, and observe the anti-coalition leader in a dark blue BMW sedan.
- The dark blue BMW sedan is unable to move due to congestion in the market area.

PLEASE SNAP YOUR CLICKER WHEN YOU HAVE MADE A DECISION

SLIDE 3

Figure 27. Baseline Information Slide.



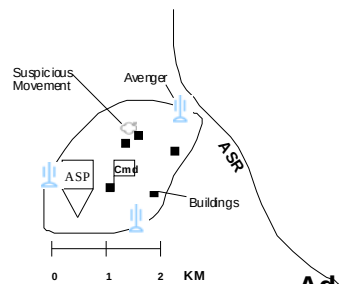
Additional Information

- At 0105 Hrs, you are located in your CO TOC, and hear the sound of incoming indirect fire. The first round lands within 50 meters of the TOC.
- Your 1SG tells you that a PSG and himself believe the round came from the South.
- Your XO and a guard on the roof report they believe the round came from the North.

PLEASE SNAP YOUR CLICKER WHEN YOU HAVE MADE A DECISION

SLIDE 4

Figure 28. Conflicting Information Slide.



Situation

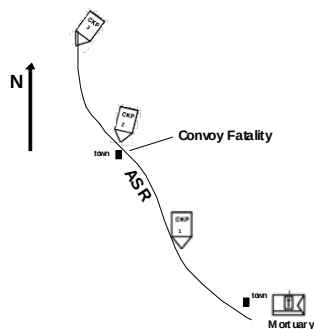
- You are the Night OIC responsible for the Division ASP security.
- ASP stocks are stored on the ground on unimproved surfaces and cover a 2km x 2km area.
- (3) Avengers (ADA Gun) with FLIR capability are manned to support security operations.
- A dismounted QRF with 6 personnel and equipped with small arms and night vision devices is co-located at the CP.
- SOP states the QRF should not be deployed until enemy activity is confirmed.

Additional Information

- It is approximately (5) minutes after shift change. The security personnel were just replaced and should be heading back to their respective platoon CPs.
- A Specialist from the QRF reports movement near the small arms munitions stocks. The Avenger Crews report they cannot observe aforementioned location.
- Previously, locals have looted the stocks and sold ammunition on the black market.

PLEASE SNAP YOUR CLICKER WHEN YOU HAVE MADE A DECISION
SLIDE 5

Figure 29. Ambiguous/Missing Information Slide.



Situation

- You are the OIC responsible for convoy security.
- During convoy operations, a local national is killed in a fatal car accident involving one of the military convoy vehicles near CKP 2.
- Battalion SOP and TTP is to remove military and civilian bodies to a Mortuary Affairs team co-located at an Iraqi Police Station regardless of political or family affiliation.

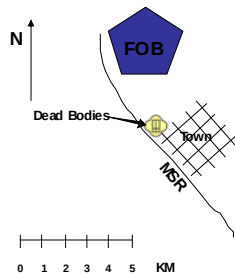
Additional Information

- You secure the area and report the accident and fatality to higher HQ. You identify the body as the cousin of a local leader.
- You have sufficient combat power on hand to both secure the convoy and escort the body to the Mortuary Affairs team.
- The Mortuary Affairs team is located approximately 20 KM south of the accident site.

PLEASE SNAP YOUR CLICKER WHEN YOU HAVE MADE A DECISION

SLIDE 6

Figure 30. Baseline Information Slide.



Situation

- You are the QRF platoon leader responding to a report of dead bodies along the MSR.
- Insurgents have been operating in the area to include emplacement of IEDs and ambush sites.
- The local townspeople are sympathetic to the insurgents.
- It is not safe to be in this area after dark.

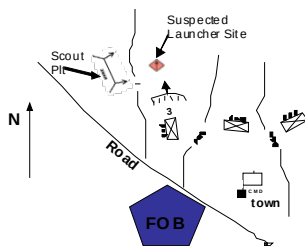
Additional Information

- You find (5) dead bodies just before dark. They were killed execution style.
- A local reports that several men in a truck dumped the bodies approximately (1) hour earlier and then continued South.
- A different local indicates the bodies were executed at the site by insurgents less than (30) minutes ago. The local gives you an exact location where the insurgents went inside the town.

PLEASE SNAP YOUR CLICKER WHEN YOU HAVE MADE A DECISION

SLIDE 7

Figure 31. Conflicting Information Slide.



Situation

- You are a CO CDR conducting nightly ambush missions outside the FOB to destroy enemy rocket launcher teams.
- Your CP is located inside the nearby town. You have (3) platoons available; 3RD Platoon is the main effort; the Battalion Scout platoon is occupying the SBF position.
- CAS (F-16's) is available and a TACP is attached; Apache Helicopters are in direct support of the unit's operations.
- You are at the limit of your communications ranges to the platoons and to higher BN headquarters.

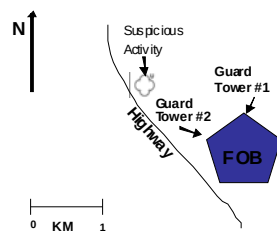
Additional Information

- You receive a relayed report that the 3RD platoon leader has been trying to reach you. 3RD platoon is reporting contact with dismounts Northwest of their location.
- All units have lost radio communications with the Scout Platoon manning the SBF position. Several attempts to raise them on the radio have failed.
- From the relayed information and the locations on the FBCB2, you are not sure if the platoon leader is actually under fire from insurgents or under attack by the friendly SBF position.

PLEASE SNAP YOUR CLICKER WHEN YOU HAVE MADE A DECISION

SLIDE 8

Figure 32. Ambiguous/Missing Information Slide.



Situation

- a. You are the Night Battle Captain in the BOC and are responsible for FOB security.
- b. Your BN is the only unit operating from this FOB.
- c. The BN QRF consists of (4) Bradley Fighting Vehicles with (4) dismounts each.
- d. As part of your duties, you have been given authority to exercise the QRF in support of FOB security.

Additional Information

1. Guard Tower #1 reports suspicious enemy activity (lights/movement) 1 KM Northwest of the FOB in the vicinity of the road.
2. Guard Tower #2 confirms observing (2) civilian pickup trucks, and reports observing enemy small arms tracer fire incoming from that area.
3. A guidons call and a status check confirms that no units are currently operating outside of the FOB.

PLEASE SNAP YOUR CLICKER WHEN YOU HAVE MADE A DECISION

SLIDE 9

Figure 33. Baseline Information Slide.

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APPENDIX F. CGSC STUDY INSTRUCTIONS



Operations Research Department
Human Systems Integration
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Naval Postgraduate School
Monterey, California 93943

Lawrence Shattuck, Ph.D.
lgshattu@nps.edu

From: LTJG K.E. Kemmerer, USN
To: CGSC Decision-Making Participants

Sbj: DECISION-MAKING STUDY INSTRUCTIONS

PLEASE READ THE FOLLOWING INSTRUCTIONS ALOUD

1. You are about to participate in a decision making study. Please read these directions carefully and aloud. We thank you in advance for your time and involvement.
2. This study consists of several different, independent scenarios. Each scenario consists of two blocks of information: (1) situational data and (2) additional data.
You will read both the situational and additional data aloud.
3. The situational information provides data concerning the tactical environment, force positioning, and the location of the scenario. **After you read the situational data and are ready to read the additional data, snap the clicker provided to you.** The additional information will provide real-time data describing the events and intelligence occurring on the battlefield.
4. After you have read both blocks of data out aloud, you will be asked to make a decision. **Please indicate you have made a decision by snapping your clicker.**
5. Once you snap your clicker, you will be asked to answer two questions:
 - 1) To provide a brief description of your decision?
 - 2) How did you arrive at your decision?**Please do not snap your clicker until you are ready to answer these two questions and speak clearly into the microphone while doing so.**
6. After you have answered both questions, **snap your clicker to proceed to the next scenario.**
7. **Please test that your clicker is working properly now.**

Once again, thank you for your time, and please answer to the best of your ability.

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