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A Framework to Simplify the Choice of Alternative Analysis and Selection Methods

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ABSTRACT

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This dissertation contributes a framework for analysts and engineering managers to investigate and choose alternative analysis and selection methods based upon their problem and its context. It began as an investigation into the alternative analysis and selection methods used in military planning. The existing military methods were inconsistent, violated the decision science body of knowledge, and provided no guidance to the practitioner on matching methods to problems. These challenges made it necessary to conduct this investigation.

This research used a three-phase mixed methods approach. The first phase applied the general inductive method to the decision making body of knowledge to elicit an evaluation theme. The second phase used content analysis to identify evaluation criteria and satisficing to choose an evaluation framework structure. The completed framework is applied to the case of U.S. Army planning in phase three as a validation case study.

This investigation's results suggest that the proposed evaluation framework methodology is valid based upon the member checks and expert feedback on the case study. The research also contributes an expert-tested scalable collaborative online tool for alternative analysis and selection method research and selection. Finally, this dissertation recommends improvements for decision making in U.S. Army planning that have been validated by military planning and operations research experts.

This dissertation is dedicated to my family. To my wife, thank you for all of your sacrifice in supporting my career. I hope these last three years balance the more challenging ones prior and ahead. You are a wonderful mother and my best friend. To my children, thank you for brightening my every day and keeping work in perspective. To my parents, thank you for the freedom to pursue my interests and supporting me in those that stuck.

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CHAPTER 1

INTRODUCTION

Research Impetus

The United States (US) military and its allies conduct tactical, operational, and strategic planning following a variety of similar yet distinct decision making methodologies (Anderson & Slate, 2003). One of those similarities is that each variation includes a step that analyzes potential military Courses of Action (COAs). In this step planning staffs evaluate COAs as discrete, predetermined alternatives against one or more criteria (i.e., attributes, goals, or governing factors) in an alternative analysis and selection process (Triantaphyllou, 2010). Most of these processes (North Atlantic Treaty Organization, 2010; United States Army, 2011; United States Joint Staff, 2011a; United States Marine Corps, 2010; United States Navy, 2007) recommend the format of a decision matrix for their evaluations as depicted in Table 1 below.

Table 1: Example military decision matrix.

Course of Action (COA)	Criterion 1	Criterion 2	Criterion 3
COA 1			
COA 2			
COA 3			

Currently, the doctrine of the US Army (United States Army, 2011), Marine Corps (United States Marine Corps, 2010), Navy (United States Navy, 2007), Air Force (United States Air Force, 2012), Joint Staff (United States Joint Staff, 2011a), and NATO (North Atlantic Treaty Organization, 2010) each recommend different alternative analysis methods for use in how to construct this course of action comparison decision matrix. These unique approaches may have developed from unique organizational cultures, planning in different battle-space domains, planning at different levels of war, or some combination thereof (Holzgrefe & Hester, 2014). Critics contend that such divergences prevent joint staff officers from effectively working together as envisioned in the 1986 Goldwater-Nichols Act (Anderson & Slate, 2003).

An initial review of military doctrine revealed 15 different alternative analysis methods across six publications, some of which are mathematically invalid (Holzgrefe & Hester, 2014). This situation presents three problems. First, the different methods complicate inter-service and international cooperation for joint and multinational operations (Anderson & Slate, 2003). Second, there is no tool for staffs to choose the appropriate method for their particular military planning problem. Third, the mathematically invalid methods may cause staffs to recommend an incorrect preferred COA to the commander. This research develops a theory of alternative analysis selection in the form of a framework to apply in generalized contexts while addressing each of these problems in a validation case study.

One consideration that was quickly identified in the beginning of this research was the need for the alternative analysis method selected for a military staff to match the resources available. For example, tactical level staffs are human resources composed of junior officers and senior non-commissioned officers with basic levels of mathematical fluency (Boukhtouta, Bedrouni, Berger, Bouak, & Guitouni, 2004). This resource limitation constrains the available alternative analysis and selection methods to those that can be understood by someone with high school math skills. Military staffs also operate in austere environments without the aid of shelter, electricity, or computing power beyond a laptop (United States Army, 2011). These materiel resources also limit the alternative analysis methods available. The author found no research on matching alternative analysis and selection methods to available resources during the literature search, providing the impetus for a broader scope of research.

Broader Research

With the resource theme in the military planning problem as a basis, this research proposes using the general inductive approach to discover additional themes in the broader multiple attribute decision making literature that can lead to a set of criteria for practitioners to match methods to problems (D. R. Thomas, 2006). Themes will be elicited through four literature streams: military decision making, normative decision making, descriptive decision making, and prescriptive decision making. Once collected, one theme will be selected as the basis for a framework for alternative analysis method selection. This themed framework will then be applied to the special case of U.S. Army operational planning to determine its usefulness.

This research is both deductive and inductive. The deductive portion determines if the theme of resources identified in the literature review of military planning is also evident in other relevant literature streams. The inductive portion seeks alternative themes that can be found in the raw data to organize a framework (D. R. Thomas, 2006).

Purpose Statement

The purpose of this study is to develop a theory of alternative analysis method selection in resource constrained contexts that is operationalized through a decision aid and applied to military staffs as a case study. Engineering managers will apply this decision aid at each level of their organization that supervises analysts employing alternative analysis methods. Chiefs of Staff and Executive Officers that lead military planning will apply the same decision aid to the alternative analysis methods used in the course of action selection step of military planning processes. Practitioners and staff may also use this framework to match alternative analysis methods to unique problems and their context.

Significance of the Study

This research will be significant for several reasons. First, this will be the first formal application of the general inductive approach to the multiple attribute decision making literature. This method allows "research findings to emerge from the frequent, dominant, or significant themes inherent in raw data" (D. R. Thomas, 2006, p. 238). This research will be the first to identify those themes in this manner. Second, this research will contribute a framework that matches alternative analysis methods to problems and their context for use by practitioners and managers. Third, this research will contribute an overarching methodology that demonstrates how to develop a framework using criteria developed using the general inductive approach.

The literature review and case study of this research will also be significant for three more narrow reasons related to military planning. First, it will be the first to specifically compare the alternative analysis methods used in COA comparison by each military organization. Previous work has looked at the different processes by aggregated steps with no attention paid to the differing alternative analysis methods (Anderson & Slate, 2003). Second, the case study will be the first to consider military planning doctrine published after 2003, which includes new doctrine from all six organizations. Third, this study is the first to consider NATO military planning doctrine as it compares to the US in the area of COA comparison.

Research Questions

This research intends to address the following questions:

Question 1: What are an appropriate set of criteria for choosing the alternative analysis methods that are suitable to each unique problem and context?

Question 2: What is an appropriate framework within which to organize the set of appropriate evaluation criteria?

Question 3: How can practitioners use the resultant framework to match alternative analysis methods to problems and their context?

Question 4: How can engineering managers use the framework to evaluate the effectiveness of alternative analysis within their technical enterprise?

Assumptions and Limitations

The primary assumption of this study is that users of alternative analysis and selection methods and their managers are competent to apply the methods correctly. A second assumption is that users of alternative analysis and selection methods and their managers sufficiently understand the context of their problem to apply the framework. Both of these assumptions address the competency of those that seek to apply the results of this research.

A third assumption is that the perception of a method being successful does not make it appropriate. Some alternative analysis and selection methods in each military organization's planning process may be defended based upon the perception of success across thousands of applications in various environments and conflicts. Non-military organizations may defend their own legacy processes on the same grounds. Intertwined with this assumption is the complementary nature of decision making within the planning processes. Commanders use naturalistic, qualitative, or expertise-based decision making in their supervisory role over COA comparison (Klein, 1993). Military staffs traditionally compliment that approach with classical and empirical decision making to recommend COAs to the commander (Boukhtouta et al., 2004).

Several limitations need consideration during this study. First, doctrine for these organizations changes every few years. As of June 2013, both the Army and Navy had draft doctrine ready to publish within one year to replace their existing methodologies. The nature of this study requires a cutoff for currently published doctrine of November 30th, 2013. A second important limitation of this study is that the author has no practical way to test any proposed method with a military staff. This means that any recommendation must be based on mathematical suitability and applications in different fields rather than traditional experimentation. To ameliorate this limitation, this study will seek assessments of face validity from military planning practitioners.

Expectations

The author expects that the resource theme will be corroborated through the general inductive approach in each of the literature streams. This theme will compete against other themes identified for use in the framework. Within the case study, the author expects that some the military methods will not be mathematically defensible. Of particular concern is the use of ordinal data in some methods that apply the simple additive weighting method. The author also expects that methods from outside the military can be adapted to address the shortcomings of those methods currently used in the military. Finally, the author expects that both the overarching methodology and framework can be successfully applied to the military planning problem.

CHAPTER 2

LITERATURE REVIEW

The literature review includes fifteen sections starting with a broad discussion of decision making that narrows down to the alternative analysis and selection methods used by each military organization from the lowest echelon (military service) to the highest (NATO). The first section reviews categories within decision science to begin pinpointing the exact type of problem found in military course of action selection. The second section reviews the schools of decision theory to provide theoretical context to the methods. The third section reviews relevant multiple attribute decision making methods to provide an academic basis for evaluation. Multiple attribute decision making methods form a subset of all decision making methods and include the alternative analysis and selection methods used by the military. The fourth section reviews military planning to familiarize the reader with the problem context. The fifth through tenth sections review the methods of the Army, Marine Corps, Navy, Air Force, Joint Staff, and NATO respectively. US military services will be addressed in their order of precedence (United States Department of Defense, 1977). Methods recommended by a single organization will be presented in the same order that they appear in the organization's doctrine. The eleventh section summarizes the findings from the previous sections. The twelfth, thirteenth, and fourteenth sections review problem context, resources, and frameworks. The fifteenth and final section presents findings and the research gap.

Decision Making

The study of decision making began in earnest half a century ago and several categories of methods have been developed (Kahneman & Tversky, 2000). This section discusses these categories to pinpoint where in the broad field of decision making that this particular problem lays. This categorization assists in identifying the correct methods for the military course of action selection problem (C. L. Hwang & Yoon, 1981; Ishizaka & Nemery, 2013).

The first categorization describes the schools of decision theory that created each multiple attribute decision making method. The normative school describes how one should decide based on achieving the most desirable outcome, as determined by maximizing the utility of the decision maker. The descriptive school describes how people actually make decisions. The prescriptive school describes how to prepare people to make good decisions in real world settings. The survey of US and allied military planning that follows shows a strong predilection for the normative school, but the author seeks to investigate methods from all categories. The subsequent section on decision theory provides additional detail on each school.

A second way to categorize decision making methods is based on the type of decision required. Roy (1981) suggests four decision types: choice, sorting, ranking, and description. The choice problem selects the single preferred alternative or reduces a set of alternatives into a subset of equally good alternatives. The sorting problem classifies alternatives into categories. The ranking problem orders alternatives from most to least preferred. The description problem describes reasonable alternatives and their consequences. Military staffs choose a course of action to recommend to the commander, and therefore engage in the choice decision type.

A third way to categorize decision making methods is based on the number of decision makers involved (Ishizaka & Nemery, 2013). Individual and group decision making methods are tailored to these two categories. Military planning involves a group, but the commander has sole authority to make a decision. Similarly, the chief of staff or executive officer has the final decision on which course of action is recommended to the commander. The group input in a military staff usually falls along lines of functional expertise, which are aggregated by the chief of staff or executive officer (Boukhtouta et al., 2004). This differs from group decision making where each group member has similar expertise in the decision subject area. Reinforcing this individual decision making categorization is the fact that all existing US and NATO methods are individual ones (Holzgrefe & Hester, 2014).

A fourth way to categorize decision making methods is based on the number of criteria considered (MacCrimmon, 1968). Approaches are generally divided into single or multiple criteria decision making methods. US and NATO doctrine requires commanders to identify several criteria important in developing the proposed mission courses of action, necessitating a multiple criteria approach (Holzgrefe & Hester, 2014).

Based on these categories, military course of action selection comprises a normative, individual, choice, and multiple attribute decision making problem. The first category describing theory deserves additional consideration as it does not result from an unchangeable element of the problem. Instead it reflects a choice of the organization that recommends the problem solving method.

Decision Theory

This review considers the broader decision theory literature in order to improve the generalizability, reliability, and validity of the proposed framework beyond the focus on alternative analysis and selection methods (Lincoln & Guba, 1985). It also expands the body of empirical materials available for theme induction. This review contains a section for each of the three schools of decision theory identified by Bell, Raiffa, and Tversky (1988): normative, descriptive, and prescriptive.

Normative Decision Theory

Normative decision making describes how one should decide based on achieving the most desirable outcome, as determined by maximizing the utility of the decision maker. The idea of utility, or subjective value, began with Bernoulli's contention in 1738 that the utility of money decreases as the total amount increases (Bernoulli, 1954). Bernoulli proposed a logarithmic function for utility, but no quantitative tools were developed until 1947 when von Neumann and Morgenstern published the second edition of *Theory of Games and Economic*

Behavior. Von Neumann and Morgenstern developed Utility Theory which applies to non-monetary values and could be measured by lotteries. These lotteries determined the decision maker's expected probability and desirability of outcomes (Goldstein & Hogarth, 1997). A decision maker that maximizes their utility in accordance with Utility Theory's axioms is considered rational, and development or divergence from this rationality is the basis for subsequent developments in decision theory.

Criticisms of Utility Theory stem from observed behavior, experiments, and psychology. Allais (1953) observed that people preferred a certain payout to a lottery of greater value. Ellsberg (1961) observed that people preferred a lottery with certain odds over one with uncertain odds, even if the expected value of the latter was greater. Simon (1964) argued that humans are incapable of perfect rationality and instead behave within a bounded rationality. Tversky and Kahneman (1974) experimentally demonstrated systemic biases resulting from heuristics, which are decision rules of thumb that violate utility theory. With these criticisms in mind, other decision researchers sought out different theories on decision making.

Descriptive Decision Theory

Descriptive decision making describes how people actually make decisions. Blaise Pascal (1670) famously described one's belief in religion as a wager, laying the foundation for probability and decision theory (Ore, 1960). Modern contributions to descriptive decision making began with Simon's (1964) satisficing and include two alternatives to Utility Theory in Prospect Theory and Social Justice Theory. A third modern idea, Naturalistic Decision Making, also falls in the descriptive school. Each of these is explained in more detail below.

Satisficing is a portmanteau of satisfy and suffice coined by Simon (1956) to describe the choice of an acceptable solution within people's bounded rationality. The solution can be optimal, but it is not forced to be. Simon described this heuristic as a decision maker setting an acceptable threshold for a solution and then searching for a solution that meets the threshold (Simon, 1956). This decision making strategy accounts for his contention that humans are unable to act as perfectly rational utility optimizers as described in the axioms of Utility Theory (Simon, 1964). Satisficing sparked research into heuristics, with at least 41 additional methods being identified (Shah & Oppenheimer, 2008).

Kahneman and Tversky (1974) developed Prospect Theory to explain the heuristics and biases they experimentally observed during research into decision making. Kahneman and Tversky identified representativeness, availability, and anchoring heuristics that lead to a series of biases that violated the axioms of Utility Theory. Prospect Theory contends that value is thought of as losses or gains in welfare or wealth compared to a reference point rather than the final outcome, as in Utility Theory (Kahneman & Tversky, 1979). Prospect Theory proposes a utility function, like that show in Figure 1 below, which captures people's increased sensitivity to losses vice gains (Kahneman & Tversky, 1979). It also reflects Bernoulli's (1954) idea of the diminishing value of increasing gains.

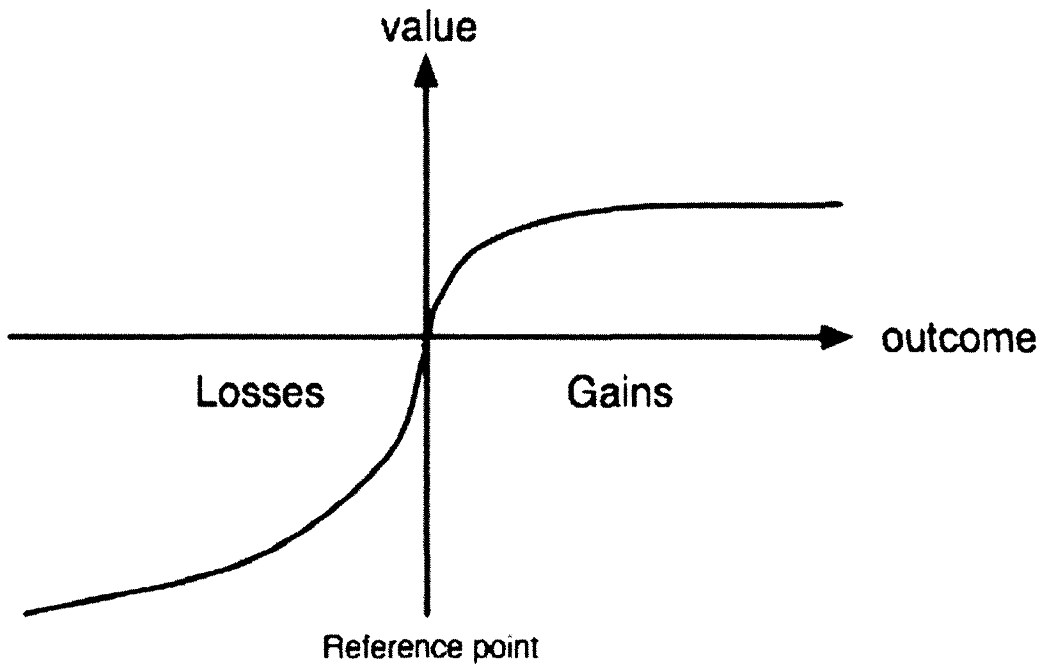


Figure 1: Prospect Theory value function. Drawing by M. Grieger (2006). Retrieved from http://commons.wikimedia.org/wiki/File:Valuefun.jpg. Copy permission released under the GNU Free Documentation License.

Social Judgment Theory (Hammond, Stewart, Brehmer, & Steinman, 1975) differs from Utility Theory and Prospect Theory because decisions are made in the moment with an emphasis on experience rather than any consideration of the future. The decider interprets cues from the environment and makes a decision based on their interpretive capability (Doherty & Kurz, 1996). This means that different deciders will make different decision based on the same information because of their different interpretations of the decision and its context.

Naturalistic Decision Making attempts to describe how experts choose in situations that are characterized by volatility, limited resources, and high stakes (Todd & Gigerenzer, 2001). Researchers studied military officers, firefighters, and other professionals that frequently made important decisions under stress

(Klein, 2008). The results described a recognition-primed decision where a small number of important variables were observed to conduct a rapid series of mental simulations based on past experiences (J. G. Johnson & Raab, 2003). From these simulations a satisfactory solution is chosen and quickly implemented.

Prescriptive Decision Theory

Prescriptive decision making describes how to prepare people to make good decisions in real world settings. Sometimes referred to as decision analysis, this field focuses on the broader aspects of decision making beyond alternative analysis and selection, like alternative generation. Although dozens of decision analysis techniques exist, this review will focus on the most popular three as representative of the population: Value Focused Thinking, the Decision Analysis Cycle, and the Analytical Hierarchy Process (Keefer, Kirkwood, & Corner, 2002).

Keeney's (1992) Value Focused Thinking (VFT) prioritizes an iterative front-end investigation of the decision maker's values in order to avoid biases and generate creative alternatives that match the true problem and its context. The decision maker's values create criteria for analyzing the desirability of each alternative. Keeney (1992) allows for any alternative analysis and selection method within VFT, including those that produce a suboptimal, yet more equitable, outcome.

Howard's (1984) Decision Analysis Cycle uses three phases to turn information into a decision. The deterministic first phase structures the problem by defining variables and their relationships in formal models. The decision maker scores potential outcomes as well, allowing for a sensitivity analysis on the variables. The probabilistic second phase creates a decision tree that captures the decision maker's probabilities and calculates a cumulative probability distribution for each outcome. Next, a utility function reflecting the decision maker's risk preference is constructed, allowing identification of the preferred alternative in the face of uncertainty. Sensitivity analysis on the probabilities follows. The informational third phase decides if the first two phases have identified a satisfactory solution or if additional information is required to begin another iteration. This feedback loop considers the expected benefit of additional information before conducting additional work. The decision maker may take action once the cycle produces a satisfactory solution.

Saaty's (1980) Analytical Hierarchy Process eschews utility theory and instead prescribes an intensity scale to rank the relative preference of attributes and alternatives against one another in several matrices of pair-wise comparisons. The sum of the products of weights and scores for each alternative produce a final priority, with the preferred alternative having the highest score. Critics cite intransitivity and rank reversal as fatal flaws in AHP (Belton & Gear, 1983; Triantaphyllou, 2010), while proponents respond that all prescriptive methods pose axiomatic challenges (Forman & Gass, 2001). AHP remains popular though, with hundreds of applications in dozens of fields reported (Forman & Gass, 2001).

Decision Theory Summary

Normative, descriptive, and prescriptive decision making provide three literature streams to complement the military decision making stream that follows. These streams cover disparate methods with varying levels of conformance to traditional Utility Theory. These methods also vary in their focus from those that only compare alternatives to those that try to generate creative alternatives. This expanded view facilitates Lincoln & Guba's (1985) approach of triangulation to add trustworthiness in qualitative investigations. Table 2 below lists the empirical materials used for the military, normative, descriptive, and prescriptive literature streams. The lists are also provided in Appendices A through D.

Table 2: Empirical materials for each literature stream.

Military Decision Making (25)	
Anderson, Slate	2003
Boukhtouta, Bedrouni, Berger, Bouak, Guitouni	2004
Dees, Nestler, Kewley	2013
Ewing, Tarantino, Parnell	2006
Holbrook	2003
Holzgrefe, Hester	2014
Isaak, Wheeler	2012
Killion	2010
Klimack, Kloeber	2006
MacGregor	1992
Matthews	2004
Morrison, Kelly, Moore, Hutchins	1996
NATO	2010
Phillips	2004
Schwartz	2010
Spruill	2012
US Air Force	2012
US Army	2010
US Army	2011
US Army War College	2010
US Department of Defense	2008
US Joint Staff	2011
US Joint Staff	2012
US Marine Corps	2010
US Navy	2007

Normative Decision Making (34)	
Bernoulli	1738
Charnes, Cooper, Ferguson	1955
Charnes, Cooper, Rhodes	1978
Churchman, Ackoff	1954
Clemen	1991
Edwards	1977
Edwards, Barron	1994
Einbu	1978
Einbu	1984
Everett III	1963
Figueira, Greco, Ehrgott	2005
Fishburn	1967
Hwang	1987
Keeney	1971
Keeney, Raiffa	1976
Koksalan, Wallenius, Zionts	2011
Koopman	1953
Lehmann	1950
Luce	1956
Luce & Raiffa	1957
Luss, Gupta	1975
MacCrimmon	1968
Miller, Star	1960
Patriksson	2008
Powell, Shapiro, Simao	2002
Raiffa	1968
Savage	1954
Schniederjans	1984
Triantaphyllou	2010
Triantaphyllou, Mann	1989
Von Neumann, Morgenstern	1947
Wald	1939
Wallenius, Dyer, Fishburn, Steuer, Zionts	2008
Yoon, Hwang	1995

Descriptive Decision Making (17)	
Allais	1953
De Martino, Kumaran, Seymour, Dolan	2006
Ellsberg	2001
Foulds	1983
Gilovich, Griffin, Kahneman	2002
Hastie, Dawes	2001
Johnson, Payne	1985
Kahneman	2013
Kahneman, Slovic, Tversky	1982
Kahneman, Tversky	1979
Kahneman, Tversky	2000
Klein	1993
Klein	2008
Pascal	1670
Simon	1956
Tversky	1972
Tversky, Kahneman	1992

Prescriptive Decision Making (34)	
Behzadian, Kazemzadeh	2010
Brans, Vincke, Mareschal	1986
Bangla, Castanon	2010
Chen, Hwang	1992
Chen, Larbani, Chang	2009
Costa, Vansick	1999
Eberle	1972
Hwang, Lai, Liu	1993
Hwang, Lin	1987
Hwang, Yoon	1981
Jain	1976
Keeney	1992
Keeney, McDaniels	1992
Klir, Yuan	1995
Lai, Lio, Hwang	1994
Lake	1976
Luss	1999
Millet, Saaty	2000
Parnell, Driscoll, Henderson	2010
Pugh	1991
Roy	1981
Roy	1990
Saaty	1980
Saaty	1982
Saaty	1994
Saaty	2008
Saaty, Alexander	1989
Saaty, Forman	1996
Saaty, Vargas	1991
Saaty, Vargas	1994
Triantaphyllou, Mann	1990
Wang	2012
Zadeh	1965
Zimmerman	1985

Multiple Attribute Decision Making Methods

Multiple attribute decision making defines a class of problems where a decision maker must choose from a finite number of predetermined alternatives based upon their performance against a finite number of criteria (S. J. Chen & Hwang, 1992). Multiple attribute decision making is often subcategorized under multiple criteria decision making, which also includes a subcategory for multiple objective decision making. In practice, military planners stay under the 7±2 recommendation of Miller (1956) for both COAs (alternatives) and criteria. Three additional characteristics are shared by multiple attribute decision making problems (S. J. Chen & Hwang, 1992). First, criteria within multiple attribute decision making problems often have different units of measure. These different units limit the types of methods that can be applied without the introduction of utility theory or conversions (Von Neumann & Morgenstern, 2007). Second, multiple attribute decision making criteria often conflict with one another, like the tradeoff in a COA between protection and speed. Third and finally, decision makers may weight different criteria based upon their assessment of relative merit. Organizations use multiple attribute decision making methods worldwide and at all levels (Triantaphyllou, 2010), to include militaries in their planning processes (Boukhtouta et al., 2004).

Multiple attribute decision making methods may include several steps of the "canonical paradigm" of decision making described by Bell, Raiffa, and Tversky (1988). These sevens steps are:

1. Recognition that a problem or an opportunity exists
2. Defining the problem or opportunity
3. Specifying goals and objectives
4. Generating alternatives
5. Analyzing alternatives
6. Selecting an alternative
7. Learning about the decision (Tang, 2006).

This research focuses on methods for the analysis and selection of alternatives because all multiple attribute decision making methods include these steps at the minimum. This subset of methods will be referred to as alternative analysis and selection methods to distinguish them from broader methods that cover additional steps.

Military Planning

Military planning may be initiated for different reasons. Planning may be hasty for an unexpected contingency, or deliberate for a well known threat. Plans may be created for a near term operation, or shelved as the basis for a future expected crisis. Planning is conducted for both real world issues and in military exercises that seek to replicate actual conflict. Planning applies across the spectrum of operations, from humanitarian assistance and disaster relief to world war. This diversity of planning is further complicated by the levels at which it may be executed.

Military staffs worldwide conduct planning daily at all three levels of war (Killion, 2000). At the tactical level of war, Army and Marine battalions along with Air Force squadrons plan operations involving hundreds of service members employing dozens of weapon systems. At the operational level of war Army Corps, Marine Expeditionary Forces, Named Air Forces, and Numbered Navy Fleets assist Regional Combatant Commands in planning campaigns that accomplish strategic objectives within large geographic theaters. These operations require thousands of service-members armed with thousands of weapon systems. At the strategic level of war staffs within the service headquarters, the Joint Staff, and allied staffs plan for simultaneous worldwide operations involving several nations. Despite this variety, the organizations of the staffs conducting this planning are remarkably the same.

A military staff works for the commander. The commander is responsible for everything that the staff and his or her unit accomplishes or fails to accomplish. Staffs are usually led by a senior officer subordinate to the commander. This allows the commander to place him or herself where they best see fit rather than being tied to the headquarters. The staff leader may be called the Executive Officer, Deputy Commander, Chief of Staff, or another title depending on the organization. This officer leads the staff through military planning. The staff itself is comprised of functional experts from different specialties like operations, intelligence, human resources, logistics, and communications. Staffs grow in size and complexity at higher levels of the organizations. Staffs are filled with enlisted service members, non-commissioned officers, warrant officers, and commissioned officers, with ranks commensurate with the staff's level within the organization. Civilians also serve on more senior level staffs. The education level of these staff members can vary from a GED to a Ph.D., which constrains the choices of alternative analysis and selection methods that can be applied by the organization. Each of these staffs follows a fairly standardized planning process (Boukhtouta et al., 2004).

The military planning process begins with the receipt of a mission. Once received, staffs analyze the information available and seek to fill any gaps in their understanding of the operational environment. The Joint Staff (2011b) defines the operational environment as "a composite of the conditions, circumstances, and influences that affect the employment of capabilities and bear on the decisions of the commander." These include enemy, friendly, and neutral forces, civilians, infrastructure, weather, terrain, and the electromagnetic spectrum within the area of interest. This mission analysis phase is followed by the staff's development of several COAs for friendly, enemy, and sometimes neutral forces. Next, the staff conducts a war game to determine the merits of each COA. These COAs are then compared and a recommendation is made to the commander. This research focuses on the mechanism by which the COAs are compared in this step. The commander may select any COA, modify an existing COA, combine elements of COAs, create a new COA, or have the staff develop more COAs before choosing an actual COA for the mission. This primacy of the commander's decision is preserved at all levels within the organizations.

Each organization under consideration codifies their planning processes in doctrine that is distributed to their respective staffs. Doctrine has been traditionally built from the lowest levels up, since services existed before the Joint Staff and NATO. Table 3 below summarizes the organizations under review, their planning process name, and their doctrinal planning publication.

Table 3: Military planning processes.

Military Organization	Planning Process Name	Doctrinal Publication
US Army	Military Decision Making Process (MDMP)	Army Tactics, Techniques, and Procedures 5-0.1
USMC	Marine Corps Planning Process (MCPP)	Marine Corps Warfighting Publication 5-1
US Navy	Navy Planning Process (NPP)	Navy Warfare Publication 5-01
USAF	Joint Operation Planning Process for Air (JOPPA)	USAF Doctrine Document 3-0
Joint Staffs	Joint Operation Planning Process (JOPP)	Joint Publication 5-0
NATO	Operational Level of the NATO Crisis Response Planning Process	NATO ACO COPD V1.0

US Army

Chapter 4 of the US Army's *Commander and Staff Officer Guide* (2011) details the procedures that Army staffs undertake in military planning, which is referred to as the Military Decision Making Process (MDMP). Army MDMP consists of seven steps, as outlined in Figure 2 below. This research focuses on Step 5 of the MDMP, which details the Army's recommended three phase process for COA comparison. These phases are outlined in Figure 3 below. The reader should note that Figures 2 through 17 are reproduced directly from each organization's doctrinal document identified in Table 3 above.

Key inputs	Steps	Key outputs
• Higher headquarters' plan or order or a new mission anticipated by the commander	Step 1: **Receipt of Mission**	• Commander's initial guidance • Initial allocation of time
	Warning order	
• Higher headquarters' plan or order • Higher headquarters' knowledge and intelligence products • Knowledge products from other organizations • Design concept (if developed)	Step 2: **Mission Analysis**	• Problem statement • Mission statement • Initial commander's intent • Initial planning guidance • Initial CCIRs and EEFIs • Updated IPB and running estimates • Assumptions
	Warning order	
• Mission statement • Initial commander's intent, planning guidance, CCIRs, and EEFIs • Updated IPB and running estimates • Assumptions	Step 3: **Course of Action (COA) Development**	• COA statements and sketches - Tentative task organization - Broad concept of operations • Revised planning guidance • Updated assumptions
• Updated running estimates • Revised planning guidance • COA statements and sketches • Updated assumptions	Step 4: **COA Analysis (War Game)**	• Refined COAs • Potential decision points • War-game results • Initial assessment measures • Updated assumptions
• Updated running estimates • Refined COAs • Evaluation criteria • War-game results • Updated assumptions	Step 5: **COA Comparison**	• Evaluated COAs • Recommended COAs • Updated running estimates • Updated assumptions
• Updated running estimates • Evaluated COAs • Recommended COA • Updated assumptions	Step 6: **COA Approval**	• Commander-selected COA and any modifications • Refined commander's intent, CCIRs, and EEFIs • Updated assumptions
	Warning order	
• Commander-selected COA with any modifications • Refined commander's intent, CCIRs, and EEFIs • Updated assumptions	Step 7: **Orders Production**	• Approved operation plan or order

CCIR	commander's critical information requirement	EEFI	essential element of friendly information
COA	course of action	IPB	intelligence preparation of the battlefield

Figure 2: Steps in the US Army's MDMP. Reprinted from *Commander and Staff Officer Guide* (p. 4-3), by US Army, 2011, Washington, DC: US Government Printing Office. No copyright.

Key inputs	Process	Key outputs
• War-game results • Evaluation criteria • Updated running estimates • Updated assumption	• Conduct advantages and disadvantages analysis • Compare courses of action • Conduct a course of action decision briefing	• Evaluated courses of action • Recommended course of action • Course of action selection rationale • Updated running estimates • Updated assumption

Figure 3: US Army COA Comparison phases. Reprinted from *Commander and Staff Officer Guide* (p. 4-35), by US Army, 2011, Washington, DC: US Government Printing Office. No copyright.

The first phase of COA Comparison directs each staff member to write a list of advantages and disadvantages for each COA while considering the evaluation criteria (attributes) determined in Mission Analysis (Process 1 in Figure 3 above). Staff members initially focus on their individual area of expertise, then share insights with the rest of the staff (United States Army, 2011). Conducting this advantages and disadvantages analysis prepares the staff to compare the courses of action directly. Figure 4 below demonstrates this method.

Course of Action	***Advantages***	***Disadvantages***
COA 1	Decisive operation avoids major terrain obstacles. Adequate maneuver space available for units conducting the decisive operation and the reserve.	Units conducting the decisive operation face stronger resistance at the start of the operation. Limited resources available to establishing civil control to Town X.
COA 2	Shaping operations provide excellent flank protection of the decisive operations. Upon completion of decisive operations, units conducting shaping operations can quickly transition to establish civil control and provide civil security to the population in Town X.	Operation may require the early employment of the division's reserve.

Figure 4: MDMP Advantages/Disadvantages Table. Reprinted from *Commander and Staff Officer Guide* (p. 4-36), by US Army, 2011, Washington, DC: US Government Printing Office. No copyright.

The second phase of COA Comparison directs the staff to "use any technique that helps develop those key outputs and recommendations and assists the commander to make the best decision" (United States Army, 2011, pp. 4-36). Despite this latitude, only one method of COA comparison is presented. This method employs simple additive weighting with interval scale weights where less is better and ordinal scale ratings where less is better. The COA with the lowest total score may be deemed the "best". Figure 5 below shows the Army's decision matrix for this approach. Note that there is an error in the matrix as it appears in the doctrine. Specifically, the unweighted score for COA 2 underneath the Maneuver criteria should be a one instead of a two. This error was corrected in the replacement manual that was published in 2014 (United States Army, 2014a).

Weight[1]	1	2	1	1	2	
Criteria[2] / *Course of Action*	Simplicity	Maneuver	Fires	Civil control	Inform and influence activities	TOTAL
COA 1[3]	2	2 (4)	2	1	1 (2)	8 (11)
COA 2[3]	1	2 (2)	1	2	2 (4)	7 (10)

Notes:
[1] The COS (XO) may emphasize one or more criteria by assigning weights to them based on a determination of their relative importance.
[2] Criteria are those assigned in step 5 of COA analysis.
[3] COAs are those selected for war-gaming with values assigned to them based on comparison between them with regard to relative advantages and disadvantages of each, such as when compared for relative simplicity COA 2 is by comparison to COA 1 simpler and therefore is rated as 1 with COA 1 rated as 2.

Figure 5: US Army decision matrix method. Reprinted from *Commander and Staff Officer Guide* (p. 4-36), by US Army, 2011, Washington, DC: US Government Printing Office. No copyright.

There are several challenges with this methodology. First, some may find the use of a less is better approach to the weights as counterintuitive. Traditional simple additive weighting uses interval weights where greater weight values are better (Churchman & Ackoff, 1954). Unfortunately, the use of ordinal ratings forces this convention, which leads to another challenge. The use of ordinal ratings hides the magnitude of preference between COAs within a criterion (Stevens, 1946). For example, the staff may believe that COA 2 is four times better than COA 1 in the Simplicity criterion, but by ranking them one and two respectively the staff loses that level of detail. This lack of fidelity could lead to the wrong COA being recommended. In fact, traditional simple additive weighting uses interval or ratio scale ratings with a greater is better approach (Klee, 1971). No academic literature was discovered to support this mathematical methodology that combines ordinal and interval values in a less is better approach.

Another major challenge is the direct weighting of criteria by the decision maker. Von Nitzsch and Weber (1993) found that if decision makers cannot adjust weights to ranges, then the weights that are determined may not be appropriate. In fact, no academic literature was discovered to support the direct weighting of criteria without some range or bucket constraint. This omission calls into question the usefulness of the weights, and by extension the results, of the COA comparison and recommendation.

In addition to this overarching decision matrix, each staff officer is recommended to develop their own decision matrix for their specialty (United States Army, 2011). The Army guide cautions users about inferring too much from this quantitative comparison, suggesting that comparisons within criteria are most useful. It also gives the commander the flexibility to change any weight or rating after the fact, which calls into question the validity and utility of the methodology since weights should be determine beforehand (MacCrimmon, 1968) to prevent manipulation of the results to achieve a predetermined outcome. A better option would be for the staff to conduct a sensitivity analysis on the scores and weights if they are capable. This post hoc manipulation of weights should not be a problem in military planning since the commander makes the final COA selection anyway (Boukhtouta et al., 2004). This decision comes at the conclusion of the third and final phase of this step, the course of action decision briefing.

US Marine Corps

The Marine Corps Planning Process (MCPP) is defined in US Marine Corps Warfighting Publication (MCWP) 5-1 (United States Marine Corps, 2010). The MCPP begins with Problem Framing and contains six steps with an emphasis on cyclic planning as seen in Figure 6 below. The Course of Action Comparison and Decision step will be of most interest in this analysis.

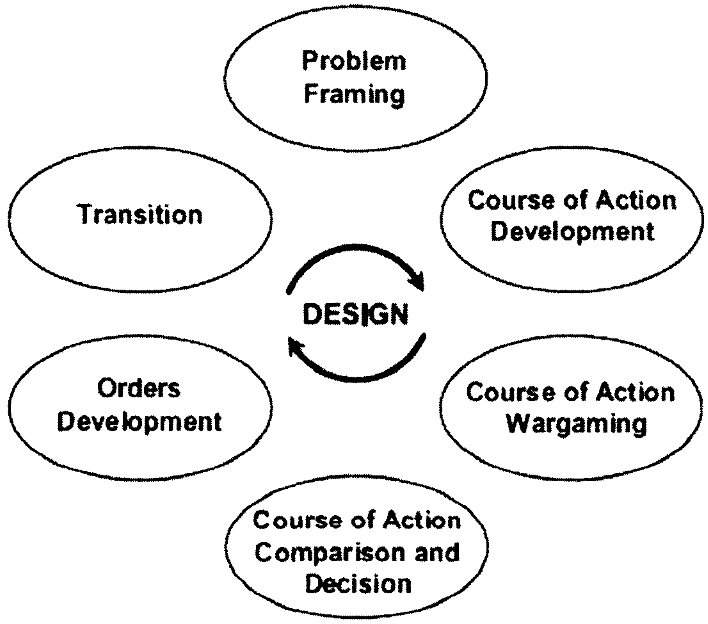


Figure 6: Overview of the Marine Corps Planning Process. Reprinted from *Marine Corps Planning Process* (p. 1-1), by US Marine Corps, 2010, Washington, DC: US Government Printing Office. No copyright.

The MCPP recommends comparing COAs with comments addressing each COA against each of the commander's evaluation criteria, as illustrated in Figure 7 below. It also warns against using any form of quantitative analysis, stating that "Commanders and staffs should guard against relying on numerical 'rankings' or other simplistic methods that can fail to underscore the complexity involved in the decision-making process" (United States Marine Corps, 2010, pp. E-9). This is an interesting perspective as the math and logic behind most alternative analysis and selection methods is anything but simplistic. It also seems to dismiss the numerous successful applications of such methods across many fields and the award of many prestigious prizes to the creators of those methods (Köksalan, Wallenius, & Zionts, 2011).

Commander's Evaluation Criteria	COA 1	COA 2	COA 3
Force protection	Moderate casualties	High casualties Increased chemical, biological, radiological, and nuclear threat	Light casualties
Tempo, surprise		Achieving surprise unlikely	High chance of achieving surprise
Shapes the battlespace	ACE interdiction of adversary lines of communications limits adversary's ability to reinforce		Deception likely to be effective
Asymmetrical operations	ACE operates against second echelon armor forces GCE mechanized forces attack adversary dismounted infantry	MEF mechanized forces against adversary mechanized forces	
Maneuver	Frontal attack followed by penetration	Frontal attack	Turning movement
Decisive actions	ACE disrupts deployment of second echelon forces through interdiction		Isolate first echelon forces Disrupt lines of communications, logistic facilities, and assembly areas
Simplicity		Simplest	Demanding command and coordination requirements.

Figure 7: MCPP decision matrix. Reprinted from *Marine Corps Planning Process* (p. E-11), by US Marine Corps, 2010, Washington, DC: US Government Printing Office. No copyright.

US Navy

The Navy Planning Process (NPP) is defined in Navy Warfare Publication (NWP) 5-01, *Navy Planning* (United States Navy, 2007). NPP is a six step process with some similar elements with MDMP and MCPP. Figure 8 below outlines the NPP, and like the MCPP, it emphasizes a circular process.

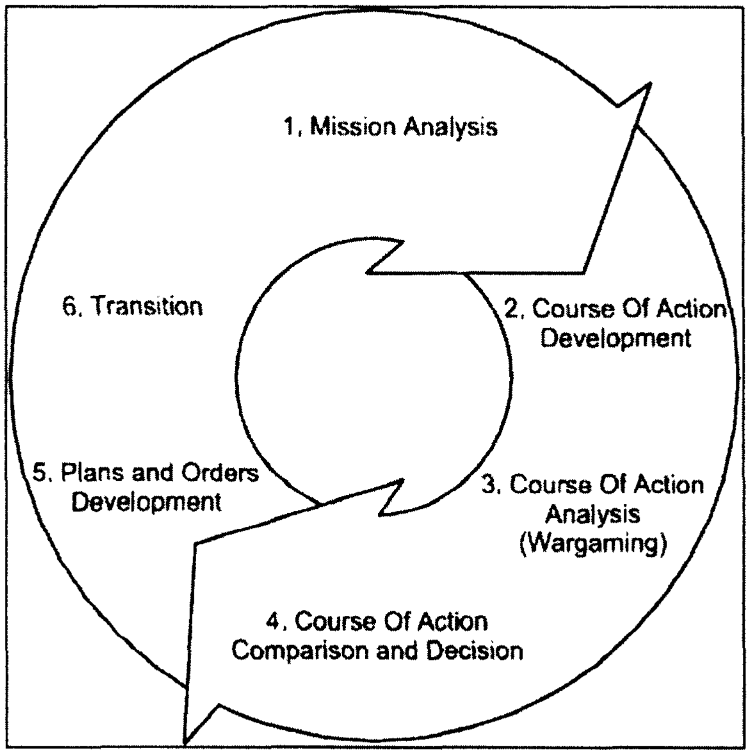


Figure 8: The Navy Planning Process. Reprinted from *Navy Planning* (p.1-4), by US Navy, 2007, Washington, DC: US Government Printing Office. No copyright.

The NPP recommends four methods to conduct COA comparison. The first is described as a non-weighted numerical method which simply adds ratings for each COA against each governing factor (criteria or attribute). This treats all governing factors equally. Ratings are applied on an interval scale with larger scores being better. The COA with the highest total score may be considered the most preferred. The results of this method can be seen in the TOTAL row of Figure 9 below.

GOVERNING FACTORS	WT	COA #1		COA #2		COA #3		COA #4	
SIMPLICITY	3	2	6	1	3	4	12	3	9
SURPRISE	1	2	2	3	3	3	3	4	4
SPEED	2	1	2	2	4	3	6	4	8
MASS	4	3	12	1	4	2	8	4	16
RISK	2	4	8	3	6	4	8	4	8
FLEXIBILITY	4	3	12	3	12	4	16	3	12
SUSTAINABILITY	3	3	9	3	9	2	6	3	9
C2	3	3	9	2	6	1	3	3	9
TOTAL		21		18		23		28	
WEIGHTED TOTAL			60		47		62		75

Figure 9: NPP decision matrix. Reprinted from *Navy Planning* (p.G-1-2), by US Navy, 2007, Washington, DC: US Government Printing Office. No copyright.

The second method recommended by the NPP is weighted numerical, which is known academically as simple additive weighting or the weighted sum method. This method also uses both ratings and governing factors' weights along an interval scale with a bigger is better approach. This matches the traditional simple additive weighting methodology (MacCrimmon, 1968). The COA with the highest weighted total may be described as the most preferred, as shown by the circled value in Figure 9 above.

The third method described by the NPP is called the Plus/Minus/Neutral Comparison Matrix, which is based on the Pugh Matrix of pair-wise comparisons (Pugh, 1991). This approach differs from all of the previous methods presented for two reasons. First, it requires at least two iterations to produce a recommendation. Second, the COAs are modified during the evaluation process. Each of these reasons contributes to an evaluation process that is lengthier than the others presented here. Changing the COAs during the evaluation process also blurs the lines between COA development and COA evaluation.

The Plus/Minus/Neutral Comparison Matrix method begins with the staff selecting one COA as the baseline for Round 1. The other COAs are given a plus(+), minus(-), or neutral(0) rating relative to the baseline COA. A plus score indicates that the COA has an advantage over the baseline COA. A minus score indicates a disadvantage, and neutral is no difference. The winning COA should have the highest number of plus ratings and the least number of minus ratings. If no COA receives any plus ratings, then the baseline COA is the winner. NWP 5-01 does not explain how to handle a tie, or if there is any compensation between plus and minus ratings. For example, what would be better, a COA with two plus and two minus, a COA with one plus, two neutral, and one minus, or a COA with four neutral ratings? Another challenge is that pluses, neutrals, and minuses do not capture the magnitude of advantage or disadvantage between COAs. The method does not suggest that multiple pluses or minuses may be used (i.e. "+ +" or "- - -"). Figure 10 below shows a sample comparison matrix for the first round.

GOVERNING FACTORS	COA #1	COA #2	COA #3
Casualty Estimate	+	Baseline	-
Sustainability	-		-
Risk	-		0
Flexibility	+		+
Number of "+"	2		1
Number of "0"	0		1
Number of "-"	2		2

Figure 10: NPP Plus/Minus/Neutral comparison matrix - Round 1. Reprinted from *Navy Planning* (p.G-2-2), by US Navy, 2007, Washington, DC: US Government Printing Office. No copyright.

In the example in Figure 10 above, COA 1 is selected as the new baseline because it has the highest number of positive markings (2) and is tied for lowest number of negative markings (2). Before the second round, the staff modifies COAs 1 and 3 to improve their disadvantages. The revised COA 1 is then set as the new baseline against COA 2 and the revised COA 3, as shown in Figure 11 below.

GOVERNING FACTORS	COA #1	COA #2	COA #3
Casualty Estimate	Baseline	-	-
Sustainability		+	+
Risk		+	+
Flexibility		-	0
Number of "+"		2	2
Number of "0"		0	1
Number of "-"		2	1

Figure 11: NPP Plus/Minus/Neutral comparison matrix - Round 2. Reprinted from *Navy Planning* (p.G-2-2), by US Navy, 2007, Washington, DC: US Government Printing Office. No copyright.

Round two is won by COA 3 since it is tied for the most pluses (2) and has one fewer minus that COA 2. COAs 2 and 3 are revised again before COA 3 is set as the baseline for Round 3. This process repeats itself until no significant improvement is possible and one COA emerges as best.

One advantage of this methodology is the explicit baseline for comparison, which differs from most of the other methods considered here. One disadvantage is that the magnitude of preference between pluses, minuses, and zeros is vague, which makes adding them suspect. Another challenge is that the COAs are being changed throughout the comparison, so insights on the COAs from the war-game become less relevant as the evaluation proceeds. Pugh (1991) intended for this method to screen and develop design concepts early in the product design cycle through a process he coined "controlled convergence."

Given Pugh's intent, it appears that this adaptation of his method may be more appropriate in COA development rather than COA comparison.

The fourth and final comparison matrix method recommended by the NPP is a simple advantages and disadvantages matrix, similar to the one found in the Army's MDMP (Figure 4). In this format though, the advantages and disadvantages are determined for the COA by using governing factors as the ratings. This also serves as a standalone analysis in NPP, in contrast to MDMP where it is the first phase of analysis. A column for modifications to the COA to compensate for disadvantages is also added. This adds an element of COA refinement to the evaluation, but less so than in the Plus/Minus/Neutral method. The staff may recommend a preferred COA based on this qualitative comparison. This is an example of another qualitative method that does not readily provide a most preferred solution. Figure 12 below provides an example.

COA	ADVANTAGES	DISADVANTAGES	MODIFICATIONS
COA #1	Command and control (C2) Logistics	Speed of operations Medical support	Begin phasing earlier in the operation Increase medical support request
COA #2	Simplicity of operation Flexibility	C2 in Phase 1	Increase bandwidth request Increase satellite availability request
COA #3	Speed Logistic support	Simplicity of operations Reserve forces merge confusing	Hold back reserves at main operating base until later in operation Merge reserve forces later in Phase 2 of operation

Figure 12: NPP Advantages/Disadvantages comparison matrix. Reprinted from *Navy Planning* (p.G-3-1), by US Navy, 2007, Washington, DC: US Government Printing Office. No copyright.

US Air Force

The Joint Operation Planning Process for Air (JOPPA) is defined in Air Force Doctrine Document (AFDD) 3-0, *Operations and Planning* (United States Air Force, 2012). Since it relies on the Joint Operation Planning Process (JOPP) described in the next section, no unique COA comparison method is recommended. What does set the USAF's guidance apart is that it prescribes risks to forces and risks to mission as evaluation criteria that should always be used. The USAF is the only US organization in this study that prescribes criteria. AFDD 3-0 also recommends outside sources for additional criteria, like the elements of operational design and principles of joint operations.

US Joint Staff

Doctrine for joint staffs, which are composed of personnel from more than one military department, is promulgated by the Joint Staff in Washington, DC. These staffs combine officers from the different services and plan at the operational level of war, so a common planning process was created (Anderson & Slate, 2003). The Joint Operation Planning Process (JOPP) is defined in Joint Publication (JP) 5-0, *Joint Operation Planning* (United States Joint Staff, 2011a). JOPP takes seven steps and closely mirrors the US Army's MDMP. Figure 13 below outlines the JOPP. This analysis focuses on Step 5, COA Comparison.

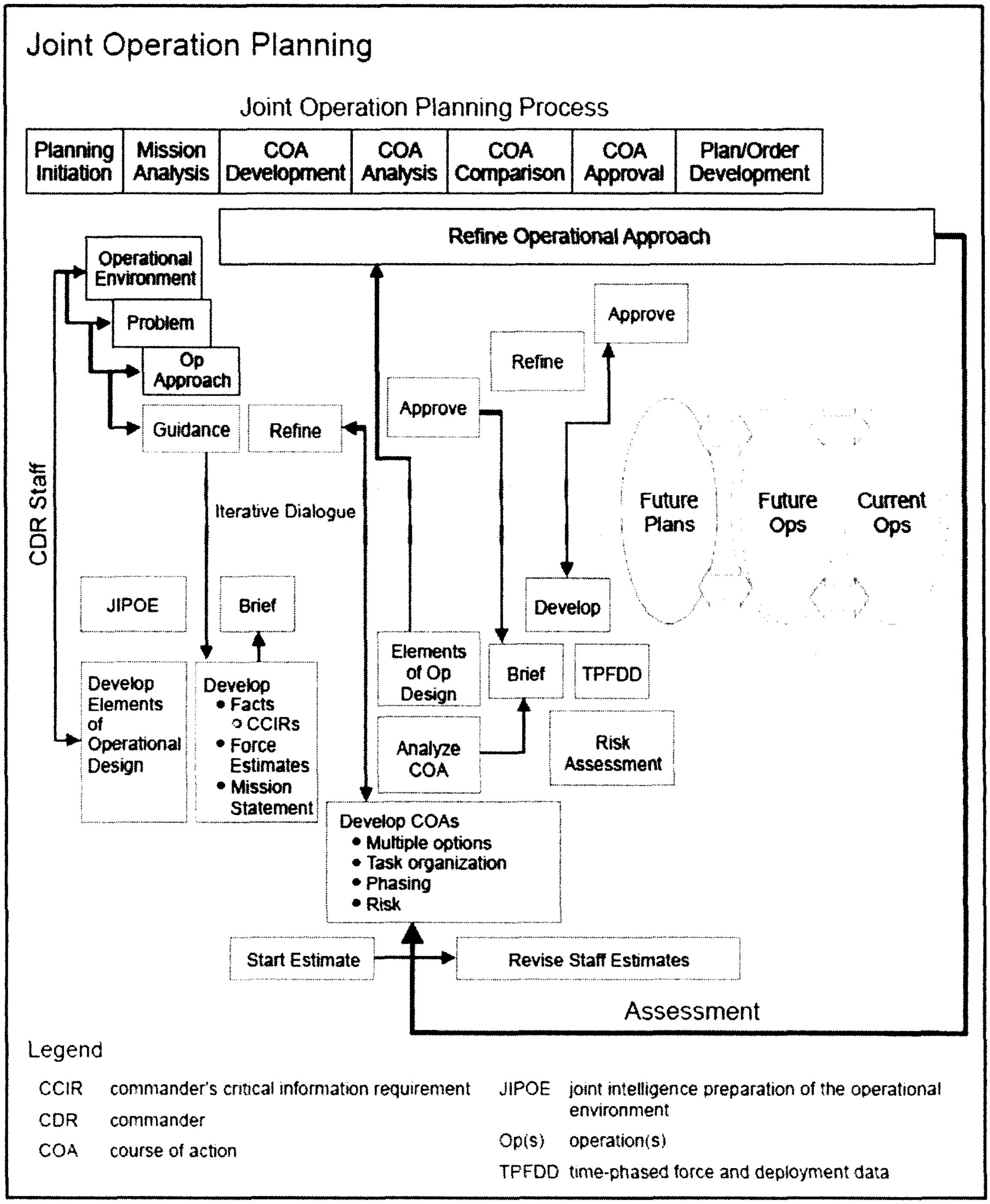


Figure 13: Joint Operation Planning Process Overview. Reprinted from *Joint Operation Planning* (p. IV-3), US Joint Staff, 2011, Washington, DC: US Government Printing Office. No copyright.

JOPP recommends five methods for COA comparison: Weighted Numerical, Non-weighted Numerical, Strengths and Weaknesses Descriptive Comparison, Advantages and Disadvantages Descriptive Comparison, and Plus/Minus/Neutral Comparison. The Weighted Numerical method is another variation of simple additive weighting, but does not match the Army or Navy approach exactly. JOPP uses interval weights and ordinal scores like the Army, but with a more is better valuation. Figure 14 below illustrates this method.

Evaluation Criterion	Weight	COA 1		COA 2		COA 3	
		Score	Weighted	Score	Weighted	Score	Weighted
Surprise	2	3	6	1.5	3	1.5	3
Risk	2	3	6	1	2	2	4
Flexibility	1	3	3	1.5	1.5	1.5	1.5
Retaliation	1	1.5	1.5	3	3	1.5	1.5
Damage to alliance	1	3	3	1.5	1.5	1.5	1.5
Legal basis	1	2	2	3	3	1	1
External support	1	3	3	2	2	1	1
Force protection	1	2.5	2.5	2.5	2.5	1	1
OPSEC	1	3	3	1.5	1.5	1.5	1.5
Total			30		20		16

Legend

COA course of action OPSEC operations security

Figure 14: JOPP Weighted Numerical comparison. Reprinted from *Joint Operation Planning* (p. G-3), US Joint Staff, 2011, Washington, DC: US Government Printing Office. No copyright.

COA 1 wins in the example in Figure 14 above due to having the largest sum of weighted rankings (30). Unfortunately, this approach suffers from one of the same challenges as the Army method. Specifically, the use of ordinal ratings (labeled Scores in Figure 14) does not capture the magnitude of preference between one COA's performance in an evaluation criterion over any other. This violates traditional rules requiring interval or ratio scale ratings in simple additive weighting (C. L. Hwang & Yoon, 1981). Users may also be confused by ranking the best COA with the highest rating. Note that this method allows for a tie between COAs within an evaluation criterion to be resolved by giving each a rating equal to the average of the ratings each would have received if they were ranked sequence. For example in Figure 14, COA 2 and COA 3 tie for the Surprise evaluation criteria, so they each receive a 1.5 instead of a 1 or a 2. No academic literature was discovered to support this mathematical methodology that combines ordinal and interval values in a greater is better approach.

A Non-Weighted Numerical Comparison is the second technique recommended in the JOPP. Despite sharing a name with the Navy's technique, the JOPP uses ordinal ratings unlike the Navy's interval ratings. Adding these ordinal ratings together, as shown in the totaled ratings boxes in Figure 15 below, violates Stevens' (1946) rules for the ordinal scale type.

		Course of Action					
		COA 1		COA 2		COA 3	
Criteria	**Weight**	**Rating**	**Product**	**Rating**	**Product**	**Rating**	**Product**
Exploits maneuver	2	3	6	2	4	1	2
Attacks COGs	3	2	6	3	9	1	3
Integrates maneuver and interdiction	2	2	4	3	6	1	2
Exploits deception	2	1	2	2	4	3	6
Provides flexibility	2	1	2	3	6	2	4
CSS (best use of transportation)	1	3	3	2	2	1	1
Total		12		**15**		**9**	
Weighted total			23		**31**		**18**

- The joint force commander's intent explained that the most important criterion was "attacking the enemy's COGs." Therefore, assign a value of 3 for that criterion and lower numbers for other criteria that the staff devises (**this is the weighing criterion**).
- For attacking the enemy COGs, COA 2 was rated the best (with a number of 3). Therefore, COA 2 = 9, COA 1 = 6, and COA 3 = 3.
- After the relative COA **rating** is multiplied by the **weight** given each criterion and the product columns are added, COA 2 (with a score of 31) is rated the most appropriate according to the criteria used to evaluate it.

Legend

COA course of action COG center of gravity CSS combat service support

Figure 15: JOPP Non-weighted and Weighted comparison techniques. Reprinted from *Joint Operation Planning* (p. G-2), US Joint Staff, 2011, Washington, DC: US Government Printing Office. No copyright.

COA 2 wins the non-weighted comparison in Figure 15 above due to having the highest total of rankings (15). The same result occurs when the weighted comparison is conducted in this example. Unfortunately these results are suspect due to the use of ordinal ratings. This method lacks both the ability to distinguish between the values of each criterion and the ability to discern magnitude of preference.

A Strengths and Weaknesses Descriptive Comparison is the third method recommended in the JOPP. This qualitative method uses narrative or bulletized statements to consider the strengths and weaknesses of each COA against each criterion. The use of strengths and weaknesses is fundamentally the same as the MDMP and NPP methods considering advantages and disadvantages, except that it considers strengths and weaknesses by criterion rather than across an entire COA. Figure 16 below demonstrates this method.

	Criteria 1		Criteria 2		Criteria 3	
COA 1	Strengths • •	Weaknesses • •	Strengths • •	Weaknesses • •	Strengths • •	Weaknesses • •
COA 2	Strengths • •	Weaknesses • •	Strengths • •	Weaknesses • •	Strengths • •	Weaknesses • •
COA 3	Strengths • •	Weaknesses • •	Strengths • •	Weaknesses • •	Strengths • •	Weaknesses • •

Legend
COA course of action

Figure 16: JOPP Strengths and Weaknesses Descriptive Comparison. Reprinted from *Joint Operation Planning* (p. G-4), US Joint Staff, 2011, Washington, DC: US Government Printing Office. No copyright.

The fourth method recommended in the JOPP simply replaces strengths and weaknesses with advantages and disadvantages. The uniqueness of this method is questionable, but it will be treated separately in this review to reflect how it is presented in the doctrine. Figure 17 below outlines this method.

	Criteria 1		Criteria 2		Criteria 3	
COA 1	Advantages • •	Disadvantages • •	Advantages • •	Disadvantages • •	Advantages • •	Disadvantages • •
COA 2	Advantages • •	Disadvantages • •	Advantages • •	Disadvantages • •	Advantages • •	Disadvantages • •
COA 3	Advantages • •	Disadvantages • •	Advantages • •	Disadvantages • •	Advantages • •	Disadvantages • •

Legend

COA course of action

Figure 17: JOPP Advantages and Disadvantages Comparison. Reprinted from *Joint Operation Planning* (p. G-4), US Joint Staff, 2011, Washington, DC: US Government Printing Office. No copyright.

Both of the preceding methods provide insights into COAs, but do not generate an easily identifiable preferred solution. Two staff officers with different valuations of criteria, strength, weaknesses, advantages, or disadvantages may arrive at a different preferred COA. This may be problematic for building consensus towards a recommendation for the commander.

The fifth and final method recommended by the JOPP is the Plus/Minus/Neutral Comparison. This method differs significantly from the Navy method of the same name and is much simpler. In JOPP the staff simply applies pluses, minuses, and zeros (for neutral) based on their assessment of the broad degree to which a criterion supports or is reflected in a COA. No baseline, totaling, or iterations are required. Figure 18 below demonstrates this method.

Criteria	COA 1	COA 2
Casualty estimate	+	-
Casualty evacuation routes	-	+
Suitable medical facilities	0	0
Flexibility	+	-

Legend

COA course of action

Figure 18: JOPP Plus/Minus/Neutral Comparison Matrix. Reprinted from *Joint Operation Planning* (p. G-5), US Joint Staff, 2011, Washington, DC: US Government Printing Office. No copyright.

The main advantage of this method is its simplicity. It is also qualitative and subjective. The information from this comparison could be fed into the frequency of good and bad features heuristic for a recommendation, but the doctrine does not mention this possibility (Alba & Marmorstein, 1987). One disadvantage of this method is that it does not provide a preferred or recommended COA.

NATO

A Joint Operations Planning Group (JOPG) conducts planning for allied operations following NATO's *Allied Command Operations Comprehensive Operations Planning Directive* (North Atlantic Treaty Organization, 2010). The directive compares COAs in three contexts, each having its own method. The first method lists advantages and disadvantages by COA, just like the first step in the Army's MDMP. The second method compares friendly COAs against the enemy's most likely and most dangerous COAs in terms of effectiveness, cost, and risk. This is the only method that explicitly mentions the two enemy COAs that are usually simulated in the war-gaming step of military planning that traditionally precedes COA comparison. Figure 19 below outlines this method.

	Own COA 1	**Own COA 2**	**Own COA 3**
Opposing Most Likely COA	Effectiveness: Costs: Risk:	Effectiveness: Costs: Risk:	Effectiveness: Costs: Risk:
Opposing Most Dangerous COA	Effectiveness: Costs: Risk:	Effectiveness: Costs: Risk:	Effectiveness: Costs: Risk:

Figure 19: NATO Friendly COA to Enemy COA Comparison. Reprinted from *Allied Command Operations Comprehensive Operations Planning Directive* (p. 4-62), North Atlantic Treaty Organization, 2010, Casteau, Belgium: NATO. No copyright.

The third and final comparison recommended by NATO evaluates COAs against the commander's selection criteria. The directive allows for any method of comparison (descriptive, plus/minus/neutral, rank ordering, numerical, or weighted numerical) that the commander prefers. This gives the staff maximum flexibility, but could also lead to the application of some of the questionable methods introduced thus far.

Summary of Methods in Military Planning

Several insights emerge from this portion of the literature review. First, there is a wide disparity in the methods recommended by each organization for COA comparison. This is somewhat surprising given the hierarchical and cooperative nature of these organizations' relationships to one another. Table 4 below summarizes the broad categories of COA comparison methods outlined in each organization's doctrine.

Table 4: COA comparison methods by organization.

		Broad COA Comparison Method				
		Descriptive	**Additive**	**Additive Weighting**	**Plus Minus Neutral**	**Enemy COA**
Organization	**USA**	Required	Recommended	Recommended	Allowed	Allowed
	USMC	Required	Prohibited	Prohibited	Not Addressed	Not Addressed
	USN	Recommended	Recommended	Recommended	Recommended	Not Addressed
	USAF	Allowed	Allowed	Allowed	Allowed	Allowed
	JS	Recommended	Recommended	Recommended	Recommended	Not Addressed
	NATO	Required	Allowed	Allowed	Allowed	Required

Table 5 below shows all of the COA comparison methods grouped into broad categories. There are 15 unique methods within these categories spread across the six organizations (really five since the USAF does not recommend any method) with almost no overlap. Interestingly, the methods divide almost evenly in to qualitative and qualitative types as show below.

Table 5: COA comparison method classification.

Organization	COA Comparison Method Name	Type	Broad Category
USA	Advantages/Disadvantages	Qualitative	Descriptive
	Unweighted Decision Matrix	Quantitative	Additive
	Weighted Decision Matrix	Quantitative	Additive Weighting
USMC	Narrative Description	Qualitative	Descriptive
USN	Nonweighted Numerical	Quantitative	Additive
	Weighted Numerical	Quantitative	Additive Weighting
	Plus/Minus/Neutral	Quantitative	Plus Minus Neutral
	Advantages and Disadvantages	Qualitative	Descriptive
Joint Staff	Weighted Numerical	Quantitative	Additive Weighting
	Non-weighted Numerical	Quantitative	Additive
	Strengths and Weaknesses	Qualitative	Descriptive
	Advantages and Disadvantages	Qualitative	Descriptive
	Plus/Minus/Neutral	Qualitative	Plus Minus Neutral
NATO	Advantages and Disadvantages	Qualitative	Descriptive
	Enemy Course of Action Comparison	Qualitative	Enemy COA

It is important to note that methods with the same or a similar name in Table 5 above are not performed in the same manner. Differences in the qualitative methods can be seen by inspecting the relevant Figures and accompanying discussion in the previous sections. Differences in the quantitative methods deserve additional consideration, beginning with the three un-weighted additive methods. Table 6 below summarizes these differences. Note that no two methods are the same.

Table 6: Unweighted additive COA comparison methods.

Organization	COA Comparison Method Name	Rating Scale	Directionality
USA	Unweighted Decision Matrix	Ordinal	Less is better
USN	Nonweighted Numerical	Interval	More is better
Joint Staff	Non-weighted Numerical	Ordinal	More is better

A similar rift occurs in the different application of the simple additive weighting method. The rating scales and directionalities remain different despite the common use of interval scale weights. Table 7 below summarizes these differences. Once again, no two methods are the same.

Table 7: Simple additive weighting COA comparison methods.

Organization	COA Comparison Method Name	Rating Scale	Weight Scale	Directionality
USA	Weighted Decision Matrix	Ordinal	Interval	Less is better
USN	Weighted Numerical	Interval	Interval	More is better
Joint Staff	Weighted Numerical	Ordinal	Interval	More is better

The literature reveals that some methods from military doctrine are not mathematically sound, which meets the author's expectation. It also reveals that staffs may not possess the human resources in terms of mathematical fluency to apply all alternative analysis and selection methods. Additionally, tactical staffs operating in austere environments may not have the capital resources in terms of computers to apply computationally intense alternative analysis and selection methods. This theme of resources limiting an individual's methodological choices demonstrates the importance of context in problem solving.

An additional finding of this portion of the literature review is that no document or tool exists that matches alternative analysis and selection methods to the information that staffs have available. This challenge, combined with the gap in understanding resources as an element of context, creates the opportunity for further investigation.

Problem Context

Problems do not exist in isolation. Problems are identified, studied, and hopefully solved by humans using resources. Those humans often belong to organizations that solve problems in teams. This interaction between a problem, the people solving it, their organization, and the resources available form a socio-technical system (Kroes, Franssen, van de Poel, & Ottens, 2006). System context includes events, incidents, factors, settings, or circumstances that in some way act on or interact with the system, perhaps as enabling or constraining factors (Crownover, 2005). This literature review has demonstrated how the human factor of mathematical fluency and environmental circumstance of planning in austere situations can constrain military staffs in their choices of alternative analysis and selection methods. These findings align with Crownover's (2005) elements of system context being human, systemic, methodological, and environmental. Each of these elements contains resources which must be considered as part of the socio-technical system context. With the understanding of resources as part of a problem's socio-technical system context in mind, an additional investigation of resources in warranted.

Resources

A resource is a stock or supply from which a person or organization can draw to function effectively or gain benefit. Generally, resources can be depleted, are not always available, and have some value. Resources have been categorized in dozens of ways, but perhaps the most common are the classical economic divisions of human, capital, and natural resources (Samuelson & Nordhaus, 2005). Human and capital resources have already been identified as part of the context surrounding alternative analysis and selection in this literature review.

Engineering management literature emphasizes the importance of understanding the interactions between humans and technical problems (Thamhain, 1992). Unfortunately, the majority of multiple attribute decision making literature focuses solely on the technical elements of solving a problem while ignoring human, political, organizational, managerial, policy elements (Adams & Keating, 2011). This literature review finds that military planning doctrine suffers the same shortcomings (North Atlantic Treaty Organization, 2010; United States Air Force, 2012; United States Army, 2011; United States Joint Staff, 2011a; United States Marine Corps, 2010; United States Navy, 2007).

Systems theory warns that ignoring these soft perspective elements of a problem often leads to unsatisfactory solutions (Adams & Keating, 2011). If one considers the military planning domain a system, then this violates the Contextual Axiom of Systems Theory (Adams & Keating, 2011). Frameworks provide a way for practitioners and managers to measure their adherence to theoretically grounded multiple attribute decision making method selection.

Frameworks

Frameworks provide logical structures for the completion of a task. Frameworks take many forms and should be tailored to the purpose of the task (Guthrie, Wamae, Diepeveen, Wooding, & Grant, 2013). Examples of frameworks include maturity models, management systems, and decision aids. This research intends to develop a framework for military staffs that may also be generalized for engineering managers.

Literature Review Findings and Gap Identification

The literature streams discussed in this chapter covered multiple attribute decision making, alternative analysis and selection methods, military planning, course of action analysis by organization, problem context, and resources. The major findings of this literature review are:

1. Military planning doctrine suggests some alternative analysis and selection methods in use are not mathematically defensible.
2. Military planning doctrine does not consider the problem's context in suggesting a method for course of action comparison.
3. Resources are an important piece of a problem's context.
4. Military planning doctrine does not provide a framework for staffs or supervisors to determine how well they are applying alternative analysis and selection methods.

These findings reveal a gap in the military planning doctrine that this research intends to corroborate in the more generalized context of engineering management. A general inductive approach will elicit themes from non-military course of action literature and general military decision making literature. A methodology that uses literature-induced themes to develop a framework will be the overarching contribution of this research. A case study within the research will apply the methodology to the problem discussed in this literature review to develop a tool for staffs to use to match military planning problems and their contexts to alternative analysis and selection methods. This tool will then be vetted by military planners for validity.

CHAPTER 3

METHODOLOGY

Introduction

The purpose of this research is to develop a framework for matching alternative analysis and selection methods to problems and their context. The general inductive approach, which is a qualitative research method, will be used to determine an appropriate set of evaluation criteria. Those criteria will then be organized into a framework for use by alternative analysis practitioners and their managers. The framework will help practitioners select the appropriate method for their problem and context. The framework will also assist engineering managers in assessing the efficacy of alternative analysis and selection within their organization. The framework will then be applied to alternative analysis and selection in the course of action selection step of US Army operational planning. This chapter presents the theoretical framework, description of the research environment, procedure, and justification of quality research for this investigation.

Theoretical Framework

A theoretical framework provides the existing theory and defined concepts for use in an inquiry (Anfara & Mertz, 2006). Theories predict events in a general context after extensive testing and are generally accepted among scholars (Leedy & Ormrod, 2010). Crotty (1998) describes the framework as a justification for the selection and application of methods and methodologies within the study, and suggests four questions to guide providing that justification:

> "What methods do we propose to use?
>
> What methodology governs our choice and use of methods?
>
> What theoretical perspective lies behind the methodology in question?
>
> What epistemology informs the theoretical perspective?" (Crotty, 1998, p. 2)

These questions are answered in reverse order throughout this chapter, beginning with a discussion of the researcher's theoretical perspective that includes not only the epistemological view, but also the ontological and methodological views recommended by Lincoln and Guba (1985). Morgan and Smircich's (1980) overview of the interrelated sets of assumptions regarding these elements of philosophy is presented in Figure 20 below and will be used to guide the subsequent discussion.

	Basic Epitemological Stance	**Core Ontological Assumptions**
Subjectivist ↑	To obtain phemenological insight, revelation	Reality as a projection of human imagination
	To understand how social reality is created	Reality as a social construction
	To map contexts	Reality as a contextual field of information
	To study systems, process, change	Reality as a concrete process
Objectivist ↓	To conduct positivist science	Reality as a concrete structure

Figure 20: Philosophical continuum. Adapted from "The Case for Qualitative Research," by G. Morgan & L. Smircich, 1980, *The Academy of Management Review, Volume* 5(4), p. 492. Copyright 1980 by the Academy of Management.

Ontological View

Ontology is the philosophical study of the nature of reality (Potter, 2013). It "attempts to describe existence in a logical manner" (Ezell & Crowther, 2007, p. 270). Potter (2013) describes the opposite ends of the ontological spectrum as idealism and materialism. The idealist believes that reality is only in one's mind, while the materialist believes in a fixed reality separate from our own (Ezell & Crowther, 2007). Morgan and Smircich (1980) use the broader terms subjectivist and objectivist to bookend their philosophical spectrum (Figure 20), with subjectivism aligning with idealism and objectivism aligning with materialism. This spectrum allows a researcher to identify their ontological position in an effort to match methodologies and methods to problems and context (Morgan & Smircich, 1980).

This problem exists within a military context that is largely objectivist. In order to avoid a potential philosophical divergence, an ontological perspective should be selected that is compatible with the eventual users of this research's outputs and outcomes (Adams & Keating, 2011). Based on the detailed descriptions provided by Morgan & Smircich (1980) and the author's experience in military planning, the approach of *reality as a concrete process* best matches this problem and its context. Specifically, these set of assumptions acknowledge the extreme difficulty in applying deterministic and reductionist methods to complex problems (Morgan & Smircich, 1980). This acknowledgment indicates the need for qualitative methods within the methodology. This set of assumptions also acknowledges the interactive relationship between humans and their world (Morgan & Smircich, 1980), and by extension the researcher to the inquiry (Erlandson, Harris, Skipper, & Allen, 1993). This interaction aligns with the naturalistic methods, like grounded theory, recommended by Lincoln and Guba (1985).

Epistemological View

Epistemology is the philosophical study of how we study reality (Ezell & Crowther, 2007). Potter (2007) describes an epistemological spectrum with constructivism at one end and realism at the other. Constructivists believe that knowledge is always a man-made construction because the world is independent of human minds (Crotty, 1998). Realists believe that mankind can come to know the truth about the natural world through objective observation (Ezell & Crowther, 2007). These constructivist and realist perspectives align with the subjectivist and objectivist approaches in Morgan and Smircich's (1980) continuum.

This research will study the process by which alternative analysis and selection methods are matched to problems and their context. This problem type, along with the objectivist context explained earlier, best match the epistemological stance *to study systems, processes, and change* described by Morgan and Smircich (1980). This epistemological stance aligns with the core ontological assumptions made in the previous section, as seen in Figure 20.

This stance reinforces the need for a qualitative method that studies a problem system and its context in a real setting, such as the case study method.

Methodological View

The methodological view within research philosophy begins with the inquirer's experience with different types of research methods. The author of this research has six years of higher education in civil engineering and six years of professional practice in operations research, both of which emphasize the quantitative and positivist methods of research. Despite this reductionist grounding, the author quickly realized that there was no methodology free of qualitative methods that could answer the research questions.

The methodology of this research may be thought of in terms of three methods. The first method elicits themes for evaluating alternative analysis and selection methods from the raw documents. The second method organizes those themes into a framework. The third and final method tests that framework in a real-world environment. This section discusses the philosophy and rationale behind each of the methods, beginning with theme elicitation.

The first method considered for eliciting an evaluation theme from the body of knowledge was content analysis. Content analysis systematically examines the contents of empirical materials for the purpose of identifying patterns, themes, or biases (Leedy & Ormrod, 2010). Unfortunately, content analysis does not allow for the induction that is supported by the ontological view discussed earlier (Creswell, 2013). Specifically, the deductive determination of empirical material themes in content analysis does not match with the inductive reasoning supported by naturalistic inquiry (Lincoln & Guba, 1985). This mismatch led to the search of another method.

The second method considered for evaluation theme elicitation was grounded theory. Grounded theory is a systematic, qualitative, social science method that discovers theory through the analysis of data (Martin & Turner, 1986). Birks and Mills (2011, p. 113) define the theory in grounded theory as "an explanatory scheme comprising a set of concepts related to each other through logical patterns of connectivity." Unfortunately, much published research that claims to be grounded theory does not actually generate theory, but instead simply provides a qualitative description with none of explanatory power required in theory development (Birks & Mills, 2011). With this caution in mind, and a mismatch in goals between theory generation and theme elicitation, the search for an appropriate method continued.

The third and final method considered for evaluation theme elicitations was the general inductive approach. The general inductive approach is a systematic qualitative research method used to describe the most important themes in a body of literature (D. R. Thomas, 2006). Thomas (2006) originally developed the approach to identify themes in evaluations, which matches with the purpose of this research to develop a framework. This inductive approach was also selected because it matched the researcher's intent to derive a model, in the form of the framework, from detailed readings of the literature. The literature serves as the raw data, or empirical materials as many qualitative researchers prefer to call them (Myers & Avison, 2002), while avoiding much of the academic criticism surrounding grounded theory (G. Thomas & James, 2006). This approach is consistent with grounded theory's practice of allowing the data to drive the discovery, but differs in that the researcher is not seeking to postulate a new theory (Glaser, 1998). In contrast, the general inductive approach is more focused on the research objectives and describing the literature's most important themes (Leseure, Bauer, Birdi, Neely, & Denyer, 2004). With the theme elicitation method identified, an additional method was sought to identify a structure for the evaluation.

Frameworks come in many structures and are usually tailored to specific types of tasks (Kahan, 2008). Most frameworks take the physical form of a two-dimensional table with either criteria or a value scale along each of the axes. Other frameworks take on a more complex structure, but that complexity does not match the desired practicality sought in the framework developed from this research. It also does not match with the objectivism identified in the problem's context, risking a philosophical divergence (Adams & Keating, 2011). Despite limiting the structure to two dimensions, there are still numerous frameworks to choose from. Given this large selection, a satisficing approach will be used to find the framework. Satisficing seeks the first alternative that meets or exceeds a satisfactory level of performance across criteria (Simon, 1956). The first criterion, a framework with two dimensions, has already been identified. The remaining criteria will be identified once the structure of the evaluation theme is determined. With the framework selection method identified, an additional method was sought to test the framework development methodology in a real-world environment.

Leedy and Ormrod (2010) recommend the case study method when a researcher seeks to validate a theory or hypothesis in an operational setting. This research seeks to test the framework development methodology in the unique case of military planning, so the case study provides a good match based upon purpose and outputs. Case studies also require similar subjectivist assumptions that align with the ontological and epistemological positions identified in the two previous sections, and therefore provide a good philosophical match (Morgan & Smircich, 1980). With the final method of the overarching research methodology identified, the discussion of the methodological view of the research philosophy is complete.

Research Environment

Participants

The human population of interest in the case study consists of military staffs in the US DoD and NATO. The generalized population of interest includes technical organizations that use alternative analysis and selection methods. No human subject participation is proposed for experimentation in this study.

Setting

This study will be conducted on unclassified information provided to the public via Old Dominion University's libraries, its affiliates, and the internet. The data will be stored and manipulated on a Microsoft Windows XP Professional computer using Microsoft Office 2007 and QSR NVivo 10. Analysis will be conducted by the author at Old Dominion University.

Procedure

This research will be conducted in three phases that align with the research questions. Phase one uses the general inductive approach to determine an appropriate set of criteria on which to select an alternative analysis and selection method based upon a problem and its context. Phase two organizes the criteria from phase one into a compatible framework selected via satisficing from a literature review once the evaluation theme structure is understood. Phase three demonstrates the framework in a case study of alternative analysis and selection in the course of action selection step of military planning. Figure 21 below provides a flowchart of the research. Each phase is described in more detail in the following paragraphs.

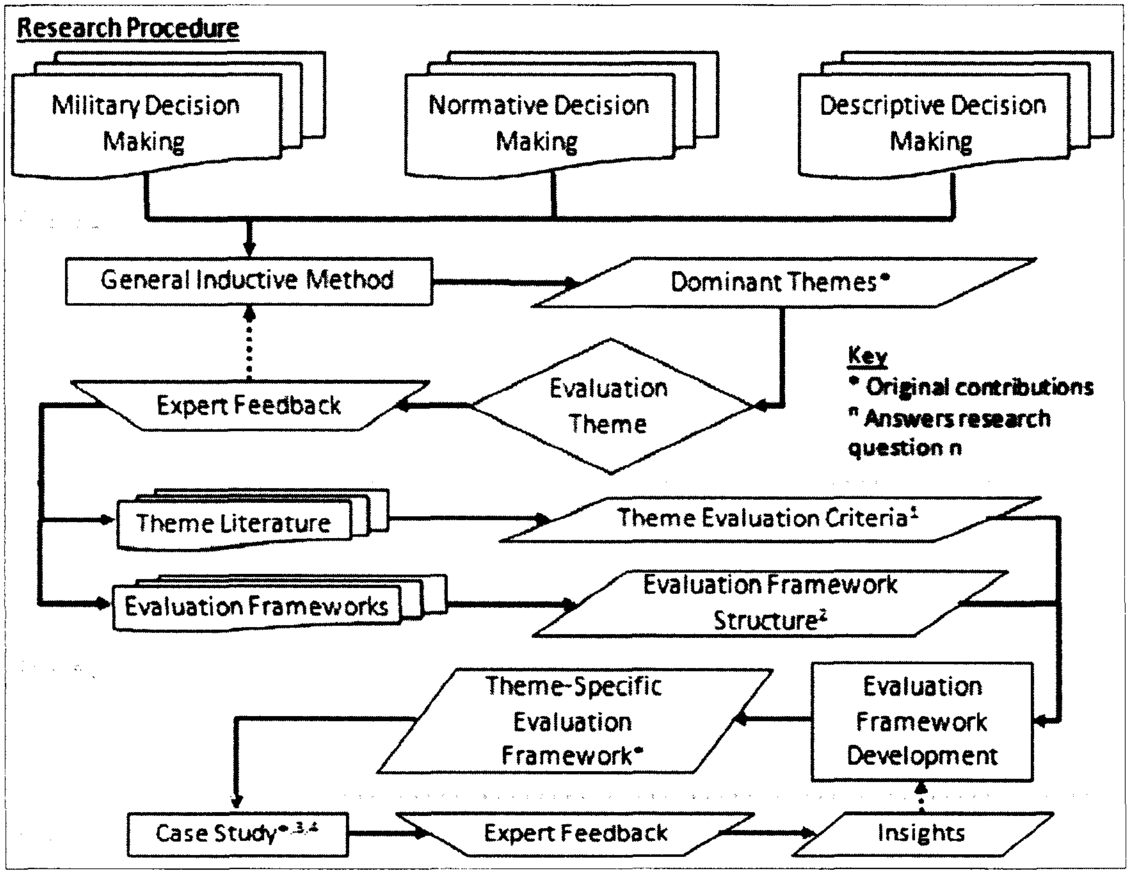


Figure 21: Research flowchart

Phase One – Criteria Theme Induction

The first phase of this study uses the general inductive approach described in the Methodological View section of this chapter to answer Research Question 1. In the case of this research, the themes sought are ones that can lead to a set of useful criteria for selecting an appropriate alternative analysis and selection method, both in terms of the problem itself and its context. This research will follow Thomas' (2006) steps for the general inductive method.

The first step of this phase collects and organizes the documents included in the literature review. The author used Thomas Reuters' EndNote X5 reference management software to process the empirical materials. Each document is loaded into an EndNote library with bibliographical data and the researcher's notes saved as an entry.

The second step of this phase cleans the data in preparation for close reading and computer analysis with qualitative data analysis software. QSR's NVivo 10 was selected for this research based upon three factors. First, it came highly recommended by two fellow researchers within the department who had conducted similar style research. Second, NVivo is easily available (Bazeley, 2013). Third, a comparative investigation of different qualitative data analysis software found negligible differences in the results of analyzing the same empirical materials for common primary research questions (Evers, Silver, Mruck, & Peeters, 2011). Empirical materials will be converted into NVivo compatible formats if necessary. Much of the data in this research comes from digitally published materials, so little effort is expected for journal articles, audio, video, social media, and web pages (Bazeley, 2013). Books and other hard copy material will have to be converted by hand.

The third step of this phase requires close reading of the text until the researcher understands the content's themes and events (D. R. Thomas, 2006). This manual identification of themes will complement NVivo's analysis in the next step. This step concludes when the researcher no longer identifies new themes while reviewing additional literature.

The fourth and final step of this phase creates a hierarchy of categories. Specific text segments related to the research objectives are identified and coded. These coded text segments are subsequently organized into categories. Coding tells the observer what to look for in the subject material (Leedy & Ormrod, 2010). Precise coding prevents observer bias by providing detailed instructions on what content meets the categories and criteria under consideration (Leedy & Ormrod, 2010). Codes are nested within categories and subcategories, which should flow from the data rather than be predefined by the investigator (Kondracki & Wellman, 2002). A hierarchical tree structure is often used to show the relationships between categories at the top and codes at the bottom (Morse & Field, 1995). This step will use NVivo software to assist in the coding and categorization as recommended by Durkin (1997). Themes should emerge as categories are aggregated, leading to a set of applicable criteria (Leseure et al., 2004). One or more of these themes will be selected as the basis for a set of criteria to form the evaluation measures for the framework.

Phase Two – Framework Development

The second phase of this study selects a set of criteria based upon the theme or themes identified in phase one and applies them to a framework. This phase will identify the exact theme criteria to be used and determine the appropriate framework in which to place the criteria. This phase will be accomplished in three steps.

The first step of this phase determines the criteria based upon a content analysis of literature associated with the theme induced from general inductive method. The author will select the evaluation theme criteria from the literature that best support the aim of the research (Guthrie et al., 2013).

The second step of this phase selects a framework based on the best fit of the evaluation theme criteria. A review of the framework literature will use a satisficing search to match the number of evaluation dimensions and evaluation theme criteria. Once the framework is selected, the theme criteria and framework will be merged into the problem-specific framework that is tailored to this problem and its context.

Phase Three – Case Study

The third phase of this study takes the framework and applies it to the specific case of alternative analysis and selection in the course of action selection step of U.S. Army operational planning. This case, which is described in the literature review, will demonstrate the usefulness of the framework. The framework will be applied to the case resulting in a tool that staffs and commanders can use to match alternative analysis and selection methods to their military planning problem and its context. Once the framework is established, it will be sent to subject matter experts in military planning for an assessment of credibility. Insights will then be drawn from the application of the framework for generalization to broader engineering management contexts.

Yin (2012) recommends an iterative six step process for case studies following these steps: 1) plan, 2) design, 3) prepare, 4) collect, 5) analyze, and 6) share. This section follows these steps to describe the procedure for the case study.

Planning the case study begins with determining if the case study is an appropriate method for the research (Yin, 2012). The methodological view section presented earlier in this chapter presents the philosophical argument for choosing a case study for this problem and its context. In addition, this choice follows Yin's (1994) recommendation for the case study method in research asking "how" questions and research focusing on contemporary events.

Designing the case study consists of five components: 1) research question statement, 2) propositions, 3) unit of analysis, 4) logic linking data to propositions, and 5) criteria for interpreting the findings (Yin, 2012). The research question this case study seeks to answer is: *How credibly does the framework apply to a real world problem and context?*

Propositions direct "attention to something that should be examined within the scope of the study" (Yin, 1994, p. 21). Two propositions have been identified for this study. The first examines if resources would be an appropriate criteria theme for evaluating an alternative analysis and selection method. This proposition is based upon the repeating theme of resources in the literature review (Boukhtouta et al., 2004; United States Air Force, 2012; United States Army, 2011; United States Joint Staff, 2011a, 2011b, 2012; United States Marine Corps, 2010; United States Navy, 2007). The second proposition examines how well a method improves understanding of the problem and its context, versus just providing an answer. This proposition is based on a suggestion from an Australian defense scientist studying some of the same issues (F. Bowden, personal communication, July 30, 2014). These two themes will be explored in the case study.

The unit of analysis defines what case will be used in the case study (Yin, 1994). This case study considers the alternative analysis and selection methods used in the course of action comparison step of the US Army's operational planning process. The literature review provides a detailed overview of this case.

Yin's (1994) fourth component of case study design links data to the propositions. This case study uses military planning doctrine as the empirical materials for elicitation of dominant themes via the general inductive method. These themes will be compared to the resource and context themes identified in the propositions.

The final component of case study design defines the criteria for interpreting the findings (Yin, 1994). The sufficiency of a theme to serve as a basis of evaluation will be determined by its emergence from the application of the general inductive method to the literature. The sufficiency of the framework methodology will be determined by statements of credibility from subject matter experts in the military decision making domain. With the design complete, Yin (1994) recommends preparation as the next step.

Preparation of the case study requires establishing a protocol that defines the procedure and data sources for the investigation (Yin, 1994). Yin (1994) categorizes data into six sources: 1) documentation, 2) archival records, 3) interviews, 4) direct observations, 5) participant-observation, and 6) physical artifacts. The data sources for this case study are documentation in the form of military planning doctrine and participant-observation in military planning by the researcher. The advantages and disadvantages applicable to this case study, as defined by Yin (1994), are summarized Table 8 below.

Table 8: Strengths and weaknesses of evidence sources. Adapted from Yin (1994, p. 80).

Source of Evidence	Strengths	Weaknesses
Documentation	Stable: can be reviewed repeatedly Unobtrusive: not created as a result of the case study Exact: contains exact names, references, and details of an event Broad coverage: long span of time, many events, and many settings	Retrievability: can be low Selectivity: can be biased if collection is incomplete Reporting bias: reflects unknown bias of author Access: may be deliberately blocked
Participant-Observation	Reality: covers events in real time Contextual: covers context of event Insightful: covers interpersonal behavior and motives	Time-consuming Selectivity: unless broad coverage Reflexivity: event may proceed differently because it is being observed Cost: hours needed by human observers Bias: due to investigator's manipulation of events

This research procedure follows Yin's three principles of data collection to overcome the weaknesses highlighted in Table 8 above:

- Use multiple sources of evidence
- Create a case study database
- Maintain a chain of evidence (Yin, 1994)

The multiple sources of evidence, documentation and participant-observation, were described earlier in this section. Yin (1994) describes the use of multiple sources as *triangulation*. The study database and chain of evidence will be created and maintained with the qualitative data analysis software and stored publicly for future scrutiny. With the preparation component complete, collection may begin.

Collecting the empirical materials for this case study is straight-forward as the military planning doctrine is publicly available on the World Wide Web. Professional and academic papers relating to military planning will also be added to the literature to be analyzed by the author and the qualitative data analysis software. The previous four components, ending with collection, prepare the researcher to undertake the analysis.

Analysis serves as the penultimate component of Yin's (1994) case study structure. This case study analyzes the empirical materials following the general inductive method both manually and with the use of qualitative data analysis software. The themes elicited through this analysis will be used to construct the framework for alternative analysis and selection in military planning. The evaluation will then be conducted and insights reported. Subject matter experts unaffiliated with the study will provide an assessment of credibility to the results. Once the analysis is complete and credible, it will be ready for the final component of a case study.

Sharing the case studies results comprises Yin's (1994) final component of case study research. This case study will be shared through the publication and public defense of the author's dissertation. The author also intends to submit articles to professional and academic publications in order to broaden the potential readership of this investigation.

Standards of Quality Research

The standards for judging the quality of research is a source for much academic debate (Leedy & Ormrod, 2010; Lincoln & Guba, 1985; Shipman, 1997). The recommended set of standards for a particular research effort depends on both the subject to be investigated and the philosophy of the research (Erlandson et al., 1993). Traditional non-social research generally relies on the conventional standards of internal validity, external validity, reliability, and objectivity (Leedy & Ormrod, 2010). Social research standards depend on the philosophical approach of the research, which Lincoln and Guba (1985) describe as conventional or naturalistic. Conventional social research takes the positivist view that reality is concrete and should be interpreted similarly by all humans using the same methods (Erlandson et al., 1993). Naturalistic social research believes that humans see reality through their own philosophical condition and that reality is merely a construct of the observer (Lincoln & Guba, 1985). Table 9 below summarizes these two views of trustworthiness.

Table 9: Social research quality standards comparison. Adapted from Erlandson et al. (1993, p. 133).

Standard	**Conventional Term**	**Naturalistic Term**
Truth Value	Internal Validity	Credibility
Applicability	External Validity	Transferability
Consistency	Reliability	Dependability
Neutrality	Objectivity	Confirmability

These philosophical and subject-based distinctions should not be confused with the type of methods used, as a study of either kind may have qualitative or quantitative methods (Erlandson et al., 1993). As outlined in the previous section, this research applies an antipositivist philosophy to a qualitative and inductive methodology, and therefore applies the naturalistic standards. As the one who formalized the general inductive method, Thomas (2006) recommends that practitioners focus on credibility and dependability as a further refinement of Lincoln and Guba's (1985) standards. This section follows Thomas' (2006) recommendations.

Credibility

Credibility in naturalistic inquiry describes the compatibility of the constructed realities of the subjects with those that are attributed to them (Lincoln & Guba, 1985). This standard of truth value aligns with internal validity in traditional non-social research (Erlandson et al., 1993). Credibility must be validated by the subjects of the investigation to ensure that the results match their constructed realities (Lincoln & Guba, 1985). Thomas (1998) recommends two of Lincoln and Guba's (1985) six credibility techniques for the general inductive method, peer debriefing and member checks. An explanation of each technique and its application in this research follows.

Peer Debriefing

Peer debriefing requires the investigator to review their perceptions, insights, and analyses with experts outside of the study's context (Erlandson et al., 1993). These experts must have enough general understanding of the investigation to provide useful feedback (Lincoln & Guba, 1985). This provides the researcher an opportunity to withdraw themselves from the problem and get an outside critique which may refine or redirect the methodology (Erlandson et al., 1993).

Peer debriefing is built into this research due to the requirements of the dissertation process. The committee consists of experts with enough general understanding of decision making and military planning to provide the researcher with the necessary critique. This critique is provided at each document revision and presentation, allowing multiple opportunities to refine or redirect the inquiry. Additional peer review will occur when the findings are submitted for publication in an academic journal.

Member Checks

Member checks require persons within the context of the study to verify the data and interpretations presented by the researcher (Lincoln & Guba, 1985). These checks serve as an internal validation that complements the external validation provided in peer debriefing (Erlandson et al., 1993). Lincoln and Guba

(1985) describe member checks as the most important strategy in establishing credibility and emphasize that it is a continuous process with formal and informal elements. Member checks also allow for members of the context being studied to provide an assessment of face validity to the researcher (Birks & Mills, 2011).

This research will conduct three types of member checks recommended by Erlandson et al. (1993) with military planners in order to validate the themes drawn from the empirical materials. First, members will be presented with parts of the report as it develops to seek commentary on the contents. Second, the author will have informal conversations with members between major reviews. Third and finally, the researcher will seek member checks on the penultimate draft of the report. Military planning context members will be drawn from volunteers among the author's professional contacts. Members in more generalized contexts may be added if resources allow.

Dependability

Dependability provides the research critic with evidence that if the inquiry were replicated with similar subjects and context that the findings would be repeated (Lincoln & Guba, 1985). This standard of consistency aligns with reliability in traditional non-social research (Erlandson et al., 1993). Thomas (2006) recommends the use of a dependability audit that provides documentation on how the themes were drawn from the empirical materials during the general inductive method.

This research will use the outputs of NVivo to provide the dependability audit in Appendix F. NVivo visually presents the linkages between the empirical materials and the codes, categories, and themes that are developed during the general inductive method. This output provides the audit trail for subsequent researchers to confirm the consistency of the findings.

CHAPTER 4

CRITERIA THEME INDUCTION

Introduction

This chapter presents the results of the criteria theme induction for an alternative analysis and selection framework, which comprises Phase 1 of this research as defined in Chapter 3. The theme will provide the basis for the criteria that answer Research Question 1. This chapter begins with a description of the data cleaning procedures used to prepare empirical materials for input into the qualitative data analysis software. The subsequent sections describe the close reading, coding, categorization, and development of a thematic hierarchy through the general inductive approach. The final sections reveal the chosen theme and the results of member checks on that choice.

Data Cleaning

Empirical materials were obtained in digital and print formats during this research. All materials were initially organized into one group within an EndNote X5 citation software library. This group was then imported into NVivo to build the empirical material list for analysis. Digital materials included the attached files and all bibliographic information. Print materials included bibliographic information only. The lack of digital text from print materials required the author to build a note that attached to the bibliographic information in order to provide qualitative data for NVivo. This note consisted of four parts. First, the researcher summarized each empirical material in text if the Notes or Research Notes fields in EndNote had not already done so. Second, any available scholarly reviews of the document were appended to the note. Third, the book description or paper abstract provided by the publisher or author was appended to the memo if those fields had not already been filled in EndNote. Fourth and finally, a word frequency list provided for some books or keyword list provided with some articles completed the memo. With the digital text, bibliographical information, and print material notes completed, the inductive portion of the approach could begin.

Close Reading

Close reading of the empirical materials is an iterative task that concludes once the researcher understands the collection's themes and events (D. R. Thomas, 2006). Google Scholar returns over 1.6 million results for a search on "decision analysis", so this research focuses on a small sample of that material which Köksalan et al. (2011) identified to be the most important and influential in their history of multiple criteria decision making. Digital documents were read in NVivo where the researcher could highlight passages, note themes, and identify codes. This information populated a memo attached to each entry. The researcher built a similar NVivo memo to capture the observed themes and codes in paper documents. This step completed the data that would be analyzed by NVivo.

Coding

Coding identifies specific text segments in the empirical materials and their associated bibliographic information, notes, and memos (D. R. Thomas, 2006). Codes come from an iterative process between the Qualitative Data Analysis Software (QDAS) and the researcher. The QDAS identifies the most frequent words and text segments as potential codes. The researcher uses their judgment to refine the code query and eventually select the appropriate codes for each literature stream. The final code query for this research specified segments from one to four words with a minimum segment length of three characters. Appendix E lists the codes identified for each literature stream.

Categorization

Codes are organized into categories to identify common themes within literature streams. The QDAS assists in this process in two ways. First, the QDAS identifies potentially related and synonymous codes. The researcher accepts, modifies, or rejects the recommendations. Second, the QDAS proposes categories for codes, which the research may accept, modify, or reject. Table 10 below shows the final categories with their associated codes.

Table 10: Categorical hierarchy of codes.

Stream	Categories	Codes
Military	Supply allocation	Supplies, logistics, classes of supply, transportation, maintenance, quartermaster, provisions, resupply
	Personnel distribution	Personnel, assignments, billets, slots, faces, spaces, authorizations, human resources, human capital
	Budgeting	Budget, programming, execution, auditing, comptroller, appropriations, funds, money, dollars
	Effectiveness	Effective, force effectiveness, system effectiveness, performance, parameters, capability
	Command	Commander, leadership, management, supervision, direction, art, purpose, direction, motivation
	Planning	Plans, staffs, orders, military decision making process, assessments, organize, allocate, distribute
	Strategy	Strategy, ends, ways, means, objectives, concepts, assets
	Operations	Missions, tactics, activities, functions, tasks, maneuver, units, domains
Normative	Optimization	Maximize, minimize, optimal, preferred, best, function, mathematical programming
	Perfect information	Effectiveness, force effectiveness, system effectiveness, performance, parameters, EVPI, transparency
	Value	Cost, price, expense, profit, lottery, amount, expected value
	Utility	Personal value, usefulness, desireability, preference, non-linear, Utility Thoery
	Resource allocation	Distribution, assets, supplies, resources, inputs, apportionment, allocation
	Omniscient decision maker	Certainty, deterministic, all-seeing, all-knowing, perfect
	Rationality	Axiomatic, maximize utility, logic, deduction, reasoning, economics
	Theory	Doctrine, method, ideology, approach, belief, hypothesis
Descriptive	High stakes	Critical, risky, sensitive, precarious, perilous, hazardous
	Experience	Wisdom, maturity, practice, know-how, background, history, memory
	Limited resources	Tradeoff, compromise, bargain, concession, settlement, competition, finite
	Expertise	Competence, skill, prowess, facility, expertness, subject matter expert
	Uncertainty	Unpredictability, incertitude, probability, likelihood, estimation, measureable/unmeasureable
	Heuristics	Rule of thumb, recognition primed decision, naturalistic, simple, frugal, fast
	Satisficing	Satisfy, suffice, acceptable, good enough, Allais, consequentialism, momentary perspective, impersonal point
	Psychology	Thought, behavior, choice, decisions, cognition, motivation, bounded rationality
	Experiments	Studies, research, subjects, observations, inferences, conclusions, hypotheses
Prescriptive	Alternatives	Course of action, option, branch, choice, exclusive, distinguishable
	Values	Value focused thinking, beliefs, principles, standards, ideals, decision maker, alternative generation
	Operations	Mission, tasks, functions, purpose, business unit, processes
	Hierarchy	Organization, chain of command, precedence, relationships, structure, nesting, network, AHP, ANP
	Sensitivity analysis	Inflection point, input factors, weighting function, eigenvalues, Lagrange, change, weight
	Software	Program, database, application, plug-in, spreadsheet, trial, system
	Applications	Real world, practice, industry, government, feedback, business, sectors
	Outranking	Ranks, ordinal, French school, ELECTRE, PROMETHEE, Gaia, concordance principle

Theme Elicitation

Overarching themes are selected from across categories and codes to represent the entire collection of literature streams. The QDAS does not recommend themes from the categorical hierarchy, but the researcher may create a separate file containing the list of categories and codes for content analysis. The content analysis of categories in this research revealed resources as the theme with the most supporting categories and codes. Table 11 below show the codes and categories that support the resources theme in italics.

Table 11: Resource-related codes and categories.

Categories	Codes
Supply allocation	Supplies, logistics, classes of supply, transportation, maintenance, quartermaster, provisions, resupply
Personnel distribution	Personnel, assignments, billets, slots, faces, spaces, authorizations, human resources, human capital
Budgeting	Budget, programming, execution, auditing, comptroller, appropriations, funds, money, dollars
Effectiveness	Effective, *force effectiveness, system effectiveness*, performance, *parameters*, capability
Command	*Commander*, leadership, management, supervision, direction, art, purpose, direction, motivation
Planning	Plans, *staffs*, orders, *military decision making process, assessments*, organize, allocate, distribute
Strategy	Strategy, ends, ways, *means*, objectives, concepts, *assets*
Operations	Missions, tactics, activities, functions, tasks, maneuver, *units*, domains
Optimization	Maximize, minimize, optimal, preferred, best, function, mathematical programming
Perfect information	Effectiveness, *force effectiveness, system effectiveness*, performance, *parameters, EVPI*, transparency
Value	Cost, price, expense, profit, lottery, amount, expected value
Utility	Personal value, usefulness, desireability, preference, non-linear, *Utility Thoery*
Resource allocation	Distribution, assets, supplies, resources, inputs, apportionment, allocation
Omniscient decision maker	Certainty, deterministic, all-seeing, all-knowing, perfect
Rationality	Axiomatic, maximize utility, logic, deduction, reasoning, economics
Theory	*Doctrine, method*, ideology, *approach*, belief, hypothesis
High stakes	Critical, risky, sensitive, precarious, perilous, hazardous
Experience	Wisdom, maturity, practice, know-how, background, history, memory
Limited resources	Tradeoff, compromise, bargain, concession, settlement, competition, finite
Expertise	Competence, skill, prowess, facility, expertness, subject matter expert
Uncertainty	Unpredictability, incertitude, *probability*, likelihood, *estimation*, measureable/unmeasureable
Heuristics	Rule of thumb, recognition primed decision, naturalistic, simple, frugal, fast
Satisficing	Satisfy, suffice, acceptable, good enough, Allais, consequentialism, momentary perspective, impersonal point
Psychology	Thought, behavior, choice, decisions, cognition, motivation, bounded rationality
Experiments	Studies, research, subjects, observations, inferences, conclusions, hypotheses
Alternatives	Course of action, option, branch, choice, exclusive, distinguishable
Values	*Value focused thinking*, beliefs, principles, standards, ideals, decision maker, alternative generation
Operations	Mission, tasks, functions, purpose, *business unit*, processes
Hierarchy	Organization, chain of command, precedence, relationships, structure, nesting, network, AHP, ANP
Sensitivity analysis	Inflection point, input factors, weighting function, eigenvalues, Lagrange, change, weight
Software	Program, database, application, plug-in, spreadsheet, trial, system
Applications	Real world, practice, industry, government, feedback, business, sectors
Outranking	Ranks, ordinal, French school, *ELECTRE, PROMETHEE, Gaia*, concordance principle

Member Checks

Member checks require persons within the context of the study to verify the data and interpretations presented by the researcher (Lincoln & Guba, 1985). These checks serve as an internal validation strategy to establish credibility (Erlandson et al., 1993). Two members were solicited as volunteers through the researcher's professional network to serve as subject matter experts on military decision making. Each member exceeds the researcher in military rank and education. None of the members knew the researcher personally prior to the request for expertise.

Member 1 is a US Army Lieutenant Colonel serving as an Assistant Professor of Operations Research at the Air Force Institute of Technology. He holds a Ph.D. in Industrial and Systems Engineering and served previously as an Associate Professor in the Department of Mathematical Sciences at the United States Military Academy. Operationally, he served as a planner for the 4th Brigade, 101st Airborne Division (Air Assault) during Operation Iraqi Freedom in 2007.

Member 2 is a US Army Lieutenant Colonel serving as the Special Projects Officer at the US Army Training and Doctrine Command's Research and Analysis Center at White Sands Missile Range. He holds a Ph.D. in Operations Research and served previously as an Assistant Professor of Military Science at Central Washington University. Operationally, he served as the Analysis Officer for the 4th Infantry Division during Operation Iraqi Freedom in 2009.

The researcher sent each member a copy of the theme elicitation along with any requested supporting materials, like copies of the written proposal, research abstract, or proposal defense presentation. Each member corroborated the resources theme in both military decision making and the broader literature streams through personal communication. This concluded the theme elicitation portion of the research.

Summary of Criteria Theme Induction

This chapter presented the results of the criteria theme induction for an alternative analysis and selection framework, which comprises Phase 1 of this research as defined in Chapter 3. The general inductive approach, applied using qualitative data analysis software, revealed resources as the dominant theme across the four literature streams. The resources theme provides the source for the criteria that will answer Research Question 1. The criteria are selected in the next chapter.

CHAPTER 5

FRAMEWORK DEVELOPMENT

Introduction

This chapter presents the development of an alternative analysis and selection framework, which comprises Phase 2 of this research as defined in Chapter 3. It also answers Research Questions 1 and 2. This chapter begins with the selection of criteria based upon the resources theme identified in the previous chapter, answering Research Question 1. The middle sections describe the selection of an evaluation framework onto which the criteria can be applied, answering Research Question 2. The final sections reveal the completed framework.

Selection of Criteria Based on the Theme of Resources

Resources were identified as the evaluation theme in Chapter 4. In order to transform that theme into evaluation criteria, specific attributes of resources must be selected. To determine these attributes, the author conducted a search of the literature describing resources and selected the most relevant criteria for alternative analysis and selection methods. The literature search found that resource categories differ by fields of study. Table 12 below summarizes these categories by their fields and provides the source for each.

Table 12: Resource categories.

Field	Source	Resource Categories
Biology	G. Miller and Spoolman (2011)	Photosynthetic, metabolic
Defense	United States Joint Staff (2013)	Forces, materiel, assets, capabilities
Economics	Samuelson and Nordhaus (2005)	Human, capital, natural
Natural	G. Miller and Spoolman (2011)	Non-renewable, perpetual, replenishable; biotic, abiotic; actual, potential
Systems	Adams and Keating (2011)	Money, manpower, material, minutes, methods, information

Evaluation criteria for alternative analysis and selection methods were initially selected or adapted from the resource categories in Table 12 above. The original list included methods, information, people, and effort. After further research two additional criteria, domain history (Köksalan et al., 2011) and familiarity (Park & Lessig, 1981), were added to further refine the recommendation. These criteria led to development of the decision flow model shown in Figure 22 below.

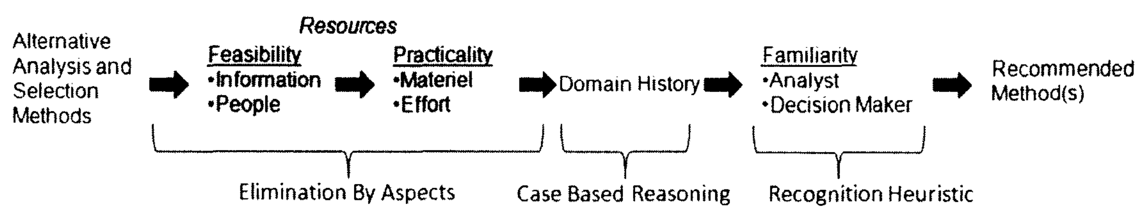


Figure 22: Decision flow model.

In this model the practitioner begins by screening alternative analysis and selection methods based on their resources to identify feasible and practical methods. Infeasible options are eliminated based on lack of information or human capability. Impractical options are eliminated based on lack of materiel or insufficient capacity for effort. Next, domain history provides prior cases of the remaining methods' implementations. Finally, the analyst may consider their familiarity with the methods. A deeper discussion of each criterion follows.

Methods

Alternative analysis and selection methods serve as the alternatives in the decision making paradox facing an analyst (Triantaphyllou & Mann, 1989). These methods provide the first dimension for the evaluation framework. Table 13 below lists the alternative analysis and selection methods considered for this investigation in an abstracted evaluation framework. More than 50 multiple attribute decision making methods were identified including those mentioned in the literature review. Many were eliminated from this list of alternative selection and analysis methods due to their focus in other parts of the multiple attribute decision making process, such as Value Focused Thinking's emphasis on alternative generation. The remaining methods all focus on alternative analysis.

Table 13: Abstract evaluation framework.

Alternative Analysis & Selection Methods	Source	Criterion 1	Criterion 2	Criterion 3
Pros & Cons	Labaree (1956)			
Dominance	Hadar & Russell (1969)			
Conjuctive (Satisficing)	Simon (1955)			
Disjunctive	Dawes (1964)			
Lexicographic	Fishburn (1967)			
Lexicographic Semiorder	Tversky (1969)			
Elimination by Aspect	Tversky (1972)			
Simple Additive	Dawes (1979)			
Simple Additive Weighting	Von Neumann & Morgenstern (1953)			
Weighted Product Model	Bridgman (1922)			
Additive Difference	Tversky (1969)			
Analytical Hierarchy Process	Saaty (1977)			
Analytical Network Process	Saaty (1996)			
Majority of Confirming Dimensions	Russo & Dosher (1983)			
Frequency of Good & Bad	Alba & Marmorstein (1987)			
ELECTRE	Roy (1968)			
PROMETHEE	Brans, Vincke, & Mareschal (1986)			

Each alternative analysis and selection method requires certain mathematical methods to accomplish it. For example, simple additive weighting requires arithmetic and normalization. The information and mathematical fluency required to complete these methods must be captured as resources in the evaluation framework criteria. These two criteria serve to screen methods for feasibility before the analyst considers the methods that are practical.

Criterion 1 - Information

The information required for an alternative analysis and selection method creates a screening criterion. Completing an alternative analysis and selection method requires information along two dimensions. The first dimension describes the differentiation of important criteria by the decision maker that may fall into three categories. This differentiation is also called criteria weighting. The first category contains methods that allow for a decision maker that gives no or equal differentiation. The second category of methods requires the ranking of criteria on an ordinal scale. The third and final category of methods requires interval scale weights for criteria.

The second dimension describes the basis for each alternative's performance. An alternative's performance in each criterion may fall into three categories. The first category of methods uses nominal comparison. Nominal comparisons use categories to differentiate alternatives, such as whether or not an alternative meets a cutoff value. The second category requires ranking the performance of each alternative against the others within each criterion. This may occur across all alternatives simultaneously or in pair-wise comparisons. The third and final category compares interval scores between alternatives. The scores may be inherent in the original data or require some transformation such as normalization or determining utility. Both of these dimensions offer opportunities to screen out infeasible methods due to the absence of necessary information.

One consideration within this criterion is the ability to transform some data types into others. For example, ordinal data in either dimension may be transformed into interval weights through methods like the rank-ordered centroid technique (Barron & Barrett, 1996). This framework reflects the data types specified in the original documents, but acknowledges that an advanced analyst may be able to invoke some methods with less information.

Table 14 below summarizes the alternative analysis and selection methods under consideration along with their information requirements. An 'X' in the box indicates the minimum information necessary to support the method. For criteria weighting, any information to the right of the 'X' may also be used. For alternative performance, ratio scale information may be transformed into ordinal scale ranks for the Dominance and Majority of Confirming Directions methods. For example, an analyst could use the dominance method with ranked criteria and ratio scores. However, an analyst could not use ranked alternative performance in the Frequency of Good & Bad heuristic without the additional information of what ranks were 'good' and 'bad.'

Table 14: Information required for alternative analysis and selection methods.

Resource Theme Criteria →	Minimum Information Required					
	Criteria Weighting			Alternative Performance		
Alternative Analysis & Selection Methods ↓	None or Equal	Ordinal Scale Ranks	Ratio Scale Weights	Nominal Scale Categories	Ordinal Scale Ranks	Ratio Scale Values or Utilities
Pros & Cons	X			X		
Dominance	X				X	
Conjuctive (Satisficing)	X			X		
Disjunctive	X			X		
Lexicographic		X		X		
Lexicographic Semiorder		X		X		
Elimination by Aspect	X			X		
Simple Additive	X					X
Simple Additive Weighting			X			X
Weighted Product Model			X			X
Additive Difference			X			X
Analytical Hierarchy Process			X			X
Analytical Network Process			X			X
Majority of Confirming Dimensions	X				X	
Frequency of Good & Bad	X			X		
ELECTRE Family			X	X		
PROMETHEE Family			X			X

Criterion 2 – Mathematical Fluency

The information required for an alternative analysis and selection method must be collected and interpreted by an analyst, which represents a human resource. Like other resources, analysts vary in their ability to achieve the desired outcome. The relevant part of this variability with respect to this framework is the analyst's mathematical fluency. Four mathematical prerequisites were drawn from the alternative analysis and selection methods: understanding of 1) better or worse, 2) order, 3) arithmetic, and 4) normalization.

Understanding of better or worse requires the analyst to determine if a value is better than a cutoff. Understanding order requires the analyst to place alternative performance along an ordinal scale that reflects the decision maker's preference. Understanding arithmetic requires knowledge of addition, subtraction, multiplication, division, and exponentiation. Understanding normalization in this framework requires the ability to normalize data along different scale intervals. Table 15 below shows the mathematical fluency required for each alternative analysis and selection method under consideration.

Table 15: Math fluency required for alternative analysis and selection methods.

Resource Theme Criteria →	People				
	Mathematical Fluency				
Alternative Analysis & Selection Methods ↓	None	Better or Worse	Order	Arithmetic	Normalization
Pros & Cons	X				
Dominance		X			
Conjuctive (Satisficing)		X			
Disjunctive		X			
Lexicographic			X		
Lexicographic Semiorder			X		
Elimination by Aspect		X			
Simple Additive					X
Simple Additive Weighting					X
Weighted Product Model				X	
Additive Difference					X
Analytical Hierarchy Process					X
Analytical Network Process					X
Majority of Confirming Dimensions		X			
Frequency of Good & Bad		X			
ELECTRE Family					X
PROMETHEE Family					X

Criterion 3 – Mathematical Tools

Analysts use mathematical tools as the materiel resource for applying alternate analysis and selection methods. The literature search found three tools beyond paper that may be required to practically complete a method. The first, a calculator, is useful for multiplication and exponents, such as in the weighted product model. The second, a spreadsheet, is useful anytime data need to be normalized. The third and final is proprietary software, which is useful when a spreadsheet model is too cumbersome to be practical. Table 16 below summarizes the mathematical tools necessary to practically complete each alternative analysis and selection method. The 'X' indicates the lowest practical resource, although tools to the right may also be used if applicable.

Table 16: Mathematical tools for alternative analysis and selection methods.

Resource Theme Criteria →	Materiel			
	Mathematical Tools			
Alternative Analysis & Selection Methods↓	Paper / Whiteboard	Calculator	Spreadsheet	Proprietary Software
Pros & Cons	X			
Dominance	X			
Conjuctive (Satisficing)	X			
Disjunctive	X			
Lexicographic	X			
Lexicographic Semiorder	X			
Elimination by Aspect	X			
Simple Additive			X	
Simple Additive Weighting			X	
Weighted Product Model		X		
Additive Difference			X	
Analytical Hierarchy Process				X
Analytical Network Process				X
Majority of Confirming Dimensions	X			
Frequency of Good & Bad	X			
ELECTRE Family				X
PROMETHEE Family				X

Criterion 4 – Effort

Effort describes the processing capacity and resources, like money and time, which can be applied to an alternative analysis and selection method.

Effort provides the analyst with the second criteria of practicality for evaluating methods. Hastie and Dawes (2001) classified the effort required for some methods. Shah and Oppenheimer (2008) extended this work by identifying five tasks required of a decision maker to complete simple additive weighting, which served as their basis for effort determination:

1. Identifying all cues—all relevant pieces of information must be acknowledged.
2. Recalling and storing cue values—the values for the pieces of information must either be recalled from memory or processed from an external source.
3. Assessing the weights of each cue—the importance of each piece of information must be determined.
4. Integrating information for all alternatives—the weighted cue values must be summed to yield an overall value or utility for the alternative. In the case of inference or judgment, this is the final step, and it produces the target judgment value.
5. All alternatives must be compared, and then the alternative with the highest value should be selected. (p. 207)

Using these techniques the researcher applied a level of effort to each method that had not already been prescribed one by Hastie and Dawes (2001). Those Hastie and Dawes (2001) levels are distinguished from the researcher's with italics in Table 17 below, which summarizes all levels.

Table 17: Level of effort for alternative analysis and selection methods.

Resource Theme Criteria →	**Effort**
Alternative Analysis & Selection Methods↓	Level of Effort
Pros & Cons	Low
Dominance	*Medium*
Conjuctive (Satisficing)	*Low*
Disjunctive	*Low*
Lexicographic	*Medium*
Lexicographic Semiorder	Medium
Elimination by Aspect	*Medium*
Simple Additive	High
Simple Additive Weighting	*Very High*
Weighted Product Model	High
Additive Difference	*Very High*
Analytical Hierarchy Process	*Very High*
Analytical Network Process	Very High
Majority of Confirming Dimensions	Medium
Frequency of Good & Bad	Low
ELECTRE Family	Very High
PROMETHEE Family	Very High

Criterion 5 – Domain History

The domain history criterion provides the analyst with the domains in which each alternative analysis and selection method has been successfully applied in the body of knowledge. This allows the analyst to compare the historical domains with his or her own domain for similarities. The analyst may use this information to select or screen methods in a simplified form of case based reasoning (Schank, 1983). Table 18 below summarizes the domain criterion for each alternative analysis and selection method.

Table 18: Historical domains for alternative analysis and selection methods.

Resource Theme Criteria →	Domains				
Alternative Analysis & Selection Methods ↓	Personal	Consumer	Business	Non-profit	Government
Pros & Cons	X	X			
Dominance		X			
Conjuctive (Satisficing)	X	X			
Disjunctive	X	X			
Lexicographic		X	X		
Lexicographic Semiorder		X	X	X	
Elimination by Aspect		X	X		
Simple Additive		X	X		
Simple Additive Weighting			X	X	X
Weighted Product Model			X		X
Additive Difference			X		X
Analytical Hierarchy Process			X	X	X
Analytical Network Process			X	X	X
Majority of Confirming Dimensions	X	X			
Frequency of Good & Bad	X	X			
ELECTRE Family			X		X
PROMETHEE Family			X		X

Criterion 6 – Familiarity

The recognition heuristic captures the experimental observation that decision makers find familiar alternatives more attractive than unfamiliar ones (Gigerenzer, Todd, & ABC Research Group., 1999). The final stage of this choice model acknowledges that preference once the feasible, practical, and applicable criteria have filtered out un-preferred alternative analysis and selection methods.

Framework Development

Table 19 below contains all of the criteria information from Tables 14 through 18 and constitutes the first part of the framework. A two-dimensional table provides the structure of the framework, answering Research Question 2.

Table 19: Framework table.

Resource Theme Criteria →	Minimum Information Required						People					Materiel				Effort				Domains				
	Criteria Weighting			Alternative Performance			Mathematical Fluency					Mathematical Tools												
Alternative Analysis & Selection Methods ↓	None or Equal	Ordinal Scale Ranks	Ratio Scale Weights	Nominal Scale Categories	Ordinal Scale Ranks	Ratio Scale Values or Utilities	None	Better or Worse	Order	Arithmetic	Statistics	Paper / Whiteboard	Calculator	Spreadsheet	Proprietary Software	Low	Medium	High	Very High	Personal	Consumer	Business	Non-profit	Government
Pros & Cons	X			X			X					X				X				X	X			
Dominance	X				X			X				X					X				X			
Conjuctive (Satisficing)	X			X				X				X				X				X	X			
Disjunctive	X			X				X				X				X				X	X			
Lexicographic		X		X					X			X					X				X	X		
Lexicographic Semiorder		X		X					X			X					X				X	X	X	
Elimination by Aspect	X			X				X				X					X				X	X		
Simple Additive	X					X					X			X				X			X	X		
Simple Additive Weighting			X			X					X			X					X			X	X	X
Weighted Product Model			X			X				X			X					X				X		X
Additive Difference			X			X					X			X					X			X		X
Analytical Hierarchy Process			X			X					X				X				X			X	X	X
Analytical Network Process			X			X					X				X				X			X	X	X
Majority of Confirming Dimensions	X				X			X				X					X			X	X			
Frequency of Good & Bad	X			X				X				X				X				X	X			
ELECTRE Family			X	X							X				X				X			X		X
PROMETHEE Family			X			X					X				X				X			X		X

In order to operationalize Table 19 above, the researcher constructed a decision flow chart for an analyst to follow when facing the alternative analysis and selection method decision making dilemma. This chart follows the tree structure recommended in previous work on decision method selection (Guitouni & Martel, 1998; C. L. Hwang & Yoon, 1981; Teghem Jr, Delhaye, & Kunsch, 1989). Figure 23 below presents the chart as a decision tool.

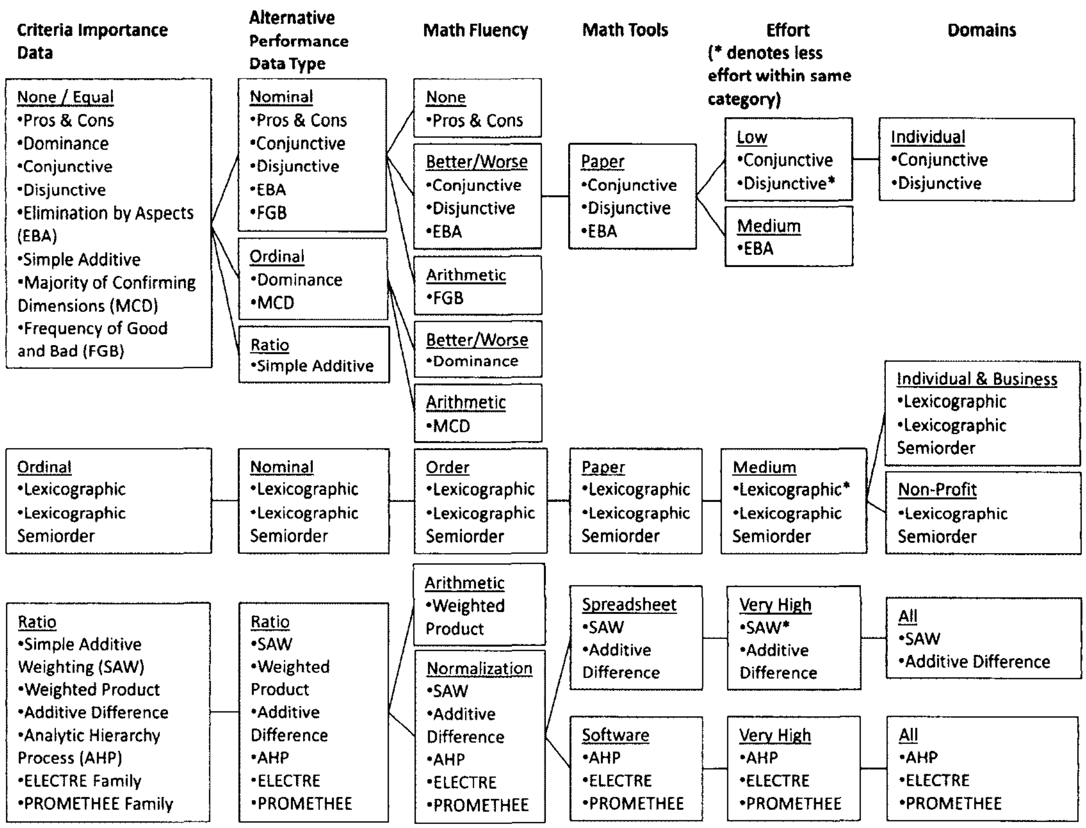


Figure 23: Alternative analysis and selection method decision tool.

The analyst enters the tool from the left with the type of data available for the importance of criteria. The analyst then moves from left to right matching their problem and context to the criteria along the top of each column. The tool filters out methods as the analyst continues to the right, terminating in either a single recommendation or a list of domains that two or more methods have been applied in. The analyst may then use their familiarity with the remaining methods to help choose.

An additional level of differentiation is provided under the effort criterion of this tool. Where discernable, the method requiring the least effort from within the same category of effort has been noted with an asterisk.

This framework represents a first step towards a more comprehensive tool that should include all of the identifiable academically-rigorous alternative analysis and selection methods. It should be updated as new methods appear, new applications occur, and information about existing methods develops. To facilitate those new applications, organizations can tailor this framework to their own resources and methods as will be demonstrated in the subsequent case study.

Framework Development Summary

This chapter presented the development of an alternative analysis and selection framework, which comprises Phase 2 of this research as defined in Chapter 3. This chapter also answered Research Question 1 with a set of appropriate criteria that are suitable for choosing an alternative analysis and selection method. It also answered Research Question 2 by organizing those criteria into a two-dimensional tabular framework that has been operationalized into a tree-structured decision tool.

CHAPTER 6

CASE STUDY

Introduction

This chapter presents the application of the resource-based alternative analysis and selection method framework to the unique context of course of action comparison in the US Army's Military Decision Making Process (MDMP). This application occurs in four sections aligned with the research questions. First, Section 1 answers Research Question 3 by demonstrating how a practitioner can use the framework to match alternative analysis methods to problems and their context. Second, Sections 2 and 3 answer Research Question 4 by demonstrating how an engineering manager can use the framework to evaluate the effectiveness of alternative analysis within their technical enterprise. Section 2 demonstrates an internal evaluation by the engineering manager while Section 3 demonstrates and external evaluation. Third, Section 4 provides the opportunity for member checks of face validity by two subject matter experts. Fourth and finally, Section 5 incorporates the feedback provided by experts and members.

Analysts and their managers should carefully consider any modification of the framework to ensure it is undertaken by knowledgeable practitioners and subjected to peer review and validation. This case study's member checks and expert reviews provide two ways to validate any framework modification.

The Military Decision Making Process

Pages 19 through 24 of the Literature Review in Chapter 2 describe MDMP in detail. The review found four challenges in the course of action alternative analysis and selection method recommended by the US Army. First, the method uses a less-is-better directionality for ratio weights of criteria. Second, the method uses ordinal ratings for the performance of each course of action on each criterion. These rankings hide the magnitude of preference by the staff. Third, the method recommends direct weighting of criteria, which has been shown to produce invalid results (Von Nitzsch & Weber, 1993). Fourth and finally, the method allows for post hoc changes to the weights and ratings by the decision maker. Despite these challenges, MDMP does allow for “any technique that helps develop those key outputs and recommendations and assists the commander to make the best decision” (United States Army, 2011, pp. 4-36). This allowance provides the opportunity to apply the proposed framework to this context.

Unit of Analysis

This case study applies the alternative analysis and selection method framework to the boundary case of a US Army battalion conducting MDMP. The case study uses the battalion echelon for three reasons. First, a battalion represents the lowest, and therefore least resourced, echelon that conducts MDMP within the US Army. This creates a lower edge or boundary case for the resource-based framework. If the framework appears valid in this case, then it should scale up to organizations with greater resources.

The second and third reasons for selecting the battalion lie in the experience of the subject matter experts and researcher. Each of the subject matter experts served as a battalion staff officer in their career. This gives first hand credibility to their member check. The researcher also served as a battalion staff officer and will apply the framework as if serving as a staff officer in Section 1 and as the battalion's executive officer (XO) in Sections 2 and 3. The researcher possesses the same rank and similar experience as a typical battalion XO.

The 1st Battalion, 87th Infantry Regiment of the US Army's 10th Mountain Division serves as this case study's example for a typical battalion. A lieutenant colonel commands the 655 soldier unit with the assistance of two majors, one of whom is the XO. The XO manages a 63 soldier battalion staff in conducting MDMP to plan the operations that achieve the battalion's mission. The battalion's mission is “to close with and destroy enemy forces using fire, maneuver, and shock effect, or to repel his assault by fire and counterattack" (United States Army, 2014b, p. 1). It conducts this mission in all conditions found on land. The battalion will be considered while planning a hasty counterattack for Section 1 of this case study. US military planning distinguishes between hasty and deliberate tasks based upon the resources available, particularly time.

Section 1: The Framework as a Decision Aid

This section applies the resource-based alternative analysis and selection method framework developed in this dissertation to the course of action selection step of MDMP for the resources possessed by a typical US Army battalion. This part of the case study answers Research Question 3 by demonstrating how an analyst can apply the framework to match alternative analysis and selection methods to their unique problem and context. The analyst in this case is a military staff member. Figure 23 in the preceding chapter presents the full framework for reference. That framework serves as the basis for an expanded framework that includes any methods used by the organization that are not already present. In this case study, the decision matrix method presented in US Army doctrine has been added, as shown by the italicized text and heavily weighted line and box in Figure 24 below.

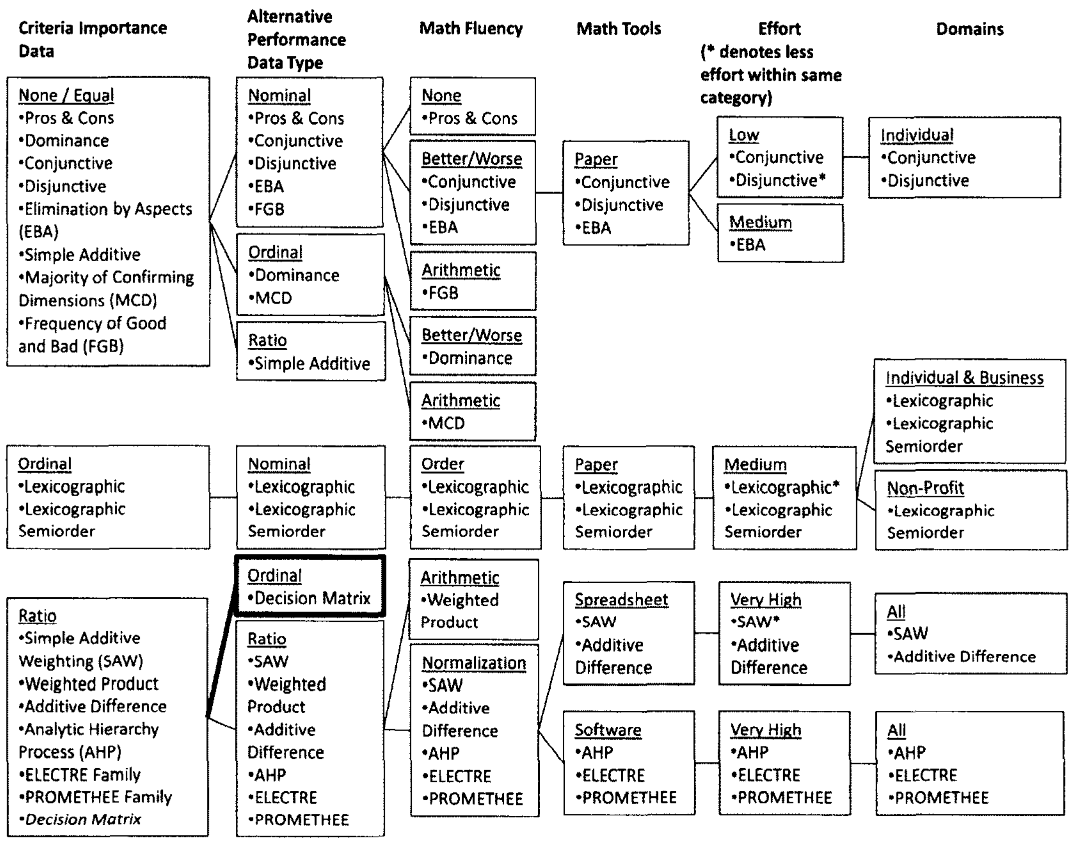


Figure 24: US Army MDMP framework application.

The US Army calls their method a decision matrix, which may be confusing. In the academic literature a decision matrix is simply a way of displaying decision making data, not an alternative analysis and selection method unto itself (Triantaphyllou, 2010). The US Army's actual alternative analysis and selection method roughly follows simple additive weighting and is described in detail in Chapter 2. The difference, as shown in Figure 25 above, is that the US Army's method uses ordinal alternative performance data, whereas SAW uses ratio. The US Army's use of ordinal alternative performance data also causes its method to use a less-is-better directionality rather than SAW's greater-is-better approach.

Criteria Importance Data

The first step of the framework considers the type of data provided by the decision maker on the relative importance of the criteria. MDMP directs the direct weighting of criteria by the commander with a less-is-better directionality, a direction that does not preclude the use of any method (United States Army, 2011). As noted earlier, the academic literature does not support the direct weighting of criteria as a valid weighting method, so this challenge will be addressed in a subsequent section (Von Nitzsch & Weber, 1993). The ratio weighting based methods from the original framework use a more-is-better directionality, so the reciprocal of the given weights would need to be calculated to match. The lexicographic methods require ordinal weighting, so the interval weights would need to be changed to ranks (Tversky, 1969). Both lexicographic methods allow for ties, so equally weighted criteria pose no challenge.

Alternative Performance Data

The second step of the framework considers the type of data available on the performance of each alternative within each criterion. MDMP directs the ranking of alternatives with a lower-is-better approach. This ordinal data eliminates all of the methods that require ratio alternative performance data. Figure 25 below shows the effects of these eliminations by graying out the infeasible methods.

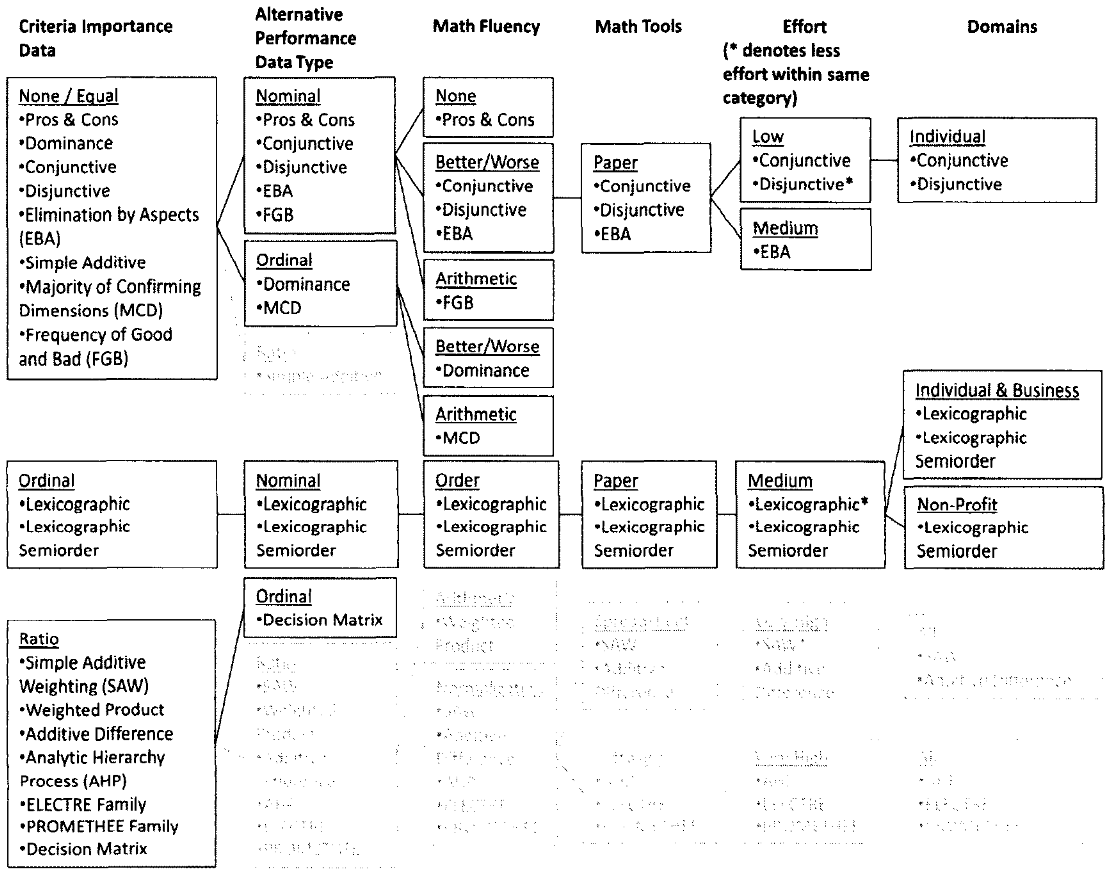


Figure 25: Framework modification for alternative performance.

Note that this screening eliminates the simple additive weighting method that most closely matches MDMP's decision matrix method. It also demonstrates an example where the ability to transform data from ordinal to ratio could provide additional options. The decision matrix method becomes the first recommended method because it creates a terminus along the path from left to right.

Mathematical Fluency

The battalion staff under consideration contains 12 officers and 51 enlisted soldiers. Every officer possesses a baccalaureate degree and every enlisted soldier a high school diploma or equivalent. Staff members in each category often possess higher degrees (Kane, 2006). These credentials suggest that all staff members should know arithmetic, so no methods are eliminated in this step.

One could reasonably expect some staff members to accomplish normalization had it been required. The end of this step results in four methods being added to the solution set: pros and cons, frequency of good and bad, dominance, and majority of confirming dimensions.

Mathematical Tools

The battalion staff under consideration conducts planning in the field from tents with electric generator power while stationary and from the back of utility vehicles while on the move. Ruggedized laptops run Microsoft Windows and Office along with specialized military software. The Defense Information Systems Agency would have to certify other proprietary software, such as those that make AHP and the outranking methods practical, before a battalion could install them. The remaining methods in this case study require only pen and paper, so all advance from this step.

Effort

The battalion under consideration is planning a hasty counterattack. The hasty description means that resources, particularly time, are limited. A counterattack occurs immediately after the enemy attacks the battalion, so there is little time for deliberate planning (United States Army, 2012). In such a case the staff will conduct an abbreviated form of MDMP and the effort available for planning is low because of the challenges in recovering from an attack and attempting to reverse the momentum of the battle (United States Army, 2011, 2012). This lack of resources for planning eliminates the methods requiring medium effort as shown in Figure 26 below.

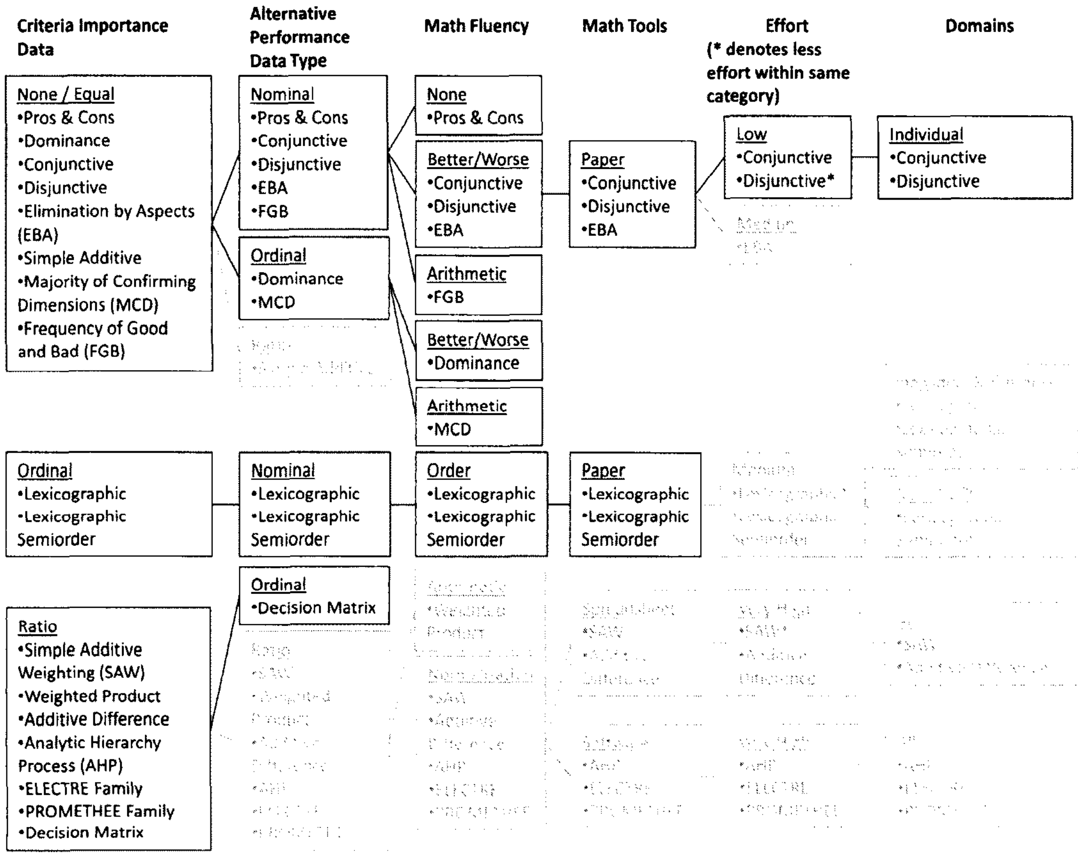


Figure 26: Framework modification for effort.

Domains

The framework cannot discriminate between the remaining methods based upon domains. This result adds the conjunctive and disjunctive methods to the penultimate solution set.

Familiarity

The final step allows the analyst to select from the list of recommended methods based off the recognition heuristic. The alternative analysis and selection methods recommended to this point are the decision matrix, pros and cons, frequency of good and bad, dominance, majority of confirming dimensions, conjunctive, and disjunctive. In an abbreviated MDMP while in contact with the enemy, a staff would likely choose the familiar decision matrix method.

Summary of the Framework as a Decision Aid

This section presented how a practitioner could apply the existing framework to their problem and context. The analyst may add organizational methods and proceed through the framework based on resources as they currently exist. The opportunity also exists for experienced analysts or managers to further adapt the framework.

Engineering Management Approach

Engineering managers improve their organization's processes to increase performance (Thamhain, 1992). Applying the framework to this case study reveals two avenues along which to improve the process of course of action comparison in the US Army's MDMP. First, an XO could tailor the framework for his or her particular battalion and its context with the goal of reducing the time required to complete the framework. Second, the XO could recommend changes to the Army's course of action comparison doctrine to facilitate the application of methods other than the decision matrix method. These two avenues of evaluation and improvement demonstrate the framework's applicability at the local (battalion) and institutional (Army) levels. The following two sections apply the framework along each of these avenues and answer Research Question 4.

Section 2: The Framework as an Internal Evaluation Tool

An XO, acting as an engineering manager, can evaluate the battalion's alternative analysis and selection process using the framework. The results of this evaluation provide the XO with two possible lines of effort. First, the XO can modify the framework to better suit his or her organization and its problem context. Alternatively, the XO can act to change the resources available to the organization so that additional methods may apply. The XO may mix these two approaches as well. An engineering manager can follow the same process for the organization they manage.

Modifying the Framework

An XO could begin by evaluating the framework's methods compared to the battalion's context. The XO could add, remove, or modify the methods presented to the staff within the framework. The modifications could reflect the organization's static resources by adding, modifying, or eliminating methods. For example, the XO could eliminate methods requiring proprietary software if the staff will reasonably never procure and learn it. This change illustrates how a manager may tailor the framework to existing conditions. Extending the example, the XO may borrow the plus-minus-neutral comparison method from the US Navy. This change illustrates how a manager may add additional resources to the framework. Figure 27 below shows a modified framework reflecting these two changes.

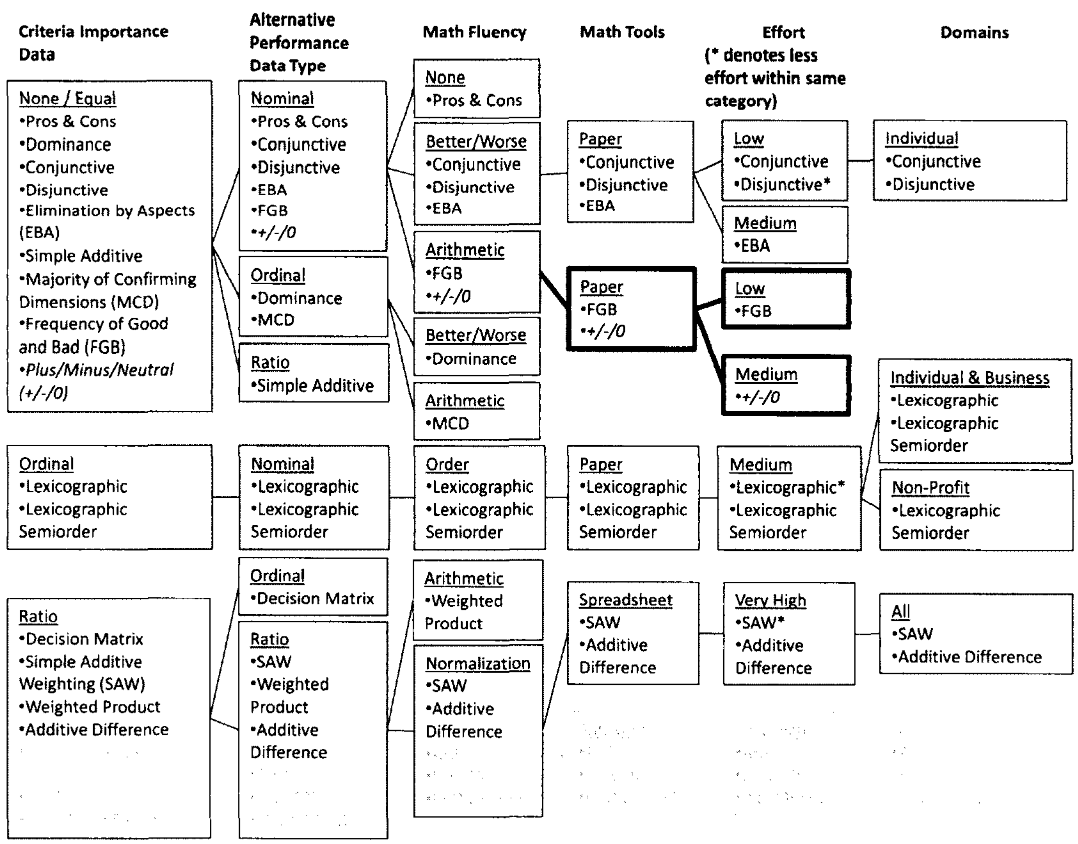


Figure 27: Framework modification for local method improvement.

The modified framework for this example grays out the undesired methods. The additional plus/minus/neutral method is in italics for emphasis. Note that the new method necessitates two additional branches, which are highlighted by bold lines and boxes. A simpler framework with the same information appears below in Figure 28.

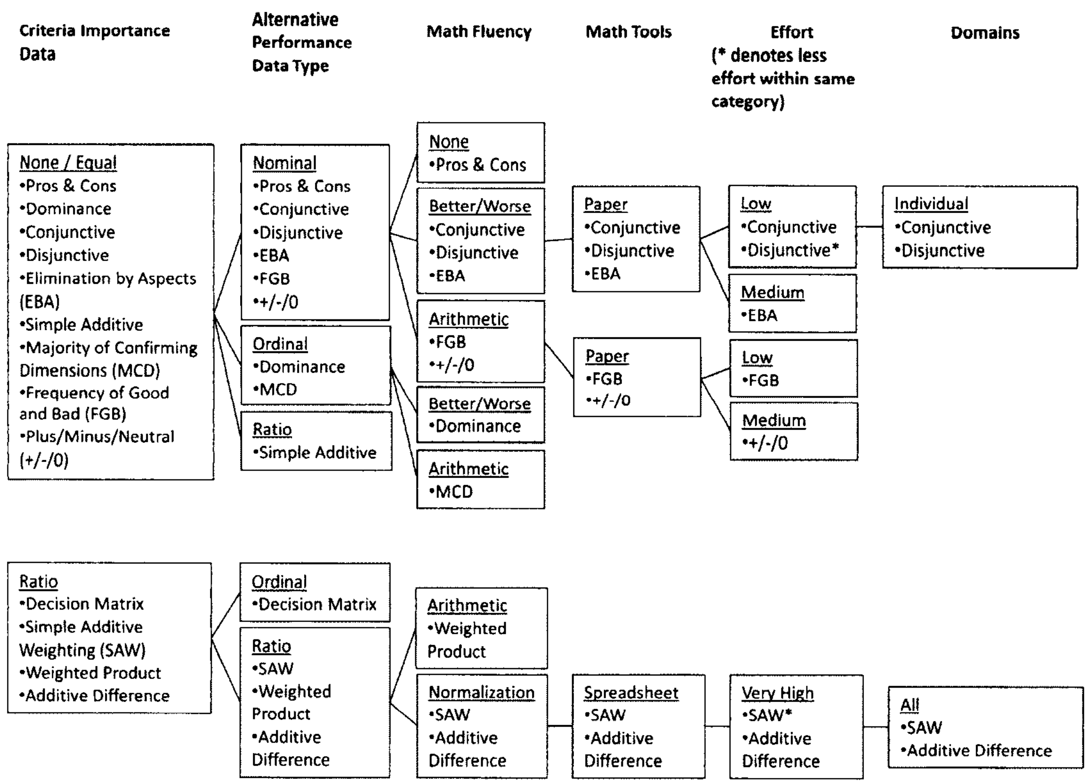


Figure 28: Simplified framework for local method improvement.

Extending the example further, an XO could also add, change, or remove any criteria that did not match the battalion's resources and context. For example, the XO may replace effort with one of two planning types: hasty or deliberate. This change would align the framework with the organization's lexicon, simplify choices, and likely increase usability. The XO may also decide that the domains do not fit the battalion's context. He or she could replace them with more relevant domains, such as those presented in Figure 29 below. Changes are again emphasized in bold and italics.

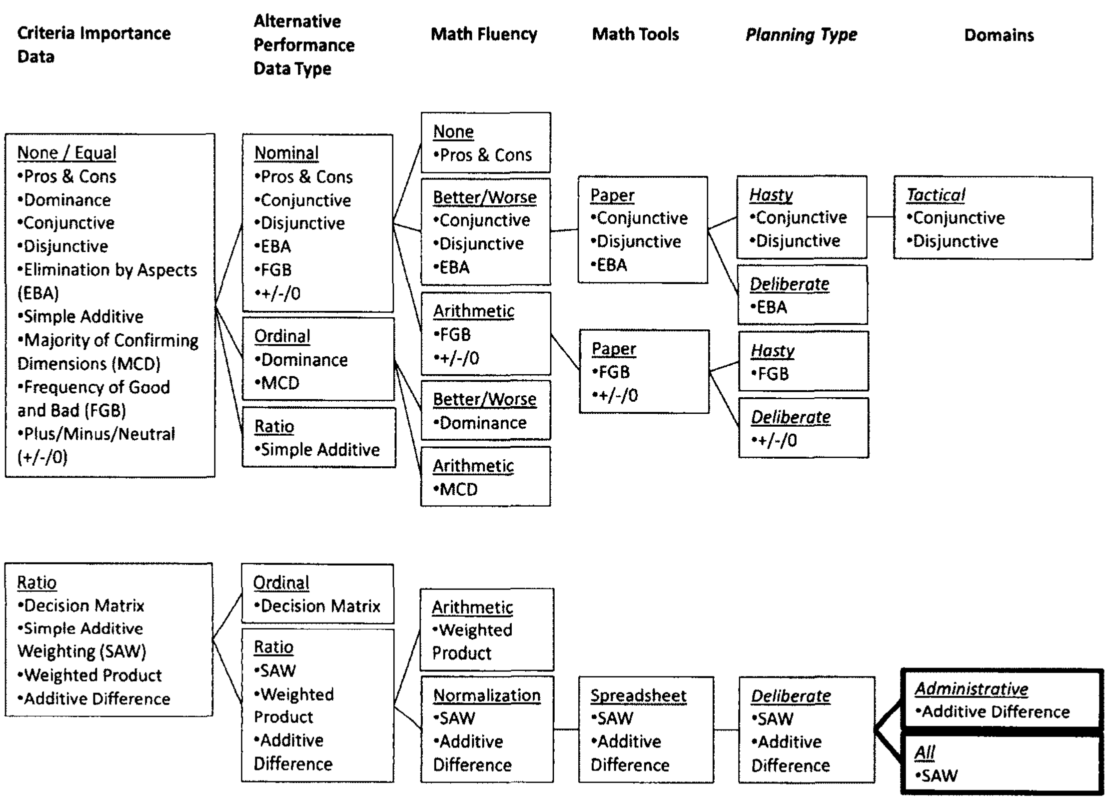


Figure 29: Framework modification for local criteria improvement.

Summary of the Framework as an Internal Evaluation Tool

The previous examples show how an XO, acting as an engineering manager, can adapt the generic framework to his or her particular organization, problem, and context. This represents an inward perspective that should be complemented by an outward one. The framework presents the opportunity to not only improve the engineering manager's own business unit, but also their larger organization.

Section 3: The Framework as an External Evaluation Tool

An engineering manager may use the framework to drive change within their larger organization. In addition to being the decision aid shown in the previous section, the framework may serve as an evaluation tool for an organization's decision making processes. Evaluating an organization's alternative analysis and selection method decision making through the framework requires considering the framework's methods and each criterion against the organization's existing process. This section presents such an application to the US Army's course of action comparison step within MDMP.

Methods

The first step of an evaluation using the framework considers the organization's existing alternative analysis and selection methods. In this case, the US Army uses the decision matrix method described in Chapter 2. Comparing this single method to the methods provided in the framework reveals several challenges.

The first challenge appears in the 'decision matrix' name of the US Army's method. In non-Army literature, a decision matrix presents alternative and criteria performance information in rows and columns (Triantaphyllou, 2010). It does not constitute an alternative analysis and selection method unto itself. This presents an opportunity for confusion by the analyst and leads to the first recommendation from this evaluation. Specifically, the US Army should present the decision matrix as a data organization tool and rename their method if it warrants keeping. Whether to keep the method and what to rename it will depend on how subsequent steps of this evaluation unfold.

The second challenge comes from the lack of method examples for staffs to draw upon. The manual allows for "any technique that helps develop those key outputs and recommendations and assists the commander to make the best decision," but only provides an example of the decision matrix method (United States Army, 2011, pp. 4-36). This results in a second recommendation that the manual should include examples of different alternative analysis and selection methods from which the staff may choose. The US Navy (2007) and US Joint Staff (2011a) include an annex or appendix with several methods in their doctrine. This evaluation also recommends including a decision tool for those methods, like the one presented in the previous section.

Criteria Importance Data

The US Army's MDMP specifies the direct weighting of criteria in a less-is-better approach by the decision maker. The method specifies weighting the most important criteria as one, and then determining "weights for each criterion based on a subjective determination of their relative value" (United States Army, 2011, pp. 4-36). The weighting method also allows for changing the criteria weights after the comparison is complete. This method runs contrary to the non-Army literature in three ways. First, it uses a less-is-better approach that matches the directionality of the rankings used for alternative performance. All of the other methods using ratio weights direct a more-is-better valuation. Second, the direct rating of weights without a scale leads to invalid measurements of relative value (Von Nitzsch & Weber, 1993). Third, MDMP allows for changing weights after the evaluation is complete, which may lead to post hoc manipulation of weights to reach a predetermined outcome (MacCrimmon, 1968).

These challenges result in several recommendations. First, the process should require a more-is-better directionality for weighting ratio scale criteria. This aligns the US Army method with the decision analysis body of knowledge and facilitates the use of other methods as outlined in the developed framework. The second recommendation requires the commander to weight ratio scale criteria based on the direct weighting method using a 100 point scale. In this method the decision maker assigns a weight between zero and 100 points to each criterion. This should not be confused with the point allocation weighting method where the decision maker must divide 100 points amongst the criteria. Bottomley, Doyle, and Green (2000) demonstrated that direct weighting was preferred by decision makers and produced more reliable weights when compared to point allocation. Figure 30 below compares the current and recommended methods for ratio scale weight assignment.

Current Method:

Weight	1	2	1	1	2	
Criteria / *Course of Action*	Simplicity	Maneuver	Fires	Civil control	Inform and influence activities	TOTAL
COA 1						
COA 2						

Recommended Method:

Weight	100 (.25)	50 (.125)	100 (.25)	100 (.25)	50 (.125)	400
Criteria / *Course of Action*	Simplicity	Maneuver	Fires	Civil control	Inform and influence activities	TOTAL
COA 1						
COA 2						

Figure 30: Recommended change to criteria weighting. Adapted from *Commander and Staff Officer Guide* (p. 4-36), by US Army, 2011, Washington, DC: US Government Printing Office. No copyright.

The revised weights in Figure 30 demonstrate the 100 point direct rating technique with a more-is-better directionality. The weighting points assigned in the lower decision matrix attempt to reflect the relative value given in the original upper decision matrix. Note that the points get totaled atop the 'TOTAL' column to assist in calculating the normalized weights, now shown in parentheses.

Although still relatively easy on the commander, this method does require additional mathematical fluency on the part of the staff.

The third recommendation requires commanders to finalize their criteria weighting after the COA Analysis step. A sensitivity analysis on the weights may be conducted if the commander is concerned with them after the analysis is complete.

Alternative Performance Data

The US Army's MDMP directs the ranking of alternative performance within each criterion, as shown in Figure 31 below.

Weight[1]	1	2	1	1	2	
Criteria[2] / *Course of Action*	Simplicity	Maneuver	Fires	Civil control	Inform and influence activities	TOTAL
COA 1[3]	2	2 (4)	2	1	1 (2)	8 (11)
COA 2[3]	1	1 (2)	1	2	2 (4)	7 (10)

Notes:
[1] The COS (XO) may emphasize one or more criteria by assigning weights to them based on a determination of their relative importance.
[2] Criteria are those assigned in step 5 of COA analysis.
[3] COAs are those selected for war-gaming with values assigned to them based on comparison between them with regard to relative advantages and disadvantages of each, such as when compared for relative simplicity COA 2 is by comparison to COA 1 simpler and therefore is rated as 1 with COA 1 rated as 2.

Figure 31: Alternative performance in MDMP. Adapted from *Commander and Staff Officer Guide* (p. 4-36), by US Army, 2011, Washington, DC: US Government Printing Office. No copyright.

Only two methods from the decision theory review support the ranking of alternative performance within a criterion: dominance and the majority of confirming dimensions heuristic. Dominance requires that a course of action rank first in every criterion to win the comparison. The example in Figure 31 results in no alternative selection from dominance because different courses of action perform better in different criteria. This example demonstrates the limitation of dominance being a non-exhaustive method.

The majority of confirming dimensions heuristic compares alternatives in pairs by how many times each one performs better than the other. Applying this method to Figure 31 would result in a win for COA 2, as shown in Table 20 below.

Table 20: Majority of confirming dimensions in MDMP.

Criteria	Simplicity	Maneuver	Fires	Civil control	Inform and influence activities	TOTAL Wins
COA 1	Loss	Loss	Loss	Win	Win	2
COA 2	Win	Win	Win	Loss	Loss	3

These examples demonstrate the lack of flexibility in choosing alternative analysis and selection methods using the US Army's existing criteria performance ranking method. The majority of alternative analysis and selection methods reviewed require either ratio scoring of alternative performance or nominal data. To increase the flexibility of choice this evaluation recommends that methods which use each alternative performance data type be suggested in the doctrine. For nominal alternative and performance data the frequency of good and bad heuristic provides the only exhaustive and compensatory method, so it is recommended. The majority of confirming dimensions heuristic demonstrated above satisfies ordinal alternative performance data, so it is retained. Three ratio methods are also recommended: simple additive, weighted product and simple additive weighting. The simple additive method matches the unweighted 'decision matrix' method and requires no criteria preference information. The weighted product model allows for dimensionless arithmetic without the need for normalization of alternative performance values (Bridgman, 1922). The simple additive weighting method best matches the existing 'decision matrix' method, so it is retained for consistency. A much simplified choice model based on these recommendations appears in Figure 32 below.

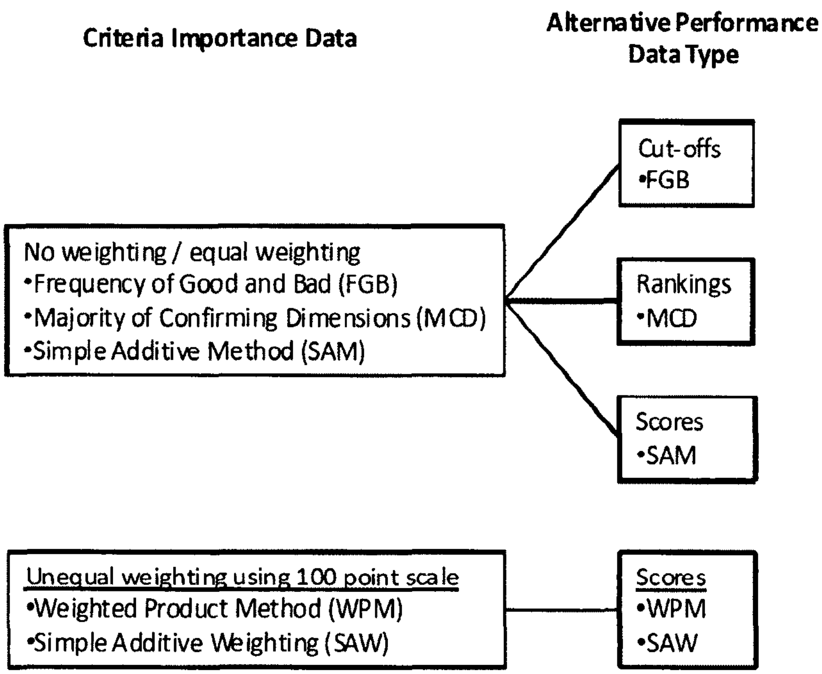


Figure 32: Simplified framework for MDMP.

This framework presents staffs with five methods, which follows Miller's (1956) recommendation for human cognition. The five methods are compensatory and exhaustive, two desirable qualities in alternative analysis methods (Hastie & Dawes, 2001). This framework incorporates the 100 point direct weighting recommendation from the previous section. The scale names have been simplified for a general audience as well. This simplified framework gives staffs the flexibility to choose from methods based on different data types. Additional criteria are required, however, to make the methods mutually exclusive.

This step marks the end of new recommendations for MDMP. The subsequent criteria develop the recommended tool for staffs to select an alternative analysis and selection method. The extension of this framework differs from previous versions in that every branch will extend to the last criterion. This extension allows staffs to understand every element of the possible methods prior to selecting one.

Mathematical Fluency

A US Army staff contains at least one dozen college-educated planners, so one can reasonably expect that any staff could apply any of the five methods recommended above (Kane, 2006). Although it does not help to screen out any methods, this criterion does help distinguish between the two unequal weighting methods, as seen in Figure 33 below.

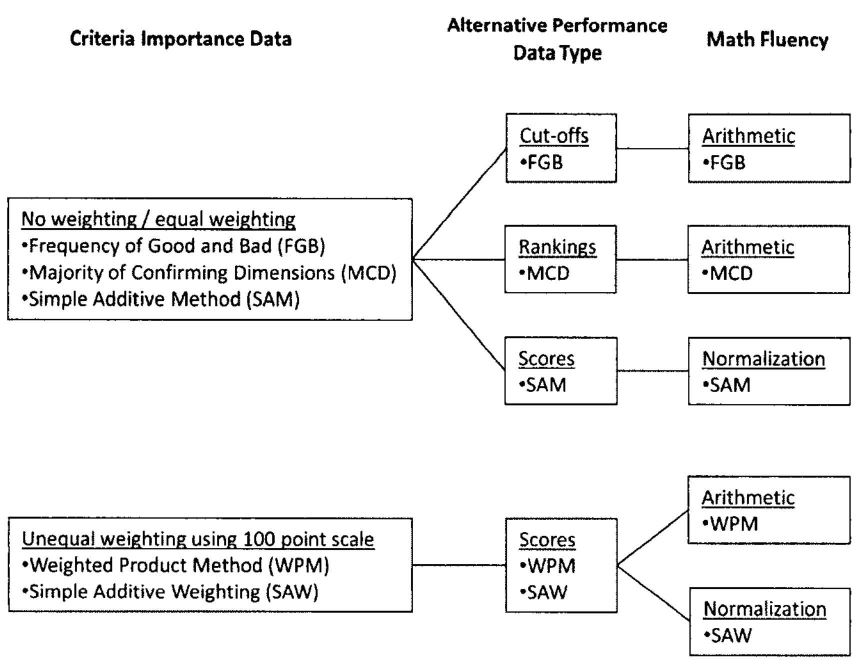


Figure 33: Addition of math fluency criterion to MDMP framework.

The frequency of good and bad heuristic requires arithmetic to add the number of good criterion assessments earned by each alternative. The majority of confirming dimensions heuristic requires arithmetic to add the number of times an alternative outperforms its pair-wise comparison partner. The simple additive method requires the analyst to normalize all criteria scores onto the range [0,1] for addition. The weighted product model requires arithmetic to add, multiply, divide, and exponentiate for weight scaling and score calculation. The simple additive weighting method requires normalizing weights and criteria scores. The nature of these calculations influences the tool suggested to make them practical for a staff.

Mathematical Tools

The framework recommends mathematical tools for each method with the intent of making each method approachable to an analyst. Figure 34 below shows the mathematical tools suggested for each of the five suggested methods. Paper and pen is recommended for addition, a calculator for multiplication and exponentiation, and a spreadsheet for normalization.

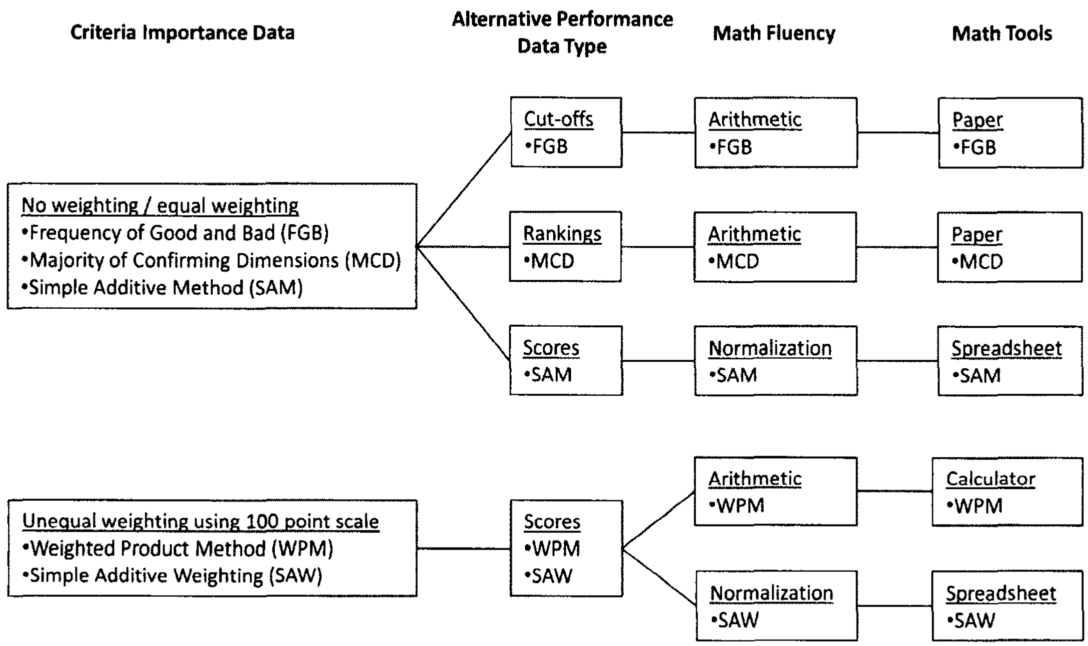


Figure 34: Addition of math tools criterion to MDMP framework.

Effort

This framework uses effort as the final criterion for staffs to choose an alternative analysis and selection method. Figure 35 below presents the final recommendation for an alternative analysis and selection method tool for the US Army's MDMP.

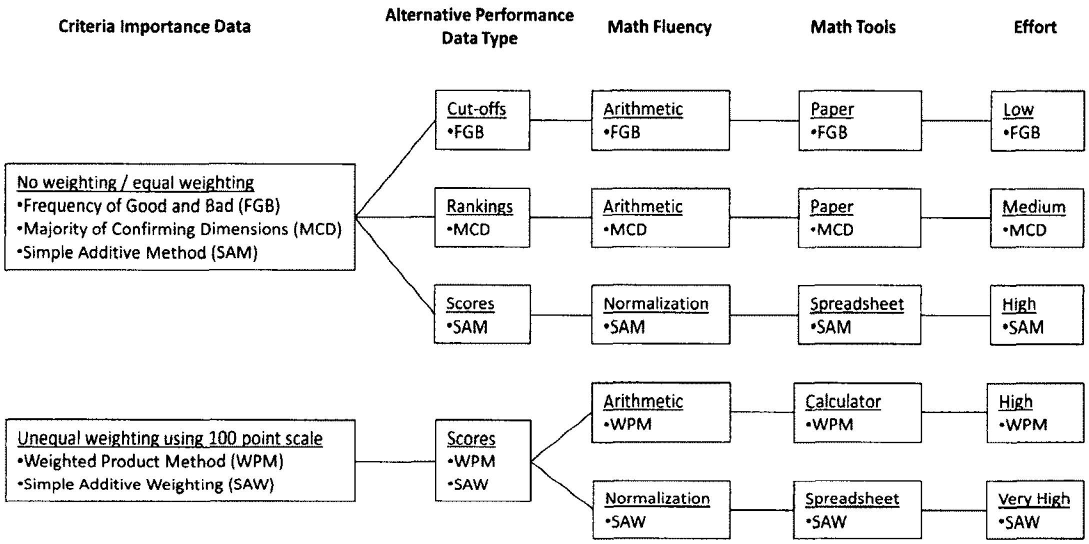


Figure 35: Final MDMP framework.

Summary of Recommendations

This section demonstrates how an engineering manager could use the framework proposed in this research to recommend changes in their institutions' alternative analysis and selection process. In this case the engineering manager is a military planner and the process is the US Army's MDMP. The specific recommendations for MDMP are:

1. Describe the decision matrix as a tool to present multiple criteria decision data rather than as an alternative analysis and selection method.
2. Cease use of the 'decision matrix' method in current doctrine on the grounds that it violates the decision analysis body of knowledge.
3. Provide planners with several alternative analysis and selection methods that use different weighting schemes, scoring data, and levels of effort.
4. Provide examples of these methods to the staffs in the planning doctrine.
5. Organize these methods into a tool that allows staffs to more easily select the appropriate method for their problem and context.

6. For weighted methods, replace the current weighting method with a 100 point direct rating technique with a more is better directionality.
7. For weighted methods, eliminate the allowance to re-allocate weights after course of action comparison. Provide the option for a sensitivity analysis of the weights instead.
8. For scoring methods, use ratio scores with a more is better directionality.

Section 4: Member Checks

Member checks require persons within the context of the study to verify the data and interpretations presented by the researcher (Lincoln & Guba, 1985). These checks serve as an internal validation strategy to establish credibility (Erlandson et al., 1993). The two military planning experts described in Chapter 4 volunteered to validate the case study's findings and recommendations. The researcher sent each member a copy of the case study's results along with any requested supporting materials, like copies of the draft dissertation. Their feedback is summarized in the Table 21 below.

Table 21: Expert feedback.

	Member 1	**Member 2**
Recommendation 1	Agree	Agree
Recommendation 2	Agree	Modify
Recommendation 3	Agree	Agree
Recommendation 4	Agree	Agree
Recommendation 5	Agree, but tool needs improvement	Agree
Recommendation 6	Agree	Modify
Recommendation 7	Agree	Agree
Recommendation 8	No comment	Agree

Member 1

Member 1 provided the following feedback on the case study:

- Improve argument through an illustrative historical case study that demonstrates how each method could change the decision. Recommend a case from military history.
- Use the same case study to show the mathematical challenges in the existing method.
- Do not present equal weighting methods when an unequal weighting method is recommended.
- Recommend only the most rigorous method for each combination of attributes to avoid confusion. Do not place the commander or staff in the decision maker's paradox.
- Use plain English questions for commanders and staffs to follow the tool.

Member 2

Member 2 provided the following feedback on the case study:

- Recommend an example that includes at least three alternatives to better demonstrate the methods, particularly the ones with pair-wise comparisons.
- Dismissing the existing method may cause some in the approval process to balk at the recommendations. Consider a more permissive approach that treats the existing method as a heuristic.
- Demonstrate the recommended weighting method rather than restricting the methods. Staffs will follow whatever the doctrine illustrates.
- Include a discussion of non-transitivity for pair-wise comparison methods.
- Eliminate the weighted product model as a recommendation. It is too complex for staffs to easily explain and defend.
- Emphasize and demonstrate the utility of sensitivity analysis instead of restricting the commander's ability to re-weight criteria.

Summary of Member Checks

Each member accepted the recommendations and provided feedback on how to improve the supporting argument and acceptability to the Army. The members emphasized the practical, philosophical, and political considerations over the strictly mathematical ones. Based on their feedback the recommendations for alternative analysis and selection in US Army MDMP have been modified below (those that have changed are shown in italics):

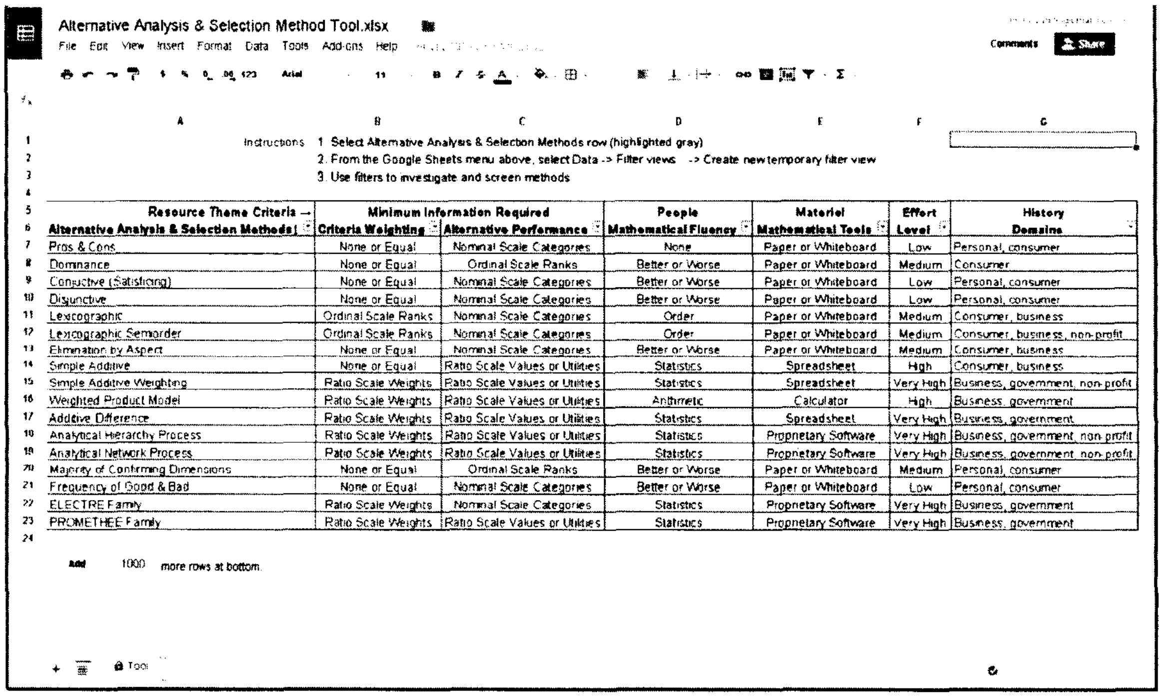
1. Describe the decision matrix as a tool to present multiple criteria decision data rather than as an alternative analysis and selection method.
2. *Propose ending the use of the 'decision matrix' method in current doctrine on the grounds that it violates the decision analysis body of knowledge. If the leadership disagrees, place the old method in an appendix and describe it as a heuristic. Most planners will follow the example in the chapter and ignore the appendix.*
3. *Provide planners with two alternative analysis and selection methods that use different data types and levels of effort. Do not place planners in the decision making paradox. Keep it simple.*
4. *Provide an example of the most rigorous method in the chapter and an example of the less preferred method in an appendix.*
5. *Use plain English and a simple table to differentiate the two methods for the staff.*
6. *Replace the current weighting method with a 100 point direct rating technique with a more is better directionality.*
7. *Eliminate the language describing the re-allocation of weights after course of action comparison to discourage it without prohibiting it. Demonstrate sensitivity analysis in the appendix.*
8. *Prescribe ratio scores with a more is better directionality for alternative scoring against each criterion.*

Section 5: Incorporation of Member and Expert Feedback

In addition to case-specific feedback, the researcher received several recommendations to automate the framework and allow the analyst or manager to manipulate the criteria in any order they chose. Automation allows the framework to exist outside of a piece of paper and make it more portable.

Freeing the order of criteria manipulation allows practitioners to explore methods early in the problem solving process and influence data collection. Together these changes should make for a more valuable tool.

The tool consists of a Google Sheets spreadsheet with a table containing the alternative analysis and selection methods aligned with their criteria, similar to the screen capture in Figure 36 below.



Alternative Analysis & Selection Method Tool.xlsx

Instructions 1. Select Alternative Analysis & Selection Methods row (highlighted gray)
2. From the Google Sheets menu above, select Data -> Filter views -> Create new temporary filter view
3. Use filters to investigate and screen methods

Resource Theme Criteria →	Minimum Information Required		People	Materiel	Effort	History
Alternative Analysis & Selection Methods	Criteria Weighting	Alternative Performance	Mathematical Fluency	Mathematical Tools	Level	Domains
Pros & Cons	None or Equal	Nominal Scale Categories	None	Paper or Whiteboard	Low	Personal, consumer
Dominance	None or Equal	Ordinal Scale Ranks	Better or Worse	Paper or Whiteboard	Medium	Consumer
Conjuctive (Satisficing)	None or Equal	Nominal Scale Categories	Better or Worse	Paper or Whiteboard	Low	Personal, consumer
Disjunctive	None or Equal	Nominal Scale Categories	Better or Worse	Paper or Whiteboard	Low	Personal, consumer
Lexicographic	Ordinal Scale Ranks	Nominal Scale Categories	Order	Paper or Whiteboard	Medium	Consumer, business
Lexicographic Semiorder	Ordinal Scale Ranks	Nominal Scale Categories	Order	Paper or Whiteboard	Medium	Consumer, business, non-profit
Elimination by Aspect	None or Equal	Nominal Scale Categories	Better or Worse	Paper or Whiteboard	Medium	Consumer, business
Simple Additive	None or Equal	Ratio Scale Values or Utilities	Statistics	Spreadsheet	High	Consumer, business
Simple Additive Weighting	Ratio Scale Weights	Ratio Scale Values or Utilities	Statistics	Spreadsheet	Very High	Business, government, non-profit
Weighted Product Model	Ratio Scale Weights	Ratio Scale Values or Utilities	Arithmetic	Calculator	High	Business, government
Additive Difference	Ratio Scale Weights	Ratio Scale Values or Utilities	Statistics	Spreadsheet	Very High	Business, government
Analytical Hierarchy Process	Ratio Scale Weights	Ratio Scale Values or Utilities	Statistics	Proprietary Software	Very High	Business, government, non-profit
Analytical Network Process	Ratio Scale Weights	Ratio Scale Values or Utilities	Statistics	Proprietary Software	Very High	Business, government, non-profit
Majority of Confirming Dimensions	None or Equal	Ordinal Scale Ranks	Better or Worse	Paper or Whiteboard	Medium	Personal, consumer
Frequency of Good & Bad	None or Equal	Nominal Scale Categories	Better or Worse	Paper or Whiteboard	Low	Personal, consumer
ELECTRE Family	Ratio Scale Weights	Nominal Scale Categories	Statistics	Proprietary Software	Very High	Business, government
PROMETHEE Family	Ratio Scale Weights	Ratio Scale Values or Utilities	Statistics	Proprietary Software	Very High	Business, government

Add 1000 more rows at bottom.

Figure 36: Alternative analysis and selection method tool.

The tool has several useful features due to the Google Sheets platform. First, users may be divided into those with edit, comment, and view permissions. The tool may also be made public, allowing any user to store and manipulate a local copy. Second, the table is scalable, so additional methods and criteria can be easily added as they are discovered. Third, the tool resides online and can be accessed by any device with a Google Documents compatible web browser and internet access. Fourth, the sheet relies on familiar sorting techniques learned by almost every spreadsheet application user. All of these features improve the usability of this tool over the paper framework.

Addressing expert feedback to free the order of criteria manipulation in the digital framework also presented an opportunity to improve the paper framework. Instead of requiring the analyst or manager to move linearly from left to right along the criteria, the final framework allows them to start at any criterion and work in either direction. This format may prove more useful earlier in the problem solving process when the analyst or manager can still influence the resources committed to the problem and the type of data collected. Figure 37 below presents the finalized paper framework.

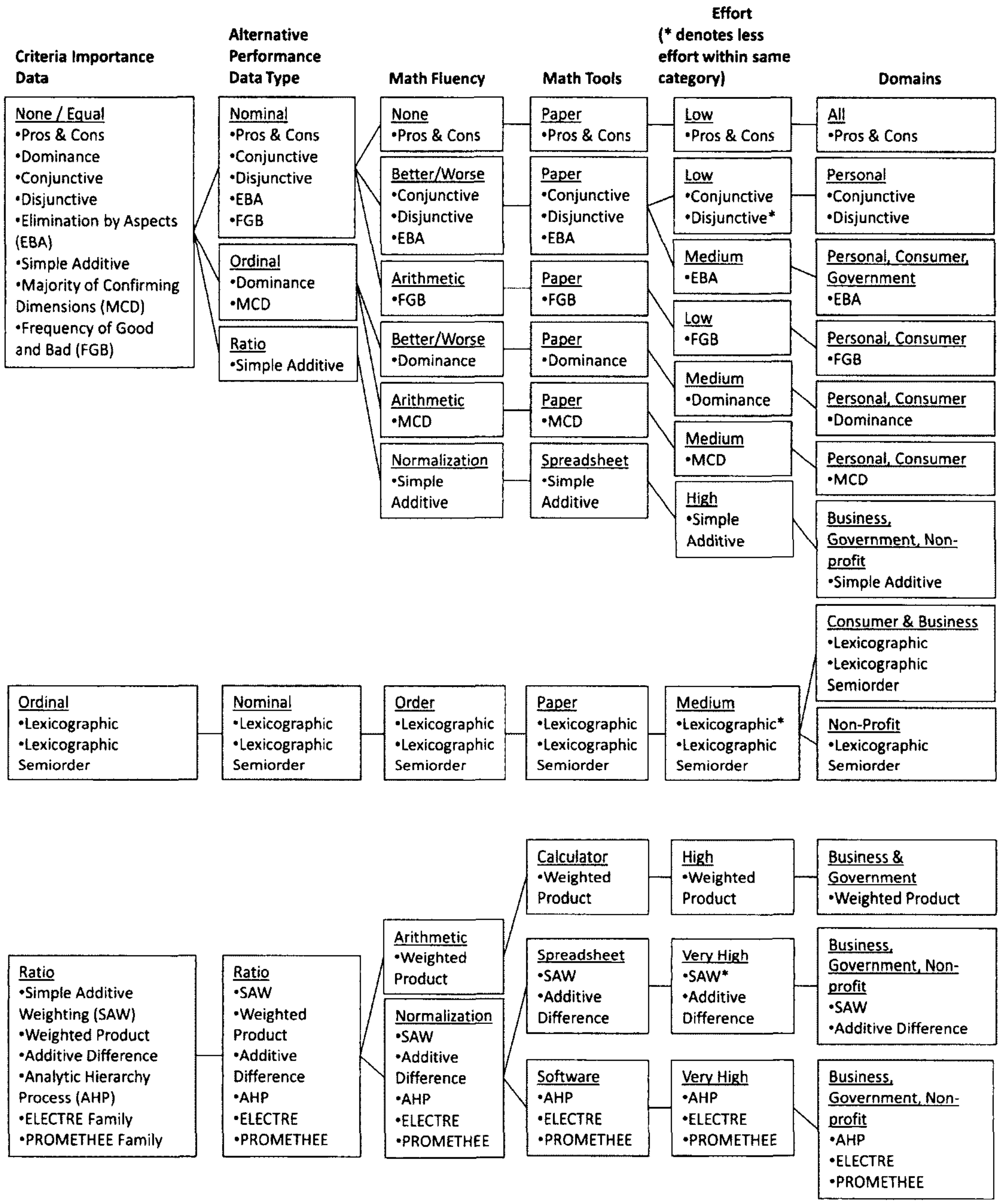


Figure 37: Final alternative analysis and selection method framework.

Summary of Case Study

This case study demonstrates several ways that the alternative analysis and selection method framework may be applied by an analyst or manager. Section 1 applied the framework as is to a problem and its context in order to answer Research Question 3. Section 2 used the framework to evaluate alternative analysis and selection within an organization. The engineering manager then modified the framework by either trimming unnecessary elements or adding resources to preserve methods faced with elimination. Section 3 used the framework to drive change at the institutional level and resulted in several recommendations for the U.S. Army's course of action comparison process. These last two sections answered Research Question 4. Section 4 summarized the expert member feedback and presented a set of modified recommendations for Army course of action comparison. Section 5 presented an online tool that improves the framework's usability.

CHAPTER 7

SUMMARY

Introduction

This chapter summarizes the research results, contributions, recommendations for future research, and conclusions of the dissertation. Many of the ideas in this chapter come from reviewers, experts, and peers that offered feedback on the research.

Research Results

The purpose of this study was to develop a theory of alternative analysis method selection in resource constrained contexts that is operationalized through a decision aid and applied to military staffs as a case study. This purpose was achieved through the development and application of the alternative analysis and selection method decision tool in Figure 23 to the case of US Army operational planning. The tool was subsequently modified into a scalable, online, and collaborative decision support tool based on the feedback of experts.

Research Question 1 asked "What are an appropriate set of criteria for choosing the alternative analysis methods that are suitable to each unique problem and context?" The research revealed that the data, mathematical fluency and tools, and effort available formed an appropriate set of criteria for choosing alternative analysis methods.

Research Question 2 asked "What is an appropriate framework within which to organize the set of appropriate evaluation criteria?" The research produced tabular and flow chart style frameworks for use in different situations. The final framework added interactive, scalable, collaborative, and online characteristics to the tabular framework.

Research Question 3 asked "How can practitioners use the resultant framework to match alternative analysis methods to problems and their context?"

Section 1 of the case study showed how an Army staff member acting as an analyst would use the framework to match methods to their problem and its context by considering the criteria from Research Question 1 and following the flow chart style framework from Research Question 2.

Research Question 4 asked "How can engineering managers use the framework to evaluate the effectiveness of alternative analysis within their technical enterprise?" Sections 2 and 3 of the case study showed how an executive officer, acting as an engineering manager, would use the framework to evaluate alternative analysis and selection inside and outside of their organization.

Theoretical Contributions

This dissertation contributes the first application of the general inductive theory to the multiple attribute decision making literature. This application identified the predominant themes, categories, and codes in that body of knowledge. This dissertation also proposed a decision flow theory for alternative analysis and selection method choice in Figure 22. The first part of this theory was developed into the framework and operationalized into the online decision aid.

Methodological Contribution

This research contributes a method to develop evaluation frameworks using a mixed methods approach. First, the general inductive theory was used to elicit the evaluation themes. Second, content analysis was used to identify the evaluation criteria. Third, satisficing was used to select the framework structure. This methodology may be applied to other domains requiring evaluation frameworks.

Practical Contributions

This research contributes three practical products for engineering management practitioners. First, it provides a table of alternative analysis and selection methods and their criteria. Second, it provides a flow chart decision tool that may be followed to match methods to a problem and its context. Third, this research provides an online, collaborative, and scalable tool for investigating and selecting alternative analysis and selection methods.

Future Research

This research generated many recommendations and ideas from peers, experts, and reviewers. Ideas that fit directly within the dissertation's scope were addressed while others were saved for future consideration. This section presents some future research directions that may be pursued.

Expanding the Framework

This research purposely kept the scope of the evaluation framework small due to limits on the resources available to the researcher. The alternative analysis and selection method framework can be easily expanded along two directions. First, more methods could be added to the framework by expanding the scope to all multiple criteria decision making methods, although the structure of the developed framework is scalable and allows for additional methods to be considered in an ad hoc manner. Second, more criteria of each method could be researched to provide additional differentiation between methods for analysts. The author created the scalable collaborative online tool for exactly this type of expansion.

Historical Case Study

Member 1 suggested a case study that considers a classic military planning event, like D-Day, to show the shortcomings of the existing methods and how different alternative analysis and selection methods may have produced a different course of action. Initial research into this idea revealed that the selection of a landing site for the Allies may be a candidate, but further investigation showed that Normandy was chosen through an elimination by aspects approach (Ford & Zaloga, 2009). A related idea would use a modern military planning event that has its course of action comparison phase recorded in the US Army Center of Military History. A modern historical example should be more likely to use the currently recommended method and thus make for a better basis of comparison.

Other Domain Case Study

The evaluation framework methodology should be applied to other domains to further validate its generalizability. Evaluations in other decision making domains like government, industry, or non-profits may yield a different set of criteria for evaluation. Evaluations of processes other than decision making should generate different evaluation frameworks altogether. Each new framework would require its own validation.

Conclusion

This research began as an investigation into alternative analysis in military planning and resulted in a scalable collaborative online tool that any analyst can use to explore and select alternative analysis and selection methods. It also produced a methodology for evaluation framework development that applies across domains. Along the way the research changed how the US Army conducts course of action comparison in its planning doctrine and educated the national security analysis community on the shortcomings of existing methods. These contributions form the foundation of future research.

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APPENDIX A: MILITARY EMPIRICAL MATERIALS

1. Anderson and Slate (2003)
2. United States Army War College (2010)
3. Boukhtouta et al. (2004)
4. Dees, Nestler, and Kewley (2013)
5. Department of Defense (2008)
6. Ewing, Tarantino, and Parnell (2006)
7. Holbrook (2003)
8. Holzgrefe and Hester (2014)
9. Isaak and Wheeler (2012)
10. Killion (2000)
11. Klimack and Kloeber (2006)
12. MacGregor (1992)
13. Matthews (2004)
14. Morrison, Kelly, Moore, and Hutchins (1996)
15. North Atlantic Treaty Organization (2010)
16. Phillips (2004)
17. Schwartz (2010)
18. Spruill (2012)
19. United States Air Force (2012)
20. United States Army (2010)
21. United States Army (2011)
22. United States Joint Staff (2011a)
23. United States Joint Staff (2012)
24. United States Marine Corps (2010)
25. United States Navy (2007)

APPENDIX B: NORMATIVE EMPIRICAL MATERIALS

1. Bernoulli (1954)
2. Charnes, Cooper, and Ferguson (1955)
3. Charnes, Cooper, and Rhodes (1978)
4. Churchman and Ackoff (1954)
5. Clemen (1991)
6. Edwards (1977)
7. Edwards and Barron (1994)
8. Einbu (1978)
9. Einbu (1984)
10. Everett III (1963)
11. Figueira, Greco, and Ehrgott (2005)
12. Fishburn (1967)
13. F. K. Hwang (1987)
14. Ralph L. Keeney (1971)
15. Ralph L. Keeney and Raiffa (1976)
16. Köksalan et al. (2011)
17. Koopman (1953)
18. Lehmann (1950)
19. R. Duncan Luce (1956)
20. R.D. Luce and Raiffa (1957)
21. Luss and Gupta (1975)
22. MacCrimmon (1968)
23. D. W. Miller and Starr (1960)
24. Patriksson (2008)
25. Powell, Shapiro, and Simão (2002)
26. Raiffa (1968)
27. Savage (1954)
28. Schniederjans (1984)
29. Triantaphyllou (2010)
30. Triantaphyllou and Mann (1989)

31. Von Neumann and Morgenstern (1953)
32. Wald (1939)
33. Wallenius et al. (2008)
34. Yoon and Hwang (1995)

APPENDIX C: DESCRIPTIVE EMPIRICAL MATERIALS

1. Allais (1953)
2. De Martino, Kumaran, Seymour, and Dolan (2006)
3. Ellsberg (2001)
4. Foulds (1983)
5. Gilovich, Griffin, and Kahneman (2002)
6. Hastie and Dawes (2001)
7. E. J. Johnson and Payne (1985)
8. Kahneman (2013)
9. Kahneman, Slovic, and Tversky (1982)
10. Kahneman and Tversky (1979)
11. Kahneman and Tversky (2000)
12. Klein (1993)
13. Klein (2008)
14. Pascal (1670)
15. Simon (1956)
16. Tversky (1972)
17. Tversky and Kahneman (1992)

APPENDIX D: PRESCRIPTIVE EMPIRICAL MATERIALS

1. Bangla and Castanon (2010)
2. Behzadian, Kazemzadeh, Albadvi, and Aghdasi (2010)
3. Brans, Vincke, and Mareschal (1986)
4. S. J. Chen and Hwang (1992)
5. Y. Chen, Larbani, and Chang (2009)
6. Costa and Vansnick (1999)
7. Eberle (1972)
8. C. L. Hwang, Lai, and Liu (1993)
9. C. L. Hwang and Lin (1987)
10. C. L. Hwang and Yoon (1981)
11. Jain (1976)
12. Ralph L. Keeney (1992)
13. R. L. Keeney and Mcdaniels (1992)
14. Klir and Yuan (1995)
15. Lai, Liu, and Hwang (1994)
16. Lake (1976)
17. Luss (1999)
18. Millet and Saaty (2000)
19. Parnell, Driscoll, and Henderson (2010)
20. Pugh (1991)
21. B Roy (1981)
22. Bernard Roy (1990)
23. Thomas L. Saaty (1980)
24. Thomas L. Saaty (1982)
25. Thomas L. Saaty (1994)
26. Thomas L. Saaty (2008)
27. Thomas L. Saaty and Alexander (1989)
28. Thomas L. Saaty and Forman (1996)
29. Thomas L. Saaty and Vargas (1991)
30. Thomas L. Saaty (1994)

31. Triantaphyllou and Mann (1990)
32. Wang (2012)
33. Zadeh (1965)
34. Zimmermann (2001)

APPENDIX E: CODES ELICITED FROM LITERATURE STREAMS

Military Decision Making – 65 codes	
missions	staffs
capability	quartermaster
transportation	dollars
appropriations	purpose
classes of supply	system effectiveness
plans	billets
execution	units
assets	management
tactics	ways
human resources	means
comptroller	organize
auditing	assessments
functions	direction
distribute	parameters
authorizations	objectives
art	strategy
leadership	budget
supplies	programming
funds	logistics
force effectiveness	money
spaces	tasks
concepts	supervision
commander	motivation
provisions	direction
faces	ends
military decision making process	effective
orders	activities
performance	personnel
resupply	maintenance
allocate	maneuver
human capital	domains
assignments	operations
slots	

Normative Decision Making – 59 codes	
omniscient decision maker	deduction
resources	value
distribution	system effectiveness
economics	force effectiveness
belief	expected value
optimal	desirability
amount	lottery
Utility Theory	resource allocation
axiomatic	approach
apportionment	perfect information
EVPI	utility
rationality	effectiveness
inputs	function
all-knowing	logic
preference	ideology
perfect	reasoning
preferred	parameters
assets	maximize utility
performance	hypothesis
personal value	non-linear
usefulness	theory
maximize	optimization
profit	supplies
certainty	method
deterministic	all-seeing
mathematical programming	expense
doctrine	minimize
best	price
cost	transparency
allocation	

Descriptive Decision Making – 69 codes	
good enough	compromise
incertitude	facility
risky	observations
psychology	probability
acceptable	concession
satisfy	Allais
uncertainty	impersonal point
fast	estimation
competition	memory
precarious	likelihood
expertness	behavior
limited resources	critical
skill	expertise
studies	research
prowess	recognition primed decision
tradeoff	conclusions
heuristics	unpredictability
wisdom	motivation
bargain	history
know-how	hypotheses
settlement	suffice
decisions	subject matter expert
momentary perspective	naturalistic
competence	thought
cognition	frugal
inferences	background
subjects	measureable/unmeasureable
sensitive	finite
perilous	satisficing
practice	bounded rationality
simple	hazardous
high stakes	maturity
consequentialism	choice
experiments	rule of thumb
experience	

Prescriptive Decision Making – 64 codes	
organization	processes
spreadsheet	mission
value focused thinking	industry
structure	operations
relationships	ranks
real world	Gaia
choice	tasks
course of action	eigenvalues
trial	branch
option	feedback
beliefs	principles
applications	application
distinguishable	French school
values	sectors
alternatives	input factors
government	nesting
decision maker	hierarchy
chain of command	concordance principle
AHP	alternative generation
practice	inflection point
business unit	system
ANP	weighting function
ideals	outranking
sensitivity analysis	Lagrange
database	change
PROMETHEE	weight
purpose	ELECTRE
business	ordinal
exclusive	functions
program	standards
software	precedence
plug-in	network

APPENDIX F: DEPENDABILITY AUDIT

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10/22/2014 2:08 PM		Reference:Translated Title	Source Classifications	Created	Imported Web Data	James P. L. Holzgrefe
10/22/2014 2:08 PM		Reference:Call Number	Source Classifications	Created	Imported Web Data	James P. L. Holzgrefe
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10/22/2014 2:08 PM		Wiley, Rob, Hunder, Chris, (2009)	Internals	Created	Imported Web Data	James P. L. Holzgrefe
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10/22/2014 11:16 AM		Von Neumann, John,Morgenstern, Oskar; (2007) - 518	Externals	Modified		James P. L. Holzgrefe
10/22/2014 11:16 AM		Von Neumann, John,Morgenstern, Oskar; (2007) - 518	Externals	Modified		James P. L. Holzgrefe
10/22/2014 11:12 AM		Triantaphyllou, Evangelos; (2010) - 494	Externals	Modified		James P. L. Holzgrefe
10/22/2014 11:10 AM		Schniederjans, Marc J.; (1984) - 674	Externals	Modified		James P. L. Holzgrefe
10/22/2014 11:09 AM		Schniederjans, Marc J.; (1984) - 674	Externals	Modified		James P. L. Holzgrefe
10/22/2014 11:04 AM		Saaty, Thomas L.,Vargas, Luis G.; (1994) - 477	Externals	Modified		James P. L. Holzgrefe
10/22/2014 11:03 AM		Saaty, Thomas L.;Vargas, Luis G.; (1994) - 477	Externals	Modified		James P. L. Holzgrefe
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10/22/2014 10:58 AM		Saaty, Thomas L.;Forman, Ernest H.; (1996) - 479	Externals	Modified		James P. L. Holzgrefe
10/22/2014 10:33 AM		Saaty, Thomas L.; (1994) - 478	Externals	Modified		James P. L. Holzgrefe
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10/21/2014 4:44 PM		Pugh, Stuart; (1991) - 531	Externals	Modified		James P. L. Holzgrefe
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10/20/2014 3:44 PM		Book:Year	Source Classifications	Created	Imported Bibliographical Data	James P. L. Holzgrefe
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10/20/2014 3:44 PM		Kahneman, D.;Tversky, A.; (1979) - 817 Imported Notes	Memos	Created	Imported Bibliographical Data	James P. L. Holzgrefe
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10/20/2014 3:44 PM		Journal Article Tertiary Title	Source Classifications	Created	Imported Bibliographical Data	James P. L. Holzgrefe

VITA

Major Jim Holzgrefe is a Functional Area 49 (FA-49) Operations Research and Systems Analysis (ORSA) officer in the U.S. Army. He completed his Ph.D. in Engineering Management as a full-time resident student through the Army's Advanced Civil Schooling program. Jim received his commission as an Aviation Officer from the University of Virginia in 2000, following seven years of enlisted service as an infantryman and artilleryman in the Virginia Army National Guard. He is a graduate of the Aviation Officer Basic and Captains Career Courses, OH-58D Flight School XXI, the Joint Firepower Course, Australia's Joint Pre-deployment Operations Analysis Course, the Command and General Staff College, the FA-49 Qualification Course, and the Defense Strategy Course.

Jim served in several leadership and staff positions in the 17th Air Cavalry Regiment and Headquarters, Department of the Army (HQDA) before beginning doctoral studies. Previous aviation assignments include service as a Class III/V Platoon Leader, Aeroscout Platoon Leader, Headquarters Troop Executive Officer, Logistics Officer, Attack-Recon Troop Commander, and Operations Plans Chief in the 2nd and 3rd Squadrons of the 17th Air Cavalry Regiment, including combat deployments for the liberation and surge campaigns of Operation Iraqi Freedom. Previous ORSA assignments include Intelligence Analysis Team Chief at the Center for Army Analysis, Senior Analyst on the Vice Chief of Staff, Army's Capabilities Analysis and Integration Task Force, and Team Chief in the Program Analysis & Evaluation Directorate of HQDA.

Major Holzgrefe holds a Master of Engineering from the University of Virginia and a Bachelor of Science from Virginia Tech, both in civil engineering. His military awards and decorations include the Bronze Star Medal, the Meritorious Service Medal with 2 Oak Leaf Clusters (OLC), the Air Medal with valor device and numeral 7, the Army Commendation Medal with 2 OLC, the Army Achievement Medal, the OIF Campaign Medal with three campaign stars, the Parachutist Badge, the Air Assault Badge, the Senior Army Aviator Badge, the Combat Action Badge, and the Army Staff Identification Badge.