Characterizing Battlefield Human Decision Making with Value Focused Thinking and Reliability Modeling

Fawaz Al-Karaeen

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CHARACTERIZING BATTLEFIELD HUMAN DECISION MAKING WITH VALUE FOCUSED THINKING AND RELIABILITY MODELING

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy

By

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M.S., Wright State University, 2003

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Military officers and soldiers in combat are faced with complex, time-critical decision problems. The battlefield, or combat, environment involves decisive operations under unpredictable and rapidly changing conditions. Decisions in battlefields take place under uncertain, time constrained conditions and in a tactical environment. A battlefield decision maker encounters a dynamic information environment. During combat, individuals gather and consider information from a variety of sources to determine what information is reliable and useful, and what information is not. There is a clear correlation between the decision making process and the value of information feeding that process. This research examines a decision making model applicable to the battlefield space, a reliability of information model, and then a combined model integrating the individual models. The decision making model will exploit the value-focused thinking paradigm. The reliability model will capture information degradation considerations after deriving and defining a new reliability of information concept. The combined model will provide a means to capture and examine the dynamics of battlefield decision making by linking the value-focused thinking model and the information reliability model. The linked model (Integrated Model) has more advantages and it is more useful than existing models of battlefield decision making. Each effort represents a novel approach and a unique contribution of this research.
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To Stacy and Khalil, my future wife and expected son
CHAPTER 1

INTRODUCTION

1.1 General Discussion

The battlefield, or combat, environment involves decisive operations under unpredictable and rapidly changing conditions. Decisions in battlefields take place under uncertain, time constrained conditions and in a tactical environment. Battlefield decisions are difficult for many reasons. For instance, a decision may involve risks especially when there is uncertainty about the consequences of the decision. Military battlefield decisions also involve conflicting objectives so even the evaluation of the alternatives is difficult.

Military officers and soldiers in combat are faced with complex decision problems. The result of their decisions affects a large number of people and vast array of resources. For a long time these decisions were made using standard procedures or by relying on personal experience. Modern technology, particularly computer simulations, has provided improved training experiences. These new training models still fall short in capturing the battlefield decision making process. In fact, most models fall short in accurately modeling human decision making. This research targets this shortcoming.

The military views decision making as both science and art. Battle command is divided into two categories: command and control. The art of command is the arena of the commander where he tries to predict the future, make decisions based on those predictions, and lead his troops. Control is the science of the battle command staff. Commander staffs compute requirements, apply means and resources to achieve the commander’s intentions, and monitor the status of the operation (TCAICE, 2006).
General Maxwell in 1981 (as referenced in Lykke, 2000) characterized a strategy as consisting of objectives, ways and means. This general concept can be used as a basis for the formulation of any type strategy whether it is political, military, or economical.

Strategists, Planners, Commanders, and team leaders are all concerned with ways to employ means to achieve objectives. Due to the criticality of the decisions and the importance of deploying the strategies, a systematic structured approach to problem solving and decision making is needed. In practice, a commander’s approach is honed by actual and exercise experience. In creating computational models, the commander’s approach must be understood and specified. This model approach is needed to not only understand the actual decision making process but also to create better models of the process.

To help improve their decision making process, any individual should be aware of what is happening around them. Military decision making is significantly affected by the environment in which individuals make decisions especially on the basis of received information. A future command decision may depend on what happened in the past. If commanders are given false information, or even valuable information late, it may lead them to incorrect problem identification and thus poor decisions.

A battlefield decision maker encounters a dynamic information environment. During combat, individuals gather and consider information from a variety of sources to determine what information is reliable and useful, and what information is not. Tactical military information is particularly uncertain. The uncertainty of information depends on many factors, including the source, reliability, and age of information. The information
must be fielded into a decision making system quickly. The cost of delaying the information can be quite high.

The temporal value of information can and should be modeled when modeling decisions. In battlefields, the value of information degrades along time. The probability of degradation along time can be modeled using certain probability distributions. However, current models do not model information degradation in this manner and in fact fail to explicitly link decision making and information models. This research will initiate the means to overcome this deficiency.

There is a clear correlation between the decision making process and the value of information feeding that process. This research examines a decision making model applicable to the battlefield space, a reliability of information model, and then a combined model to capture both of the individual models. The decision making model will exploit the value-focused thinking paradigm. The reliability model will capture information degradation considerations. The combined model will provide a means to capture and examine the dynamics of battlefield decision making. Each effort represents a novel approach and a unique contribution of this research.

1.2 Past Efforts

The following paragraphs describe some of the past efforts applied to the general area of battlefield decision making.

1.2.1 Decision Analytic Methods

The first extensive use of formal analytic methods as an aid to military decision making was made by operations analysis teams in World War II (Quade, 2000). A typical
example of an operations analysis problem was the selection of the bomber formation in attacking targets deep in Germany.

An early outstanding example of the use of decision analysis techniques, one that had a significant impact on United States strategic policy, was the “Selection and Use of Strategic Air Bases” in Europe. The project was carried out by the RAND society in 1951, and a full report was published in 1954 (as referenced in Quade, 2000). The project main concern was to deter a possible Soviet attack on Western Europe. The general objective was the deterrence of such an attack based on the unilateral atomic capability. The decision problem was to analyze where and how to base the strategic Air Force and how to operate this force in conjunction with the base system chosen and the main objective.

The cold war period provided the United States with the most academically rigorous and enduring theories of conflict in the history of war studies. Beene (2002) translated some of the theory developed during the cold war era into terms to make it relevant to strategies and force structures today. Decision analysis techniques, value-focused thinking in particular, were used to create a framework for assessing the contribution of force structure toward achieving national strategic goals and the contribution of strategy toward achieving national policy goals. Beene assessed the US national strategy by breaking it down into a hierarchy to provide focus and organization. His work highlights the unique nature of the US national strategy from a decision analysis perspective. The techniques were illustrated using a specific context example, a coercion strategy wherein the US seeks to compel an adversary to reverse its military
action against a friendly state. The contribution of military force to a strategy of coercion was analyzed and investigated.

TCAICE (2006) presents the Tactical Decision Making Process (TDMP), defined as, “The process in the military version of the decision making tailored to the unique needs of the military”. The TDMP involves four essential steps: mission analysis, course of action development, course of action analysis/comparison, and finally decision and execution.

The mission analysis step begins with the review of the commander’s intent and ends with the commander approval of the restated mission. The course of action development step starts after receiving the commander’s guidance; the entire staff develops courses of action to identify and retain for subsequent analysis to achieve the mission. The course of action analysis/comparison step starts after the courses of action are developed; the staff analyzes each course of action and compares them to identify the best course of action to recommend to the commander. Finally, the execution step occurs when the commander selects the course of action he feels is most advantageous.

TCAICE (2006) views the tactical decision making process as having three methodologies: deliberate decision making, combat decision making, quick decision making.

- Deliberate decision making is characterized by maximum planning time and the involvement of staff and the opportunity to examine many courses of action.
- Combat decision making is used when time is constrained. The process usually is commander driven.
• Quick decision making is used when the commander has no staff, the staff is not readily available, or when there is a crisis or emergency requiring a decision.

Murray (2002) presented a systematic approach for defense decision making. The approach is based on executive decision making applicable to senior military officers or career defense civilians involved in complex decisions that affect the long term capabilities of the military organization, force structure, organization, modernizations, policy, and the welfare of the nation.

In Murray’s type of decision problems, a time frame boundary is not a direct constraint. Such is not the case in combat decisions problems where the time is almost always a binding constraint. Information value degradation along the time horizon in the executive decision making process is not as critical when compared to the temporal aspects of the combat decision making process.

Allen (2005) identified the current external influences on command decision making. He investigated how these influences have necessitated a change in the command decision making process. He concluded that experience is the main factor in military decision making. A specified decision model (the Recognition-Primed Decision model, RPD) was used to support his findings. The origin of RPD stemmed from the recognition of the human strengths and weaknesses that impact on how well people do under adverse decision making problems. The model is based on the fusion of two processes: the way decision makers size up the situation to recognize which course of action applied, and the way decision makers evaluate the course of action by imagining the execution of that course of action (Klein, 1992).
Buede and Bresnick (1992) discussed applications of decision analysis in the military systems acquisition process. They discussed applications in the four major phases of the acquisition process. These phases were derived by White and Hendrix (as referred in Bude and Bresnick, 1992). The use of decision analysis can provide the defensible decisions that should be produced by the acquisition process. The acquisition process cannot be separated from the planning, programming, and budgeting system (PPBS) founded by McNamara in 1961 (as referred in Bude and Bresnick, 1992). They presented a methodology for linking systems acquisition to PPBS by allocating resources to the systems.

John, Callan, and Proctor (2000) experimentally examined the effects of uncertain battlefield information on the nature of tactical decisions. In their first experiment, they investigated whether decision making can be improved by how information is displayed. For this purpose, they developed textual and graphical representations of uncertain enemy intent and future troop movements on realistic battlefield maps.

In a second experiment, they investigated how uncertainty affects the tactical decision making and how adverse effects of uncertainty can be minimized or eliminated. They designed an experiment to examine the effect of situation uncertainty on decision time and choice of battle plan in a series of three controlled tactical scenarios.

Islam, Biswal, and Alam (1997) verified the applicability of the Analytic Hierarchy Process (AHP) to the problem of choosing the best transport aircraft among several alternatives, using Saaty’s (1990) suggestion (as referred in Islam, Biswal, and Alam, 1997) of clustering alternatives into groups according to a common attribute. Saaty’s clustering technique is valid when the number of alternatives is high and the
evaluation scores of alternatives on the criteria are widely dispersed. The procedure starts by breaking down the decision problem to construct the hierarchy of inter-related decision elements. Then it adopts a subjective suitable scale to rank all the alternatives with respect to a certain criterion. It then makes clusters of alternatives having closure magnitudes and finds the priority weights of all the alternatives belonging to each of the clusters. Finally, the procedure obtains the ranking of all the alternatives by applying the usual principle of hierarchal composition. Islam, Biswal, and Alam (1997) solved the problem of choosing the best transportation aircraft using the traditional AHP and using the clustering procedure. They concluded that in the clustering procedure, the number of comparisons required is much less than that required in the unified approach and the rankings that result are sufficiently close to the standard AHP with all the pairwise comparisons. Their conclusion was sustained by the computed rank correlation coefficients and a statistical test.

Bassham, Bauer, and Miller (2006) presented an evaluation methodology that incorporates the preferences of an evaluator and the war fighter, each having a vested interest in the Automatic Target Recognition (ATR) system. Their methodology implements a decision analysis approach to incorporating the preferences and value structure of the various decision makers. The decision analysis techniques were based on an overview from Clemen (1990).

Baker, Green, Lowe, and Francis (2000) offer an approach for performance-based decision making and budgeting that objectively orders alternatives according to established mission criteria. A model was employed using value focused-thinking to address the contemporary focus on performance and mission-oriented results. The model
was applied on equipment purchases for the Dean of the US Air Force Academy (USAFA) Faculty.

Jurk, Chambal, and Thal (2004) used a value-focused thinking (VFT) model to choose an alternative among innovative force protection alternatives ideas. Usually, a variety of proposed solutions or initiatives are presented to the battle-labs as alternatives to meet the demand of improving the ability of the Air Force to execute its core competencies and joint war-fighting. Therefore, the battle-labs must prioritize those initiatives to select the best application of their limited resources. The purpose of their study was to demonstrate the usefulness of applying the VFT process in a generic setting, while tied up to a particular topic of interest, the force protection environment. The results and conclusions of the Force Protection Battle-lab (FPB) focus case may be logically extrapolated to address similar challenges faced by the other battle-labs.

1.2.2 Simulation Methods

A good deal of research has been done simulating battlefields. These efforts vary from low-resolution simulations where the battlefield is simulated in general constructs to high-resolution simulations where even the infantry soldier is represented in detail in the simulation. Simulations were used to measure or improve human factors engineering topics like estimating the operational effectiveness of a soldier, improving situation awareness of a soldier, or improving the ability of allocating resources for a commander (Tollefson, et al., 2004).

Kaste, May, and Heilman (2003) reported the results of a collaborative effort between researchers at the Army Research Laboratory (ARL) and The Ohio State University (OSU) experimenting with a decision tool for mining ARL combat simulation
data to gain battlefield-planning insights. The collaborating team developed and used an approach based on multiple criteria decision-making to enhance battle planning. Decision support systems can assist commanders in examining simulation data for relationships between Courses of Action (COA) structure and various objectives. However, there were no efforts directed toward simulations that would measure and analyze the values or the characteristics of an officer or a soldier in a battlefield system.

Ntuen and Park (2003) described an analytical decision aid, the Alternative Course of Action Display (ACAD), for supporting the commander’s course of action planning and analysis based on the battle asset information. The paradigm of Mission, Enemy, Troops, Terrain, and Time (METT-T) is the main knowledge that drives the ACAD software.

Another planning decision aid is FOX-GA, which is a COA generating tool developed at the University of Illinois at Urbana-Champaign (UIUC) by Schlabach and Hayes in 1998 (as referenced in Ntuen and Park, 2003). FOX-GA mimics the state-space mappings predetermined friendly force strength to that of the enemy. CORAVEN was developed for intelligence collection management and analysis by Jones, et al., in 2000 (as referenced in Ntuen and Park, 2003). CORAVEN runs in a multimedia system. It uses the Bayesian belief network as a modeling tool. A last example is OWL, a decision analytic war-gaming tool for predicting alternative outcomes of a battle based on uncertain information available about friendly and enemy forces. The software was developed at the Rockwell Science Center by Uckun, et al. in 1999 (as referenced in Ntuen and Park, 2003). The software randomly generates inputs to execute the same war scenario in several iterations.
Managing major defense systems successfully requires deliberate and continuous attention to risk due to the reduced budgets, expanded mission objectives, and increased schedule pressure (Cho, Garvey and Giallombardo, 1997). Cho, Garvey and Giallombardo (1997) present a management tool called RiskNav for prioritizing, displaying, and tracking program risk. RiskNav provides program offices a structure for conducting continuous risk assessments. As a decision aid, the tool (RiskNav) assists in identifying where engineering resources are best allocated to mitigate potentially crippling areas of risk to a program.

Some of the research by the Department of Defense includes training programs that prescribes the policies, procedures and responsibilities for headquarters and commanders. Those regulations outline the battle command training program (BTCP). For example see, U.S. Army Training and Doctrine Command (2005).

Another example is Battle Book (2005) which provides information to the battle commanders at the brigade and battalion levels on the employment of the battlefield operating systems. In other words, it presents what commanders should consider and care about, along with the regulations and applied restrictions. Understanding this pamphlet leads to better understanding of commanders’ values and how these values influence their decision making.

1.2.3 Reliability-Focused Methods

Reliability technologies are a main concern of the Department of Defense. Reliability modeling and analysis is applied in a direct way in military industries. The importance of reliability modeling and analysis started in the military field. The Department of Defense in 1952 (Ebeling, 1997) established the Advisory Group on
Reliability of Electronics Equipments (AGREE), and the efforts and studies in reliability have continued since then. A good deal of research is available that focuses on applying reliability to different components and systems in the militarily industries. However, there appear to be no efforts modeling the information reliability for battlefield decision making. This research is the nucleus of future research in this field.

The following are some of the past efforts applied to the area of battlefield information:

Bracken, Kress, and Rosenthal (1995) present simple models of an air defense situation that illustrates the expected payoff from a reduction in uncertainty by utilization of the products of sensor and Command, Control, Communication, and intelligence (C³/I) capabilities. Each model consists of a single defensive system that assists in defending a high-value area against massed missile attack. The defensive system makes use of information available so as to plan the defensive resource allocation. They investigated the effects and the value of information available to the defense against the mass attack. Three probabilistic models were developed. Each model corresponds to a different information level available to the defender. They concluded that the availability of a relatively higher level of information should enable the defender to enhance his strategy and achieve a gain in his defense effectiveness.

1.2.4 Information-Focused Methods

With the rapid growth of information technologies, especially those associated with information transfer, there is a need to secure information from being accessed and used by an unauthorized third party. Since the military can often not sacrifice the speed of transferring information, it must find ways to assure its protection. Joint Doctrine (as
Beauregard, et al. (2002) defines Information Assurance (IA) as “information operations that protect and defend information systems by ensuring their availability, integrity, authentication, confidentiality, and non-repudiation”. The difficulty in increasing IA lies in the balance between the level of IA and the impact of that IA level on the system operational capability and resource costs.

Beauregard, et al. (2002) created an Information Assurance Analysis Model (IAAM) to aid organizations within the Department of Defense (DoD) in their efforts to appropriately protect valuable information and information systems. The model was composed of three different value hierarchies that measure the total level of information assurance as tradeoff between IA, system operational capability, and the resource cost of implementing an IA strategy. The objective of the IAAM is to aid a military decision maker in determining which IA strategy to implement. The hierarchical models and their associated measures are used to identify the most beneficial information assurance strategy based on the value-focused thinking approach.

In securing information systems, there is a required tradeoff between security and functionality. Hamill, et al. (2002) presents an approach to improve the risk management process associated with the operation and implementation of information systems, by incorporating value-focused thinking. In their approach, the value of information being protected serves as a focus to prioritize vulnerabilities requiring remedy. The risk management approach approximates the current level of risk and relies upon a decision making model to determine if risk is at an acceptable level.

In their approach, the information was the focus; a value model of information was developed as opposed to the typical focus on information systems. The value model
for information was constructed by deriving those aspects of information and information systems valued by the decision makers. The resulting value model can be used to evaluate current performance and proposed improvements to information systems, and facilitate the development of previously unforeseen alternatives. The alternatives (current performance and proposed improvements) were evaluated based upon the value model of information. In other words, the value of information model helps in the identification of consequences or the impact due to exploited vulnerabilities.

Their concluding assumption was that if the model accurately represents the decision makers’ preferences regarding the information within their respective information system, the approach offers a clear focus on the cost effective elimination of Information Systems (IS) vulnerabilities.

Beene (1998) captures the degradation of situation awareness over time in his efforts to develop a methodology for mathematically quantify awareness in a military command and control (C2) environment; battlefield environment. Endsley in 1995 (as referred in Bolstad, et al, 2005) defined situation awareness as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”. Beene developed an information warfare entropy model based on Shannon’s original entropy model. Shannon (1949) developed a measure of information based on what an individual knows and how well or precisely they know it. Shannon defined entropy in an information theory context as:

\[ H = -K \sum_{i=1}^{n} p_i \log(p_i) \]

where \( k \) = a scaling parameter
\[ p_i = \text{probability of outcome } i \]

Beene (1998) derived a function for entropy over time using a formulation that defines the probability of a certain event as a function of time.

Sherrill and Barr (1996) investigated the effects of intelligence on battlefield results. They also developed entropy as a measure of information in a battlefield environment by quantizing the battlefield space into a grid and eliciting the decision maker’s probability of an enemy asset being located in each grid cell. Their entropy scale is reversed; the higher value for entropy implies less awareness, and the lower value for entropy implies higher awareness.

Shupenus and Barr (1999) reported the development of a measure of performance for battlefield information systems called Information Gain. Their measure is based on decreases (and increases) in Shannon’s entropy to quantify the probability of various information states that result from receipt of data by a commander. The approach measures the level of information a commander has at a given point in time by modeling the amount of uncertainty regarding an adversary, in terms of probability distributions over sets of possible enemy states. The probability distributions are updated when the commander receives new information. The new resultant distribution is assumed to reflect the new state of the commander’s uncertainty. They investigated the effects of target mobility on information loss when surveillance of a target is broken. The investigation was based on a stochastic model of target movements, together with an approximation appropriate for implementation in a spreadsheet. They concluded that the shapes of the information loss curves were dependent on terrain features affecting the
movement of the target, and that information is lost rapidly once contact with the target is lost.

Perry (2000) developed a probability model of knowledge using information entropy to measure the amount of uncertainty in the commander’s current knowledge, his current situation awareness, of the battle space. The initial model distribution depends upon the information available to the commander from his sensors and sources. As additional sources or sensors reports arrive, the probability distribution is refined.

Driscoll and Henderson (2006) propose a unifying meta-model architecture for fusing information in sensor-based decision support system. Metamodeling is the construction of a collection of concepts within a certain domain. The sensor decision support systems are capable of delivering to the user strong inference results in support of tactical decision-making.

Doyle, Deckro, Kloeber, and Jackson (2000) developed a structure to view information operations. The structure is used as a basis to create measures of merit for offensive information operations (IO) by applying value-focused thinking. Offensive information operations (IO) are operations undertaken to affect an adversary’s decision making in a way that benefits the friendly forces. The offensive information operations (IO) objectives hierarchy for the information realm is consisting of attacking information, attacking information systems, and attacking information-based processes. The result of their analysis was a set of measures that quantitatively describe the expected effect of (IO) on the adversary’s decision making.
1.3 Research Layout

The dissertation is divided into ten main chapters. This first chapter is an introduction, an overview of the past efforts applied to the area of battlefield decision making and battlefield information, and a discussion of the contributions. The second, the third, and the fourth chapter provide background on human decision making, value-focused thinking, and reliability analysis, respectively. In chapter two, the human decision making topic is discussed generally with different human decision making models. In chapter three, the elements of a decision and how they are interrelated are introduced, and then the decision or value model construction is presented. Chapter three adapts the value focused thinking as a strategy for decision making. Chapter four introduces the reliability background needed to model the reliability of different components and systems, which in this research will pertain to the information in a decision making system.

Chapter five provides a scenario background for the battle of Khafji scenario used in the research. This scenario is used to focus the research theories. It is not the first time that the battle of Khafji was a research concern. Clevenger (1996) analyzed the battle of Khafji to assess air power effectiveness. His analysis was later used to recreate battalion and brigade size portions of the battle in a mission-level model for analytical purposes. The objective of the battle re-creation was to provide a historically-based framework for analysis of force structures, weapons systems, tactics, command and control, and their interactions.

Chapter six builds a value model of the research scenario. The decision makers’ values are determined and are organized into hierarchies. A quantitative and qualitative
analysis is then applied to build a value model. This value model is used to evaluate alternatives. This model is an initial effort using value-focused thinking to model battlefield decision making.

Chapter seven presents the new topic of information reliability and an information reliability model of the research scenario. This model will be a unique contribution of this research.

In chapter eight, the value model and the information reliability model are combined together in a single integrated model. A theoretical background of the model is introduced, and then applied to the research scenario.

In chapter nine, different scenarios or cases of decision situations that might occur in reality are discussed based on the employment of the integrated model.

Finally, the conclusion, and future avenues will be presented in chapter ten.

1.4 Contributions

In combat, time pressures on decision making are extreme and coordination among units requires mutually predictable behavior and responses to problems. All commanders must make and execute decisions faster than the enemy to be successful. Limited time forces the decision maker to make decisions rapidly.

In the military, commanders are selected to command based on their experience and ability to make successful decisions. In some combat decision making situations, relying on experience is a powerful methodology for making decisions. The individual aggregates their life experiences from making decisions in similar problems. This collective experience, plus requirements of the current scenario, forms the individual decision model. Capturing exemplar decision models and using these models for analysis
to enhance future decision making research and augment training for decision making is a focus of this research.

The results and conclusions of this research can be captured and incorporated into institutional doctrines and training systems in order to improve the decision making abilities of commanders, team leaders, and soldiers. Past efforts focused on the commander decision making problem, although there were no efforts to model and capture the different individuals’ values in the decision situation. The interactions between the different individual’s models are recorded.

This research presents a methodology for dividing the dynamic decision situations of a battlefield scenario into a group of static decision situations. The research generates value hierarchies that represent the basic objectives of different individuals in the military chain of command. This value hierarchy might be used as a generic hierarchy for similar cases or scenarios with few editions if required. Thus, this research provides an initial VFT-based model of battlefield decision making.

Reliability modeling is usually applied to physical components or systems. This research applies reliability modeling to the non-physical information value. The reliability of information is modeled using the probability distribution functions that are used in reliability analysis. A definition of reliability of information is derived and a suitable model is presented. This represents an initial effort to model battlefield information reliability in the context of battlefield decision making.

A final contribution of this research is the integrated model that combines the decision value-focused thinking model with the information reliability model. This model is theoretical but detailed enough to generate a computational model presenting that
linkage. This also represents a unique contribution of the research; an initial combined
decision making, information reliability model.
CHAPTER 2

HUMAN DECISION MAKING

Examining the process of decision making systematically, and exploring how each part of the decision process contributes to a good decision, is what yields a better understanding of decision making and what makes a good decision maker. Clemen (2001) advocates that applying decision analysis techniques can lead to better decisions that give the best possible outcomes. This chapter provides a broad discussion of different aspects of decision making and decision making models. Chapter three will discuss the specific required background, value-focused thinking, used in this research.

2.1 Introduction

An important element of a decision making problem is the existence of at least two choices or alternatives. The decision is then usually based on the decision maker’s judgment. Lehto (2006) defined judgment as “a closely related process in which a person rates or assigns values to the attributes of the alternatives considered”. The decision making process might be as simple as choosing a restaurant or as complicated as choosing a spouse. Decision making may take place under time pressure constraints, such as battlefield decisions, or it may take place over a longer time period, such as choosing a house. Another way to categorize decision making is whether decisions require a single decision maker or a group of decision makers. In this chapter and throughout the research, the focus is on a single decision maker. This chapter will discuss the difficulty of decision making, then briefly discuss a human decision making integrative model. Different theories of decision making such as: the classical decision making theory, the
behavioral decision making theory, and the dynamic and naturalistic decision making theory are briefly discussed along with their related models.

2.2 Difficulty of Decision Making

Decision making is not an easy process. Clemen (2001) discussed four reasons for the difficulty of decision making. His four reasons are summarized as the following:

- The complexity level of the decision situation. Some decisions involve a large amount of details and information. Russo and Schoemaker (1990) note that there is a limit to the amount of information that a human can handle at one time.

- The inherent uncertainty in the decision making situation. This uncertainty can take the form of uncertain outcomes associated with choosing among alternatives.

- The conflicting multiple objectives. A tradeoff is required between competing objectives, where the decision maker must trade off benefits in one area against possible consequences in another.

- Different perspectives that leads to different conclusions. This source of difficulty is associated with group decision making where more than one decision maker is involved in a decision, and each has a different perspective on the problem.

2.3 Human Decision Making Integrative Model

Clemen’s four areas of difficulty are the main cause of conflict in decision making. Welford in 1976 (as referred to in Lehto, 2006) defined human decision making as “a stage of information processing that falls between perception and response execution”. Welford’s perspective was used by Lehto and Nah (as presented in Lehto, 2006) to present an integrative model of decision making that relates conflict resolution to the elements of decision making (alternatives, outcomes, and uncertainty associated
with the alternatives). They defined decision making as “the process followed when a response to a perceived stimulus is chosen. The applied decision strategy decides the process followed. An integrative model is shown in Figure 1 (adapted from Lehto, 2006).

![Figure 1 Human Decision Making Integrative Model (Lehto, 2006)](image)

The decision strategies in Figure 1 correspond to the different paths between the situation assessment node and the execute action node. In the model, the decision context and the conflict occurrence decide the decision strategy followed. Lehto (2006) distinguished four categories of decision making:

**Group Decision Making**

Group decision making is the case where a group of decision makers collectively arrive at a decision. This category is represented at the highest level of the integrative model in Figure 1.
Dynamic Decision Making

Dynamic decision making occurs in an environment where a future decision may depend on what happened in the past. The multi-stage nature of the environment requires the use of feedback. Battlefield decision making is an example of a dynamic decision making environment. This category is represented at the lowest level of the integrative model in Figure 1.

Routine Decision Making

Routine decision making occurs when the experience and the knowledge of the decision makers are the basis of their decisions. This category is represented in Figure 1 as a pattern matching step between the situation assessment node and the execute action node. Usually routine decision making is considered a subset of dynamic decision making.

Conflict Driven Decision Making

Conflict-driven decision making occurs when a decision requires resolving various forms of conflict. This category involves a complicated path between the nodes.

2.4 Classical Decision Making Theory

There is a need for a systematic approach of structuring decision problems to overcome the difficulties and the conflicts associated with decision making. Classical decision theory focuses on the notion of rationality and has been applied to two problems: Choice and statistical inference (Lehto, 2006).

2.4.1 Choice Procedures

Classical decision theory uses four basic elements to represent preference and choice problems:
• A set of alternatives or actions \( (A_i) \)

• A set of events \( (E_j) \)

• A set of outcomes or consequences \( (C_{ij}) \) associated with each combination of alternative \( i \) and event \( j \).

• A set of probabilities \( (P_{ij}) \) for each combination of alternative \( i \) and event \( j \).

After the decision situation is represented in terms of these elements, a decision making rule is required to make decision. Several of these decision rules are discussed briefly (based on Lehto, 2006).

**Dominance**

 Dominance occurs if alternative \( A_i \) is at least as good as \( A_j \) for all \( E \) events, and for at least one event \( E_k \), \( A_i \) is preferred to \( A_j \). Dominance is a normative decision rule; the dominating alternative is always better than the dominated alternative.

**Lexicographic Ordering and EBA**

The Lexicographic ordering decision rule considers cases where alternatives have multiple consequences. These consequences are organized according to their importance. The alternatives are compared sequentially, starting with the most important consequence. An alternative is selected if it is found better than the others on the most important consequence. If no alternative is better, comparisons continue with the next most important consequence level. The process continues until an alternative is selected.

The Elimination by Aspect (EBA) is similar to the Lexicographic decision rule, except that the consequences used for the comparison are used in a random order.
Minimum Aspiration Level and Satisfying

This decision rule considers screening the alternatives sequentially until an alternative is selected; the screening process is terminated when an alternative \( i \) exceeds a minimum aspiration level \( S_{ij} \) for each of its consequences \( C_{ij} \) over the possible events \( E_j \).

Minimax Cost and Minimax Regret

The Minimax Cost decision rule considers selecting the minimum worst-case cost alternative \( A_i \) among the other alternatives. Mathematically,

\[
A_i \text{ is the alternative for which over the events } j, \quad \text{Max}_j (C_{ij}) = \text{Min}[\text{Max}_j (C_{ij})].
\]

The Minimax Regret decision rule involves regret calculations instead of cost. The best alternative for each possible event is identified. The regret \( R_{ij} \) associated with each outcome \( C_{ij} \) for the combination of event \( E_j \) and alternative \( A_i \) then becomes

\[
R_{ij} = \text{Max}_i (C_{ij}) - C_{ij}.
\]

The \( R \) calculation are carried out for the set of all events \( E_j \), resulting in regret values for each combination of events and alternative actions. The selected alternative is the alternative which over the event \( i \), \( \text{Max}_j (R_{ij}) = \text{Min}_i [\text{Max}_j (R_{ij})] \).

Maximizing Expected Value

The MEV decision rule picks the alternative with the highest expected value. The expected value of an alternative \( A_i \) is equal to weighting of its outcome \( C_{ij} \) over all events \( E_j \), by the probability \( P_{ij} \) that the event will occur. Mathematically,

\[
EV[A_i] = \sum_j P_{ij} C_{ij}.
\]
More details on expected value of an alternative are in chapter 3 as this approach is used for a risk-neutral decision maker in the value-focused thinking modeling paradigm.

**Expected Utility (EU) Theory**

The Expected Utility (EU) theory is the same as the expected value theory except that it uses a utility measure instead of the value. Utility theory distinguishes between risk neutral, risk seeking, and risk averse human behaviors by the shape of the utility function. In other words, the theory describes how different individuals react to risk or uncertainties. More details about utilities are discussed in chapter 3 of this research.

**Multi-attribute Utility Theory**

The multi-attribute theory (MAUT) extends the EU case to the case where the decision maker has multiple objectives. More details on MAUT are discussed in chapter 3.

**Holistic Comparison**

Holistic Comparisons is a non-analytical method. The process involves a holistic comparison of the alternatives outcomes instead of measuring them separately and then recombining probability measures, values, or utility. Thus, a preference ordering between the alternatives is obtained. The Holistic Comparison method does not require formal consideration of probability or utility.

**2.4.2 Statistical Inference**

Decision makers can use statistical hypothesis testing about the past, the future, or the present states of the world to determine whether reject a hypothesis or fail to reject a
hypothesis. Some of the techniques for inferring the probability \( P_i \) that a hypothesis \( H_i \) is true are described below.

**Bayesian Inference**

The Bayesian Inference technique is based on Baye’s rule (Savage, 1954). Baye’s rule defines the posterior probability of hypothesis \( H_i \) given evidence \( E_i \) is present. Mathematically,

\[
P(H_i | E_j) = \frac{P(E_j | H_i)P(H_i)}{P(E_j)}
\]

where \( P(E_j | H_i) \) is the probability of obtaining evidence \( H_i \) given that the hypothesis \( H_i \) is true, and \( P(H_i) \) is the probability of the hypothesis \( H_i \) is true before obtaining the evidence \( E_i \).

The Bayesian Inference technique infers the probability \( P_i \) that a hypothesis \( H_i \) is true using evidence \( E_i \) that links the hypothesis to other observed states of the world. For more information on Baye’s rule, see Savage (1954).

**Signal Detection Theory**

Signal detection theory assumes that the decision maker uses Baye’s rule to estimate the probability of a signal occurring in a noisy observation system. An operator receives evidence from the environment about the true state of the world. The conditional probability \( P(E|S) \) stands for the probability of obtaining evidence observed, given that the signal is there, measures the relationship between the signal \( S \) and the evidence \( E \). For more information on Signal-Detection theory, see Heeger (1997).
**Dempster-Schafer Method**

The Dempster-Schafer method is used to accumulate evidence for or against a hypothesis proposed for use in the decision analysis. A basic probability assignment (bpa) function $P$ describes the relation between the hypothesis ($H$) and the evidence ($e$). For an evidence $e$, the function $P_e(n)$ assigns a value, between 0 and 1, to each subset of $H$ such that the sum of the assigned values is 1. For example, consider $X$, $Y$, and $Z$ as three hypotheses. The bpa assigns a value of 1, when no evidence is available, to the set of hypotheses $H = (A, B, C)$ and 0 to all subsets: $(A)$, $(B)$, $(C)$, $(A,B)$, $(A,C)$. Also, given that evidence $P_e(A) = x$ supporting a specific hypothesis $A$ is found, the method assigns $1 - P_e(A)$ to $H$.

The method uses a belief function $B(n)$ to assign a total belief to $n$, where $n$ is a subset of the set of possible hypotheses $H$, as the sum of the beliefs assigned to $m$, where $m$ is the set of possible subsets of $n$. For more information on Dempster-Schafer method, see Shafer (1976) or Kohhlas and Monney (1995).

**2.5 Decision Analysis**

Decision analysis applies classical decision theory to improve human decision making. Keeney and Raiffa in 1976 (as referenced in Clemen, 2001) defined decision analysis as “A perspective approach designed for normally intelligent people who want to think hard and systemically about some important real problems”. Bodily, S. (1992) defined Decision analysis as “any activity that involves analysis for purposes of making a decision”. Brown (1992) defined decision analysis as “any quantitative analysis of uncertainty or value based on normative models that is designed to aid decisions”.
Howard (1992) defined decision analysis as a “quality conversation about a decision designed to lead to clarity of action”.

Decision analysis is typically an iterative process. The process starts by structuring the decision, then assessing subjective probabilities, utility functions, and preferences of the decision maker. Different techniques for each phase of this process are briefly discussed in the following subsections.

2.5.1 Structuring Decisions

Frameworks are used to represent what is known about the decision problem. Some of these framework techniques are discussed below.

Decision Matrices

The decision matrix technique arrange the consequences of a decision problem in a matrix with rows of alternatives $A_i$ and columns of events $E_j$. The technique is often used for single stage decision problems. The technique is not used for modeling any sequence of events or passage of time.

Decision Trees

The decision tree technique can be used for both single-stage decision problems and multi-stage decision problems. In a decision tree, different shapes represent different decision elements, typically decision elements, chance elements, and outcomes. The decision tree represents all of the possible paths that the decision maker might follow through time (Clemen, 2001). The different nodes in a tree are interpreted in sequence from left to right. For example, the left side of tree starts with a decision node or a chance node, followed by subsequent decision nodes or chances nodes in chronological orders. For more details on decision trees and their use and structure, see Clemen (2001).
**Influence Diagrams**

Influence Diagrams define the relations between events and actions in a decision problem. The different decision elements are represented in different graphical shapes referred to as nodes. The nodes are connected by links that define the relations among them. The diagrams provide a graphical representation of a decision situation. For example, a link from an event $A$ to an event $B$ represents the conditional probability of event $B$ occurrence based on the occurrence of event $A$. A link from a decision node to an event node represents the probability of the event occurrence based on action taken at the decision node. For more details on influence diagrams, see Clemen (2001).

**Value Trees**

The value tree technique organizes objectives, attributes, and values in a hierarchical fashion. More details on constructing value trees and developing objectives, attributes, and values are discussed in chapter 3.

**Event Trees**

An event tree shows how a sequence of events, starting from a primary event, might lead to one or more outcomes. This technique works backward; it starts at a single undesired event and ends at its causes. The technique assumes a set of hypotheses at the top level of the tree, and relates these to evidence depicted at the lower levels (Lehto, 2006).

**2.5.2 Probability Assessment**

Different techniques are used in decision analysis to assess probabilities. The better known techniques (Lehto, 2006) are presented and briefly discussed next.
**Direct Assessment**

In direct assessment, the decision maker directly assigns a value for the probability of an event occurrence. Kirkwood (1997) presents techniques to avoid different biases in assessing these values. In this method, the decision maker must have a good knowledge of probability.

**Fitting a Subjective Belief Form**

The Subjective Belief Form contains statistical parameters estimation questions that require answers from the decision maker. The decision maker will assign an estimated true value of a certain probability, and then he will be asked to assign statistical measures such as: the mean, the mode, or median. In a more detailed form, the decision maker is asked to estimate a confidence interval on his assigned values. For more details on fitting a subjective belief form, see Buck (1989).

**Bisection Method**

The bisection method is used to fit a subjective pdf. The pdf is fit by asking the decision maker to determine the median \( (p_{0.5}) \) of the subjective pdf. The question asked is “for what value of \( p \) do you feel it is equally likely that the true value \( p^* \) is greater than or less than \( p \)” as cited in Lehto (2006). The step is repeated for various subintervals to obtain the required pdf.

**Conditioning Arguments**

The conditioning arguments method assumes that the probability of a complicated event \( A \) is based on the probabilities of simpler events \( C_i \) that relate to it. If the complicated event is \( A \), and \( C_i \) then the possible conditions under which \( A \) might happen, then:
\[ P(A) = \sum_i P(A|C_i)P(C_i). \]

**Reference Lotteries**

The Reference Lottery method obtains point estimates of the decision maker’s subjective probabilities. The method relates a lottery to the decision maker’s point estimate. For example, to measure the decision maker’s subjective probability of an event \( A \) occurring, the decision maker is asked to consider a lottery with prize \( x \) if event \( A \) occurs, and a prize \( y \) if event \( A \) didn’t occur. The decision maker is then asked how much he is willing to pay, \( z \), for the lottery. Values of \( x \), \( y \), and \( z \) are varied until the decision maker is indifferent. Finally, the decision maker’s subjective estimate of \( P(A) \) is estimated:

\[ P(A) = (z - y)/(x - y). \]

Reference lotteries are often used in value-focused thinking. Clemen (2001) provides the axioms of utility that justify the use of reference lotteries.

**Scaling Methods**

In scaling methods, the decision maker rates or ranks the probabilities to be assessed. Various approaches are available for this method. An example is the Analytic Hierarchy Process (AHP). The AHP process finds the best alternative from several by considering a number of conflicting criteria. AHP structures the decision making problem hierarchically. The strategic objective is placed at the top of the hierarchy and the criteria, sub-criteria and the alternatives on each descending level. A local priority weight for the elements is found by pairwise comparisons among the elements in a level with respect to an element in an immediately higher level. The global weights of the alternatives are
obtained by synthesizing the local weights from each level of the hierarchy. For more details, see Saaty (1990).

2.5.3 Utility Function Assessment

The certainty equivalent is a standard method for assessing a decision maker’s utility function. This method is discussed in detail in chapter 3 of this research.

2.5.4 Preference Assessment

There are quite a few methods to measure the strength of a decision maker’s preference. These methods include: indifference assessment, direct assessment, and indirect assessment. The indifference methods modify one of two sets of stimuli until the decision maker is indifferent between the stimuli. In the direct assessment method, the decision maker rates or assigns numerical values to attributes. These values are then used to obtain preferences for the specified alternatives. The indirect measurement method avoids asking the decision makers to rank or rate directly the importance of factors that affect their preferences. Instead, the decision makers are asked for preference orderings between alternatives. For more information on these three methods, see Keeney and Raiffa (1976).

2.6 Behavioral Decision Theory

People use heuristics during judgments tasks (Lehto, 2006). There is a need for an approach to capture this aspect in the process of human decision making. Stevenson in 1993 (as referred to in Lehto, 2006) states that descriptive models that relax assumptions of the classical decision theory models, but retain much of their essence, are being evaluated in the field of judgment and decision theory. In this section, research on statistical estimation and inference, and decision making under uncertainty are discussed.
2.6.1 Statistical Estimation and Inference

Lehto (2006) discussed human abilities and limitations in performing tasks. He then discussed heuristics that people might use to cope with their limitations, and how these heuristics can cause biases. He also discussed the role of memory and selective information processing from a similar perspective.

Brunswik developed the Lens model (Brunswik, 1952) to describe how people perceive their environment. The Lens model is used in many approaches to describe human judgment on some criterion in terms of two symmetric concepts: the ecological validity of probabilistic cues, and the cue utilization. The ecological validity is defined in terms of the correlation or the probabilistic relation between a cue and the criterion. While the correlation or the probabilistic relation between the cue and the judgment defines the cue utilization. For more information on Lens model, see Brunswik (1952).

Several approaches describe human judgment mathematically include the use of policy-capturing models in social judgment theory, probabilistic mental models, multiple-cue probability learning models, and information integration theory. The work in this field was built on the Lens model.

**Social Judgment Theory**

Social Judgment theory is used to develop policy-capturing models to describe how decision makers make use of the probabilistic environmental cues to make judgments. Regression modeling is used to relate judgments to environment cues.

**Probabilistic Mental Models**

The Probabilistic Mental model assumes, as in the Social Judgment Theory, that human knowledge is described as a set of cues, their values, and their ecological
validities. The ecological validity of a cue is defined as “the relative frequency with which the cue correctly predicts how well an object does on some criteria measure” (Lehto, 2006).

**Multiple-Cue Probability Learning Model**

The Multiple-Cue Probability Learning model assumes that providing cognitive feedback about cues and their relation to the effects inferred leads to faster learning than with feedback about the outcomes (Lehto, 2006).

**Information-Integration Theory**

This Information-Integration theory develops models of how cue information is used when judging. The theory emphasizes the use of factorial experimental designs for collecting data with which to develop models. This approach determines how decision makers scale cues when determining their subjective values, and determine how these scaled values are combined to form all over judgments.

**2.6.2 Preference and Choice**

There is a good amount of research on human preference and choice to compare observed preference to the predictions of subjective utility theory. Lehto (2006) summarizes some common violations of the subjective expected utility axioms. He also summarizes a body of research in the area of framing decisions. This research suggests that the way the decision is presented can have a huge influence on the decision maker’s preferences. For more details on this topic, see Tversky and Kahneman (1981).

**Prospect Theory**

Prospect theory considers behaviors that are not consistent with the expected utility model by including decision farming as a phase in judging preferences among risk
alternatives. Decision framing means the manner in which a decision problem has been presented. The theory assumes that the decision makers are risk averse in terms of gain, and risk seekers in terms of losses. The resulted value function weights losses disproportionately. For more information on prospect theory, see Lehto (2006).

**Labile Preferences**

The decision maker’s preferences and attitudes toward risk might change over time. A good deal of research captures this aspect, where the preferences of the decision makers are modeled as the collective decisions obtained by a group of internal agents. Another approach is to model utility as a random valuable to explain the inconsistency in preference while ordering alternatives.

**2.7 Dynamic and Naturalistic Decision Making**

Decision makers take actions sequentially in a dynamic decision making environment. Their actions might result in a new set of decision problems. Klein in 1998 (as referred in Lehto, 2006) discussed his Naturalistic Decision theory and how it applies to the decisions in the real world environment. The deriving force of the theory is the notion that most decisions are made in a routine and non-analytical way. In this section, models of dynamic and naturalistic decision making are briefly discussed. The models assume that decision makers rarely weigh alternatives and evaluate them in terms of their expected values or expected utilities. The models also assume that the decision maker’s experience, the task, and the decision context decide their different decision strategies.

**2.7.1 Levels of Task Performance**

The assumption that the decision maker makes decisions based on past behavior plays an important role in this modeling perspective. There are four levels of
performance: skill-based, rule-based, knowledge-based, and judgment based. When tasks are routine in nature, then the performance is skill-based or rule-based. Knowledge-based performance occurs during learning activity during which people cognitively simulate the alternatives and develop plans. The judgment-based performance occurs when reactions of a decision maker change his goals or goals priorities. For definitions of each level of task performance, see Lehto (2006). Lehto (2006) defines each level of task performance, and discussed the reasons for error occurrence in each level.

2.7.2 Recognition-Primed Decision Making

The Recognition-Primed Decision Making (RPD) method is based on the assumption that decision makers make decisions following a past behavior pattern when faced with a similar situation. Klein (1989, 1998) developed the RPD model. The model distinguishes between three different conditions. The first condition is when the decision maker recognizes the situation and takes the usual appropriate action. The second condition is when the decision maker mentally simulates the action to evaluate the alternative before executing it. The third condition is when the decision maker simulates the action and mentally rejects it. In the RPD model, the decision maker compares the actions that seem useful based on his experience. For more details on the PRD model, see Klein (1989, 1998).

2.7.3 Image Theory

Image theory is a purely descriptive theory. The theory considers that knowledge used to make decisions can be categorized as follow: value images, trajectory images, and strategic images. The decision maker’s values are described by the value image, the decision maker’s goals are described by the trajectory image, and the means to achieve
goal are described by the strategic image. The theory also categorizes decisions as: adoption decisions and progress decisions. In the adoption decisions, an alternative is selected from a screened set of alternatives. In the progress decisions, an alternative is selected after a comparison between goals and the expected result of choosing the alternative. For more details on Image theory, see Beach (1998).

2.7.4 Contingent Decision Making

The Contingent Decision Making method assumes that the characteristics of the tasks and the decision context decide the decision maker’s decision strategy. The cost and benefit of a decision strategy decide the decision strategy. Accuracy and cognitive efforts depend on the task characteristics such as: complexity and response mode. They also depend on the contextual characteristics such as the similarity of the compared alternatives, ranges and correlations of the attributes, and the quality of the options considered. For details on this theory, see Beach and Mitchell (1978).

2.7.5 Dominance Structuring

The Dominance Structuring method assumes that decisions in real situations are composed of the following four steps: first a preediting stage to screen alternatives from further analysis. The next step is to select a promising alternative from the set of the initial screening survived alternatives. Then a test is made to check if the alternative dominates the other alternatives. If there is no dominance, then the alternative is redeveloped or restructured to apply the dominance over the other surviving alternatives. For more details on this theory, see Montgomery (1989).
2.7.6 Explanation-Based Decision Making

The theory assumes that decision makers build a mental model to explain the received facts that shapes the decision problem. It also assumes that decision makers generate alternatives while building that mental model. Finally, these alternatives are compared based upon the mental model not based upon the facts that are used to build the model. For more details on this method, see Pennington and Hastie (1988).

2.8 Summary

The chapter described methods of decision making. The integrative model developed by Lehto and Nah (as presented in Lehto, 2006) presents how the various approaches fit together as a whole. The specific sources of conflict, the methods of conflict resolution followed, and the types of decision rules distinguish each path through the model. The different paths represent different ways of making decisions. The different ways of making decisions range from routine situation assessment driven decisions to satisfying, analysis of expected utility.

Behavioral decision making theory is more of a descriptive process. Studies of naturalistic decision making theory revealed that most decisions are made on a routine non-analytical basis. The classical decision theory provides a formal way for reaching optimal solutions but does not describe how people make decisions. It focuses on the ways that decision makers pull together all available information into their choice of a best alternative. Most of the decision aids have been developed based on the basis of the classical decision theories (Orasanu and Connolly, 1992). The goal of this research is to develop a model and a methodology to better capture battlefield decision making. In battlefields, optimal solutions are desired more than satisfactory solutions derived from
non-classical decision making theories. The classical decision theories are preferred when consequences are critical (Orasanu and Connolly, 1992), such as the case in battlefields. The value-focused thinking model is the candidate model for this research. It provides optimal solutions by examining a set of alternatives, weighing the likely consequences of choosing each, and making a choice. The decision maker evaluates the alternatives in terms of a set of goals, purposes, or values that he clearly knows. It was chosen because of its analytical nature and applicability to the situation.
CHAPTER 3
HUMAN DECISION MAKING WITH VALUE-FOCUSED THINKING

3.1 General Discussion

An important element of a decision situation or a decision problem is the existence of choices or alternatives. The reason for studying decision analysis is to learn techniques that help lead to selecting the best available, or least harmful, outcome. Studying decision analysis aids the understanding of decision problems we face and thus helps us make better decisions and choices. That understanding includes developing the problem structure, determining the uncertainty inherent in the alternatives and outcomes, and examining trade-offs inherent in the alternatives and outcomes. Keeney and Raiffa in 1976 (as referenced in Clemen, 2001) defined decision analysis as “A perspective approach designed for normally intelligent people who want to think hard and systemically about some important real problems”.

These are other definitions of decision analysis. Bodily, S. (1992) defined Decision analysis as “any activity that involves analysis for purposes of making a decision”. Brown (1992) defined decision analysis as “any quantitative analysis of uncertainty or value based on normative models that is designed to aid decisions”. Howard (1992) defined decision analysis as a “quality conversation about a decision designed to lead to clarity of action”.

Decision analysis is typically an iterative process. Throughout the process, the decision maker’s perception of the decision situation changes, subjective beliefs about the occurrence of different uncertain events might change, or new subjective beliefs might
develop. In addition, the preferences for outcomes might change or develop along the process of the decision analysis (Clemen, 2001).

Modeling is critical in decision analysis, whether this modeling is quantitative or qualitative. This modeling should capture all the relevant aspects of the decision problem and all the subjective beliefs and preferences of the decision maker. A requisite model is defined as a model that provides no further insight beyond what is already captured.

This chapter focuses on decision analysis applied to a single decision maker functioning within a group of decision makers. The decision context involves a group of independent decision makers. The focus is not on a group trying to reach a single decision.

3.2 Values and Value Focused Thinking

Values are what a decision maker cares about. Values are a fundamental notion in modeling a decision making problem. Values are the basis for the effort and time spent thinking about decision problems. Keeney (1994) defined values as “principles used for evaluation of the actual or potential consequences of action and inaction, of proposed alternatives, and of decisions”.

Value-focused thinking decision making focuses on how to study decision making on the basis of values versus alternatives. Alternatives are the means to achieve the fundamental values in a decision making problem (Keeney, 1994). A decision making process that generates better alternatives and properly evaluates those alternatives is favored. Naturally, military decision making should select the best alternative.

There are five activities in value-focused thinking. First, the decision problem is recognized. Second, the values for the decision maker are then specified. These values are qualitatively derived then quantified in the third activity. The values are then used to
derive alternatives for the decision problem in step four. Finally, in step five the alternative evaluation process and the selection of an alternative can then be based on any established evaluation or analysis method. Table 1 presents the five activities for examining decision problems with value-focused thinking.

<table>
<thead>
<tr>
<th>For Decision Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Recognize a Decision Problem</td>
</tr>
<tr>
<td>2. Specify values</td>
</tr>
<tr>
<td>3. Create Alternatives</td>
</tr>
<tr>
<td>4. Evaluate alternatives</td>
</tr>
<tr>
<td>5. Select an alternative</td>
</tr>
</tbody>
</table>

Table 1 Sequence of Activities with Value-Focused Thinking
3.3 Objectives

The values of decision makers are made explicit by the identification of objectives. In other words, the values are made explicit through statements that express the value judgment of the decision maker in terms of their objectives.

3.3.1 Definition

An objective as defined by (Keeney, 1994) is “a statement of something that one desires to achieve”. Kirkwood (1997) defined an objective as “the preferred direction of movement with respect to an evaluation consideration” where the evaluation consideration is “any matter that is significant enough to be taken into account while evaluating alternatives”.

Clemen (2001) defined an objective as “a specific thing that you want to achieve”.

3.3.2 Types of Objectives

A principle of thinking about values is to evaluate the reasoning for the objectives and how those objectives are related. It is important to distinguish between two types of objectives: fundamental objectives and means objectives. Both of these objectives depend on the decision context. A fundamental objective characterizes an essential reason for interest in making any decision. The fundamental objectives state every concern in the decision situation. A means objective is of interest in the decision context because of its implications for the degree to which the fundamental objective might be achieved. In other words, the means objectives are means to achieve the fundamental objectives.
3.3.3 Hierarchies and Networks

Fundamental objectives are organized into hierarchies such as shown in Figure 2. The upper level in the hierarchy contains more general objectives, while the lower levels in the hierarchy explain or describe important elements of the upper level objectives.

Figure 2 Example of Fundamental Objectives Hierarchy

Means objectives are organized into networks as shown in Figure 3. The Means objectives can be connected to several objectives indicating that they help in achieving the higher level objectives in the network.

Figure 3 Example of Means Objectives Network

The means objectives are used to develop the models that help analyze decision problems. They might also be used to develop more alternatives. Fundamental objectives are used as a guide to the efforts in the decision situations and in the evaluation of alternatives as measured against supporting means objectives.
Structuring objectives aids the understanding and the specification of the decision context. The structured objectives are the basis for the quantitative modeling and analysis. Fundamental objective hierarchies indicate the set of objectives upon which the attributes of those objectives should be defined. Means objectives network indicates the objectives needed to develop a model to relate the alternatives to their consequences. In general, the fundamental objectives hierarchy indicates the interest in the decision problem while the means objectives network proposes the methodology to improve matters within the decision context or situation.

3.3.4 Strategic Objective

In addition to the two types of objectives, fundamental objectives and means objectives, it is important to define a strategic fundamental objective. Keeney (1994) defined a strategic fundamental objective as “the overall objective is the same for both the fundamental objective and the means objectives structures. It characterizes the reason for interest in the decision situation and defines the breadth of concern”. The strategic objective may be a single statement in some decision situations or it may be a combination of the more specific fundamental objectives.

Based on the definition, the strategic fundamental objective should provide common guidance to the decisions taken along the decision problem time horizon. Those decisions made over time are means to pursue the strategic objective.

3.3.5 Constructing Hierarchies and Networks

There are some methods in practice to differentiate means objectives from fundamental objectives. A common method is called the WITI test. The test consists of the following question “Why Is This Important?” The answer to this question
differentiates the means objectives from the fundamental objectives, and reveals connections among the objectives. For example, if the question is, “Why is Objective X important?” and the answer to the question is, “the objective X is important because it helps achieving the objective Y,” then the objective X is a means objective. In the same manner the test iterates through Y…Z, until the answer to the WITI question is, “This objective is important because simply it is important” then this objective is a fundamental objective. The WITI test is used to move objectives among the means set and the fundamental objectives set. To structure within the fundamental objectives hierarchy, the question is “What do you mean by that?”

Table 2 (Adapted from Clemen, 2001) summarizes the techniques used for organizing means objectives and fundamental objectives.

<table>
<thead>
<tr>
<th>To Move:</th>
<th>Fundamental Objectives</th>
<th>Means Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ask:</td>
<td>Downward in the Hierarchy: “What do you mean by that?”</td>
<td>Away from Fundamental Objectives: “How could you achieve that?”</td>
</tr>
<tr>
<td></td>
<td>Upward in the Hierarchy: “Of what more general objective is this an aspect?”</td>
<td>Toward Fundamental Objectives: “Why is that important?”</td>
</tr>
</tbody>
</table>

Table 2 How to Construct Hierarchies and Networks (Clemen, 2001)

The starting point for moving downward in both the fundamental objectives hierarchies and means objectives network is the strategic objective. The end point, when the construction proceeds to lower levels in the means objectives network, is arriving at alternatives or classes of alternatives.
3.3.6 Desirable Properties for the Fundamental Objectives

It is possible to construct several different fundamental objectives hierarchy for a decision situation. To ensure that any fundamental objectives hierarchy is correct, the set of the fundamental objectives should possess the nine properties listed in Table 3 (Adapted from Keeney, 1994).

<table>
<thead>
<tr>
<th>Desired properties of the set of fundamental objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Essential, to indicate consequences in terms of the fundamental reasons for interest in the decision situation.</td>
</tr>
<tr>
<td>2. Controllable, to address consequences that are influenced only by the choice of alternatives in the decision context.</td>
</tr>
<tr>
<td>3. Complete, to include all fundamental aspects of the consequences of the decision alternatives.</td>
</tr>
<tr>
<td>4. Measurable, to define objectives precisely and to specify the degrees to which objectives may be achieved.</td>
</tr>
<tr>
<td>5. Operational, to render the collection of information required for an analysis reasonable considering the time and effort available.</td>
</tr>
<tr>
<td>6. Decomposable, to allow the separate treatment of different objectives in the analysis.</td>
</tr>
<tr>
<td>7. Non-redundant, to avoid double-counting of possible consequences.</td>
</tr>
<tr>
<td>8. Concise, to reduce the number of objectives needed for the analysis.</td>
</tr>
<tr>
<td>9. Understandable, to facilitate generation and communication of insights for guiding the decision making process.</td>
</tr>
</tbody>
</table>

Table 3 Desired properties of the set of fundamental objectives (Keeney, 1994)
A set of fundamental objectives are essential when each alternative in a decision context affects the degree of the achievement of each objective. They are controllable when all the alternatives that might influence the outcomes are included in the decision context. A set of fundamental objectives are complete if knowing about the outcomes with respect to each objective provides a description of all the implications of interest when any alternative is selected. A set of fundamental objectives is measurable if the information used to analyze and measure the achievement of the objectives is available. Objectives are operational when factual information is available to relate the alternatives to their possible outcomes. The factual information can be gathered and collected easily when the fundamental set of objectives is decomposable. Objectives are decomposable when the aspects of the outcomes related to a specified attribute have no effect on the aspects of the outcome related to another attribute.

The set of fundamental objectives should be non-redundant, and concise to reduce the effort required to collect data and apply analysis methods when using the objectives to evaluate alternatives. Objectives should be understandable so the insights provided by value-focused thinking can be adequately understood by and communicated to different individuals involved in making the decision.

3.3.7 Linking Hierarchies and Networks

There are several relationships between a fundamental objectives hierarchy and a means objectives network. While analyzing the alternatives of a decision problem, the fundamental objectives hierarchies and means objectives networks are connected. Sometimes, the possible outcomes in terms of achieving the fundamental objectives depend on the means objectives network. This connecting criteria help define what is the
best means in terms that relate directly to the decision maker’s fundamental objectives (Clemen, 2001). Figure 4 presents an example connecting fundamental objectives hierarchies and means objective networks.

![Figure 4 Example of Connecting Objectives hierarchies and Means Objectives Networks](image)

**3.4 Decision Context**

Keeney (1994) defined the decision context as “the set of alternatives appropriate to consider for a specific decision situation”. The decision situation is composed of course of events. Compatibility must exist between the decision context and the fundamental objectives. To achieve this compatibility, the decision context must be specified correctly. Incorrect identification can lead to capturing an incomplete or inaccurate picture of the decision problem which means we may end up solving a different problem, sometimes referred to as type III error.
3.5 Attributes

The fundamental objectives represent the reasons a decision maker is interested in a decision problem. These objectives represent how the available alternatives of a decision problem should be evaluated. Attributes are used to measure the achievement of these objectives located in the lower level objectives in a fundamental objective hierarchy. The measurement of these lower level objectives clarifies their meaning and might lead to enhanced alternatives when used in a creative manner.

An attribute is a scale used to measure the achievement of a fundamental objective by alternatives. In this chapter, the term fundamental objective is also referred to as objective for ease of explanation. Other terms that are sometimes used for an attribute are measure of effectiveness, criterion, performance measure, or metric.

Kirkwood (1997) refers to an attribute as an evaluation measure and defines it as “a measuring scale for the degree of attainment of an objective”. He classifies attributes as either natural or constructed, and as either direct or proxy.

A natural scale is a scale that is in general use with a common interpretation. The scale definition of a natural attribute is usually available. For example, for the objective “Minimize the number of trees lost”, a natural attribute is “The numbers of tree lost”.

A constructed scale is a scale developed for a particular decision situation to measure the degree of objective achievement by the value of the attribute. A constructed scale is used when a natural scale is not available for the decision problem. A full description of meaningful levels related to the objective is defined as a constructed attribute. Table 4 presents an example of a constructed scale for an attribute to evaluate public attitudes toward the decision of going to war.
<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of attribute level</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Strongly support: Two or more groups have organized support to the war.</td>
</tr>
<tr>
<td>1</td>
<td>Support: One group has organized support to the war.</td>
</tr>
<tr>
<td>0</td>
<td>Neutrality: All groups are indifferent.</td>
</tr>
<tr>
<td>-1</td>
<td>Opposition: One group has organized action against the war.</td>
</tr>
<tr>
<td>-2</td>
<td>Strongly opposition: Two groups or more have organized action against the war.</td>
</tr>
</tbody>
</table>

Table 4 Example of a Constructed Attribute

The constructed attribute in Table 4 involves verbal descriptions of five different levels of public attitudes. A numerical value is assigned to each level.

A proxy scale reflects the degree of the achievement of an associated objective, but does not directly measure this objective. The proxy scale should be closely related to the original objective. While a direct scale directly measures the degree in which an objective is achieved, sometimes direct scale measures are impractical. In such case a proxy attribute is employed. Proxy scales, like direct scales can be quantitative or qualitative.

It is possible to have direct scales that are either natural or constructed. Similarly, it is possible to have proxy scales that are either natural or constructed. Figure 5 highlights this distinction.
The desirable properties of the attributes are related to the desirable properties of the fundamental objectives. There are three desired properties for the attributes. The attributes have to be measurable, operational, and understandable.

An attribute is measurable if it defines and clarifies the related objective more than the objective statement does by itself.

An attribute is operational if it defines the possible consequences of its related objective, and if it provides a sound basis for value judgments about the desirability of the possible degree of achievement of that related objective.

An attribute is understandable if there is no ambiguity regarding how attributes describe the consequences or the outcomes related to each level of the attribute.

### 3.6 Alternatives

An alternative can be thought of as a course of action taken within some decision situation meant to achieve the objectives of the decision situation. An important factor in a decision problem is the alternatives. If there are not at least two alternatives, there is no decision problem. One of the benefits of value-focused thinking decision making is the
ability to generate alternatives beyond the initial obvious set of alternatives. Keeney (1994) proposed a methodology to generate alternatives using the elements of the decision problem, the fundamental objectives, attributes, means objectives, and evaluated alternatives.

There are four approaches used to generate alternatives when there is uncertainty in the decision problem: hedging, sequencing, risk sharing, and insuring.

It is possible to hedge against the uncertainty related to the outcomes of different alternative by generating an alternative that will neither do very poorly regardless the outcome, nor will do very well if you happen to guess right about the future.

The sequencing approach involves developing an alternative that allows the decision maker to sequence his decision. By breaking down the decision to small components along the time horizon of the decision situation, there is a better chance of making the right decision. Decision sequencing in some cases is the cause of the loss of precious time in a decision situation.

Another possible approach is to share risk with a partner. The decision maker thus neither gains all the profit nor absorbs all the loss.

Finally, it might be possible to buy insurance against the risk. This approach is not applicable to all decision situations.

Using the four mentioned approaches, and considering experts’ experience, it is possible to create alternatives for the decision problem.

While deriving alternatives, it is very important to consider constraints. There are two kinds of constraints, restrictions on resources, or restrictions on the types of alternatives. Examples of restrictions on resources are barriers, lack of time, people, or
supplies. An example of a restriction on the type of alternatives is a military unit that must attack along a designated axis of advance. Restrictions on resources limit what a decision maker can do, restrictions on the types of alternatives are things the decision maker can not do.

### 3.7 Value Model

A value model clarifies any complex matter related to values. A value model \( v \) assigns a number \( v(x) \) to each consequence \( x = (x_1, \ldots, x_N) \), where \( x_i \) is a level of attribute \( X_i \) measuring objective \( O_i \). This number \( v(x) \) is used to measure the desirability of the consequences of an alternative and thus is used to evaluate alternatives. In most decision situations, there is no alternative that yields the best value with respect to all the possible outcomes related to all objectives. A value tradeoff is usually required. Also, different decision makers have different attitudes toward risks. Both value tradeoffs and attitudes toward risks are explicitly addressed in building a value model for a decision maker in a particular decision context.

Before building a value model, the fundamental objectives are identified, the attributes used to measure the achievement of those objectives are defined, and the alternatives are generated. Then a general structure for combining the attributes together is developed. In other words the alternatives are ranked when the different attribute measures are combined into a single index of desirability for an alternative (Kirkwood, 1997). This combination requires the determination of a single dimensional value function used to derive an ordinal ranking of alternatives.
3.8 Determining a Single Dimensional Value Function

Usually a single dimensional value function will vary between 0 and 1 over the range of attributes levels that of interest. These value functions are often nonlinear.

When the number of the attributes levels are relatively small, a piecewise linear procedure is used to generate a piecewise linear single dimensional value function so that linear modeling approaches can be used.

The piecewise procedure to determine the functions requires that the value increment between the attribute levels be specified. The value increment refers to the degree to which the decision maker prefers higher levels to the lower levels. The procedure steps (Kirkwood, 1997) are:

- The increments in the level value that results from each successive increase in the level value of a certain attribute are considered. These increments are placed in order of successively increasing value increments.
- Define the value increments in terms of the smallest value increment.
- Find the smallest value increments by setting the total of all increments to 1.
- Determine the single dimensional value for all the levels of the attribute.

The above steps work for an attribute where higher levels value are preferred to lower levels value. To consider the case where the lower levels value are preferred to higher levels value in an attribute, the increments in level value of the attribute that results from each successive decrease in the level value are considered. These are placed in order of successively increasing value increments.

For an example, consider that an attribute \( X \) has the following levels: -1, 0, 1, and 2 with \( X = -1 \) as the least preferred level and \( X = 2 \) as the most preferred level.
Suppose that the value increment between \( X = 0 \) and \( X = 1 \) is the same as the value increment between \( X = 1 \) and \( X = 2 \) and this value increment is the smallest among all the other value increments between two neighboring levels in the attribute \((X)\). Also, suppose that the value increment from \( X = -1 \) to \( X = 0 \) is twice the value increment between \( X = 0 \) and \( X = 1 \).

Consider that \( y \) represents the smallest value increment, and that the sum of increments from \( X = -1 \) to \( X = 2 \) is 1, then
\[
2y + y + y = 1 \quad \text{leads to} \quad y = 0.25
\]

To obtain the values for each level in attribute \((X)\), the value increments between the lowest level and the highest level of interest are added.
\[
V(-1) = 0.00 \\
V(0) = 0.00 + 2 \times 0.25 = 0.50 \\
V(1) = 0.00 + 2 \times 0.25 + 0.25 = 0.75 \\
V(2) = 0.00 + 2 \times 0.25 + 0.25 + 0.25 = 1
\]

\( V(-1) = 0.00 \) since it is the least preferred level, and \( V(2) = 1 \) since it is the highest preferred level.

![Figure 6 Single Dimensional Value Function](image)
The single dimensional value function based on this example is shown in Figure 6. In Figure 6, straight lines are drawn between each of the single dimensional values, and the resulting function is called piecewise linear single dimensional value function. In practice the actual value increments are determined using structured interviewing techniques. The functions lead the decision making through a definition and then a validation of the value increments and the resulting value function curve.

3.9 Determining Weights

In reality, not all attributes are of equal importance. Therefore, the next step to determine a value function (or a value model) is to find the weights applied to the different attributes. The weight \( W \) of an attribute is equal to the increment in value of moving the level on that attribute between its least preferred level to its most preferred level. The procedure of determining the weights (Kirkwood, 1997) are:

- The increments in values from increasing each attribute from its least preferred level to its most preferred level are considered.
- Each of these increments is defined as a function of the least value increment.
- The sum of all the increments in terms of the smallest increment value is set to one.
- Find the weights of all the attributes.

For an example, suppose that three attributes, \( X_a, X_b, \) and \( X_c \), along with their levels are available. Consider that \( X_a = -1 \) is the least preferred level and \( X_a = 2 \) is the most preferred level for attribute \( X_a \), \( X_b = 100 \) is the least preferred level and \( X_b = 0 \) is the most preferred level for attribute \( X_b \), and \( X_c = -2 \) is the least preferred level and \( X_c = 1 \) is
the most preferred level for attribute $X_c$. A swing is defined as moving from the least preferred level to the most preferred level of an attribute.

Also, suppose that the swing over the total range of attribute $X_a$ has the smallest increment in value, the swing over the total range of attribute $X_b$ is as 1.5 the swing over attribute $X_a$, and the swing over the total range of attribute $X_c$ is as 1.25 the swing over attribute $X_b$. Expressing that algebraically:

$$W_b = 1.5 W_a$$

$$W_c = 1.25 W_b = 1.25 * 1.5 W_a$$

The summation of the weights is equal 1.

$$W_a + W_b + W_c = 1$$

then $W_a = 0.22$, $W_b = 0.35$, and $W_c = 0.43$ are the determined weights for this notional example.

There is no specific meaning for the value number without knowing the ranges of the levels of the attributes. The value model development procedure was specified so that if an alternative has the least preferred level on all the attributes, it will have a value of zero. Similarly, if an alternative has the most preferred level on all the attributes, it will have a value of one. The value number assigned to an alternative gives the percentage of the value improvement relative to the worst possible alternative (Kirkwood, 1997).

There are also procedures where attribute weights are determined via interviews. For instance the decision maker may provide weights directly. Another approach involves the decision maker indicating some strength of preference among the attributes. In either case, the modeler derives weights that capture the believed relationship among the attributes.
3.10 The Value Model (Value Function)

After determining the single dimensional value functions and the weights, the form of the final value function becomes:

\[ v(X_a, X_b, X_c) = w_a v_a(X_a) + w_b v_b(X_b) + w_c v_c(X_c) \]

where \( X_a, X_b, \) and \( X_c \) are different attributes, \( w_a, w_b, \) and \( w_c \) are the weights on the three attributes, and \( v_a(X_a), v_b(X_b), \) and \( v_c(X_c) \) are the single dimensional value functions over each of the three attributes. The value function scales to accommodate any number of attributes beyond the three shown in the example.

3.11 Evaluating Alternatives Using the Expected Value of a Value Function

A rational decision maker wants to choose an alternative that most improves their position. The hierarchies and networks define what is important to the decision maker. The value function measures, and ranks, each alternative with respect to the hierarchies and networks. In general, considering weights as a likelihood, or probability, function means the expected value operator suffices as a means to rank order alternatives. The final measure is also called a weighted value function.

To determine the expected value number for each alternative in a decision problem, the expected value for the value function is calculated as:

\[ \text{Expected value for an alternative} = E [w_a v_a(X_a) + w_b v_b(X_b) + w_c v_c(X_c)]. \]

In other words, the expected value for any alternative is determined by calculating the value for each single dimensional value function, then multiplying this by the related weights, and finally summing the results.
The expected value number states that there is a high probability that the average outcome for a large number of decisions will be close to the average of the expected values for the decisions.

In applying the expected value criterion, it is useful to use probabilities. It is helpful to organize the different attributes’ levels into an event space, before eliciting probability values to each possible level (outcome) in all the different attributes in the decision problem. Kirkwood (1997) presents procedures for determining and eliciting probabilities from decision makers.

The expected value is appropriate criterion for making business decisions, but there are situations where this criterion is not appropriate, such as situations where risk must be explicitly considered.

3.12 Probability Assessing

A good deal of research has been conducted to help assess the probability that a given risk might occur. Risk practitioners, and most humans, experience difficulty trying to assess the probability of a given risk or that some event might occur. The reasons for this difficulty are summarized below (Hillson and Hulett, 2004):

- Terminology. Probability has a precise statistical meaning, but not everyone is familiar with it.
- Unique nature of projects. All projects are unique in some manner, so there is no unique body of relevant previous experience from which to draw upon.
- Unknowable risks. Sometimes risks are identified for which some details are inherently unknowable.
• Estimating versus measuring. Risks are possible future events that have not yet occurred; their probability of occurrence can not be measured but can only be estimated.

Subjective natural terms are often used to describe probability. Even though these words might be well defined and in common use, individuals tend to translate probability-related terms into percentage values or ranges unreliably. In other words, the same word or phrase can be interpreted subjectively and has different meanings to different people. This is due to the subjective nature of the language used to describe probability. Another reason is the inherent difficulties in dealing with uncertainty (Hillson, 2005). For example, when someone says a risk is likely to occur, this can be interpreted to mean anything from around 50% probability through to a 70% chance of occurring.

There is a body of research on assessing values to verbal probability-related terms. A methodology to deal with this dilemma is to explore the range of probability values associated with commonly used natural languages phrases. For examples of authors reporting such studies, see Lichtenstein & Newman (1967), Moore (1987), Boehm (1989), and Hamm (1991). Table 5 displays the study results carried by Boehm (1989) and Hamm (1991) respectively.
<table>
<thead>
<tr>
<th>Term</th>
<th>Boehm 1989</th>
<th>Hamm 1991</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mode (Range)</td>
<td>Proposed value</td>
</tr>
<tr>
<td>Almost certain</td>
<td>98 (85-99)</td>
<td>95</td>
</tr>
<tr>
<td>Highly probable</td>
<td>-</td>
<td>90</td>
</tr>
<tr>
<td>Quite likely</td>
<td>-</td>
<td>80</td>
</tr>
<tr>
<td>Good Chance</td>
<td>75 (60-90)</td>
<td>75</td>
</tr>
<tr>
<td>Likely</td>
<td>60 (55-85)</td>
<td>-</td>
</tr>
<tr>
<td>Probable</td>
<td>70 (55-85)</td>
<td>-</td>
</tr>
<tr>
<td>Better than even</td>
<td>52 (50-60)</td>
<td>60</td>
</tr>
<tr>
<td>Possible</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Unlikely</td>
<td>30 (15-45)</td>
<td>-</td>
</tr>
<tr>
<td>Improbable</td>
<td>20 (15-45)</td>
<td>-</td>
</tr>
<tr>
<td>Seldom</td>
<td>-</td>
<td>15</td>
</tr>
<tr>
<td>Highly unlikely</td>
<td>5 (0-15)</td>
<td>10</td>
</tr>
<tr>
<td>Rare</td>
<td>-</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 5 Studies on Probability-Related Terms (Percentage Values)

Assessing probability from a narrative scenario is not a simple procedure. The above discussion is applicable to a decision maker assessing probabilities, or to an analyst eliciting probabilities from a decision maker. In a narrative scenario, it is not always the case that the author of the scenario used the exact phrases as the scenario’s characters (decision makers) used in reality. The remedy in such a case is to gain a deep understanding of the scenario’s character (decision maker) values, and then assess the probabilities accordingly. The understanding of the methodology of assessing values to verbal probability-related terms will help to gain understanding of the decision maker’s values.

3.13 Biases in Eliciting Probability

Humans think and process information in different ways. These ways have an influence on the way they handle decision situations. Organizational problems are the source of most failures in decision analysis (Brown, 1992). One of the reasons for those
failures is biases. Biases are errors or oversimplifications in thinking that occur in decision situations with similar characteristics (Keeney, 1994).

The primary consideration in eliciting probabilities is to use methods that overcome the various reasoning difficulties. The following are some biases that should be counteracted while eliciting probabilities.

Decision makers can be overly influenced by any information they have, even if logic shows that the information is unrelated to the situation; sometimes, decision makers focus on specific compelling examples without giving weight to other information. This dilemma is known as the anchoring bias. Anchoring might also occur in the creation of alternatives; people tend to anchor on the first alternative to create the other alternatives (Kenney, 1994).

A very common bias (Kirkwood, 1997) is when decision makers underestimate the degree of uncertainty in a situation.

Another bias is the motivational bias which is a conscious or unconscious adjustment in the individual’s probability based on personal rewards from the situation; the occurrence of a certain outcome might include a reward for the decision maker. Similarly, a decision maker might assign a lower probability to avoid certain consequences.

Merkhofer in 1987 (as referred in Kirkwood, 1997) reviewed probability elicitation procedures to overcome different possible biases. Also, for more details on overcoming biases, see Russo and Schoemaker (1990).
3.14 Attitudes toward Risk

Different individuals have different attitudes toward risk. When an individual takes a more conservative attitude toward risks than expected value would suggest, his attitude toward risk is called risk averse. In other words, when an individual will sell an alternative for less than its expected value, then his attitude toward risk is called risk averse; they are willing to receive less to avoid risk.

When the individual will sell an alternative for more than its expected value, then his attitude toward risk is called risk seeking; they are willing to accept more risk to get the gain.

Finally, when an individual will sell an alternative for exactly its expected value, then his attitude toward risk is called risk neutral.

To apply this idea to multiple attribute situations, consider two alternatives, A and B, having the same expected value. Alternative A has a probability of yielding a highly undesirable outcome where the attributes are at their worst levels. Alternative B has a probability of yielding a desired level on one attribute and an undesired level on another attribute at the same time.

A decision maker that prefers Alternative B to alternative A is called multi-attribute risk averse. A decision maker that prefers alternative A to alternative B is called multi-attribute risk seeker. A decision maker that is indifferent between the two alternatives is called multi-attribute risk neutral. The multi-attribute qualifies is used to accommodate those real-life situations in which a decision maker must consider performance along more than one attribute.
3.15 Determining Utility Function (A Power-Additive Utility Function)

Using expected value is not appropriate as a criterion for making decisions if the decision maker is risk averse. A Utility function is commonly used to model attitudes toward risk. Under risk an expected utility analysis is conducted instead of an expected values analysis to evaluate alternatives as the attribute value function measures are replaced with corresponding utility function values.

This procedure is done by assigning a utility number to each possible outcome (attribute level) that takes into consideration the risk attitude of the decision maker. These utility numbers are then used into the expected value calculations.

The utility concept is explained using Figure 7 (Adapted from Kirkwood, 1997).

![Utility Function Example](image)

Figure 7 Utility Function Example (Kirkwood, 1997)

Each line represents a different utility function. The lines marked $\text{Rho}_1$ and $\text{Rho}_2$ represent examples of utility functions where the utility of an attribute level is less desirable than the actual level of the attribute $x$. A risk averse decision maker always has a utility function with this “hill-like” shape, and a risk seeking decision maker always has
a utility function with a “bowl-like” shape (Kirkwood, 1997) (see lines Rho_3 and Rho_4).
The straight line, Rho = infinite, represents the usual expected value, for a risk neutral
decision maker.

Keeney and Raiffa in 1976 (as referenced in Kirkwood, 1997) proved by theory
and applications the applicability of an exponential form of the utility function. The
utility function is derived using the following equation:

\[
u(x_1, x_2, \ldots, x_n) = \begin{cases} 
1 - \exp\left[-v(x_1, x_2, \ldots, x_n)/\rho\right] & , \rho \neq \infty \\
1 - \exp(-1/\rho) & , \text{otherwise}
\end{cases}
\]

where \(x_1, x_2, \ldots, x_n\) are the attributes, and

\[v(x_1, x_2, \ldots, x_n) = w_1v_1(x_1) + w_2v_2(x_2) + \ldots + w_nv_n(x_n),\]

where the \(w_i\) are weights, the \(v_i(x_i)\) are the single dimensional value functions, and \(\rho\) is
the multi-attribute risk tolerance parameter.

The specific shape of the exponential utility function depends on the multi-
attribute risk tolerance parameter \(\rho\). The smaller the risk tolerance \(\rho\), the more curved
the shape of the exponential utility function. When the risk tolerance \(\rho\) is smaller than
one tenth the range of the attributes levels of interest, the utility function shape is so
bowed which indicates unusual situation that requires special study. If the risk tolerance
\(\rho\) is greater than ten times the range of attributes levels being considered, then the curve
is approximately a straight line, and the expected value criterion can be used to evaluate
alternatives.

Kirkwood (1997) proved that a multi-attribute risk averse utility function has a
positive multi-attribute risk tolerance, and multi-attribute risk seeking utility function has
a negative multi attribute risk tolerance.
3.16 Determining the Multi-Attribute Risk Tolerance $\rho$

It is important to find a numerical value for the multi-attribute risk tolerance $\rho$ in order to determine the utility function. The multi–attribute risk tolerance $\rho$ models the degree of the decision maker’s risk aversion.

The procedures to determine $\rho$ are:

- A hypothetical uncertain alternative with equal probabilities of yielding an outcome with all the attributes at their least preferred level or all the attributes at their most preferred level is considered.
- A hypothetical certain alternative which is equally preferred to the uncertain alternative is determined.
- A Statistical Table is used to determine the multi-attribute risk tolerance $\rho$.

The statistical Table contains pairs of numbers $z_{0.5}$ and $R$ that solve the equation:

$$0.5 = \frac{1 - \exp(-z_{0.5} / R)}{1 - \exp(-1 / R)}$$

The value of the hypothetical certain alternative that has been determined is located in the $z_{0.5}$ column. Then the value of $R$ in this table corresponding to that $z_{0.5}$ is the needed value of $\rho$. Such a table can be found in any statistics text book.
CHAPTER 4

RELIABILITY MODELING

Reliability engineering is a relatively new discipline. The increased degree of complexity in technology, government contractual requirements to meet reliability specifications, and the profit and cost considerations resulting from failures are all factors that affect the growth of the reliability engineering field (Ebeling, 1997).

There are two different views of reliability. One view assumes that failures will occur randomly over time. This random process can be modeled using probability distributions, where the failure events or the non-failure events, can be predicted statistically. The other view attempts to analyze the physics of the failure process where the time to failure is determined using a derived mathematical model. It is essential to have knowledge about the failure mechanism and the causes of failures to develop these mathematical models regardless of the particular view adopted.

4.1 Reliability Concept

Reliability as defined in Ebeling (1997) is, “The probability that a component or system will perform a required function for a given period of time when used under stated operating conditions”. To determine the reliability of a system or a component, three steps are performed. These three steps are derived from the definition specifications. First, describe the failure observably and unambiguously. Second, identify the unit of time. For example, the specified time interval maybe based on calendar, operating hours, or cycles. A cycle might be an on/off cycles or mission cycles. Third, observe the system or component under normal performance. This observation step includes such factors as loads, environment, and operating conditions (Ebeling, 1997).
Reliability is a subset of quality; it extends quality into the time domain. Reliability is defined as the quality of the system’s (component’s) operational performance over time. A high quality system has high reliability; similarly, a poor quality system has low reliability.

4.2 Mathematical Reliability Functions

4.2.1 Reliability Functions

Ebeling (1997) defined reliability as “The probability that a system (component) will function over some time period t”. Mathematically,

\[ R(t) = P(T \geq t) \] (1)

where \( T \geq 0 \) is a continuous random variable representing the time to failure of a system (or component).

For a given value of time \( t \), the reliability is the probability that the time to failure \( T \) is greater than or equal to that given value of time \( t \). \( R(t) \) is a probability and hence the usual axioms of probability hold.

\[ R(t) \geq 0, \quad R(0) = 1, \quad \text{and} \quad \lim_{t \to \infty} R(t) = 0. \]

Define \( F(t) \) to be the probability that a failure occurs before time \( t \),

\[ F(t) = 1 - R(t) = P[T < t] \] (2)

and

\[ f(t) = \frac{dF(t)}{dt} \quad \text{or} \quad f(t) = -\frac{dR(t)}{dt}, \] (3)

\( F(t) \) is the cumulative distribution function (CDF) of the failure distribution, and \( f(t) \) is the probability density function (PDF) of the failure distribution.
The failure rate, or hazard rate function, is a function used in reliability studies. It provides an instantaneous (at time $t$) rate of failure (Ebeling, 1997). The following mathematical derivation is adapted from Ebeling (1997).

The following formula expresses the probability of a failure occurring within some interval of time $[t, t + \Delta t]$:

$$P[t \leq T \leq t + \Delta t] = R(t) - R(t + \Delta t). \quad (4)$$

The conditional probability of a failure in that time interval, given that the system has survived to time $t$, is:

$$P[t \leq T \leq t + \Delta t \mid T \geq t] = \frac{R(t) - R(t + \Delta t)}{R(t)}. \quad (5)$$

Then,

$$\frac{R(t) - R(t + \Delta t)}{R(t)\Delta t} \quad (6)$$

is the conditional probability of failure per unit of time (failure rate).

Set

$$\dot{\lambda}(t) = \lim_{\Delta t \to 0} \frac{-[R(t + \Delta t) - R(t)]}{\Delta t} \cdot \frac{1}{R(t)}. \quad (7)$$

Using the $\lambda(t)$ definition in equation (2),

$$\dot{\lambda}(t) = \frac{-dR(t)}{dt} \cdot \frac{1}{R(t)} = \frac{f(t)}{R(t)} \quad (8)$$

$\dot{\lambda}(t)$ is known as the instantaneous hazard rate or failure rate function. The failure rate function $\lambda(t)$ provides an alternative way of describing the failure distribution. It is the failure rate per unit of time. It is similar in meaning to reading a car speedometer at a particular instant and seeing 60 mph. The next instant the failure rate may change or it may stay constant. Failure rates in some cases are characterized as increasing (IFR)
when $\lambda(t)$ is an increasing function, decreasing (DFR) when $\lambda(t)$ is a decreasing function, or constant (CFR) when $\lambda(t)$ is a constant function.

The bathtub curve is a special form of the hazard rate function $\lambda(t)$ and shown notionally in Figure 8. The bathtub hazard rate function captures the performance of systems (components) that experience decreasing failure rates early in their lifetime, then a constant failure rate, finally increasing failure rate.

![Figure 8 The Bathtub Curve](image)

4.2.2 Reliability Summary Measures

Summary measures of reliability, mean time to failure, variance of the failure distribution, and median time to failure, can be determined from the reliability functions.

The mean time to failure (MTTF) is a measure of central tendency of the failure distribution:
\[
MTTF = E(T) = \int_0^\infty t f(t) dt = \int_0^\infty R(t) dt
\]  \hspace{1cm} (9)

The variance of the failure distribution \( \sigma^2 \) is:

\[
\sigma^2 = \int (t - MTTF)^2 f(t) dt = \int t^2 f(t) dt - (MTTF)^2.
\]  \hspace{1cm} (10)

The average squared distance for a failure time to the MTTF is represented by the \( \sigma^2 \).

Another central tendency measure is the median time to failure:

\[
R(t_{med}) = 0.5 = P\{T \geq t_{med}\}
\]  \hspace{1cm} (11)

The median divides the failure distribution in half. The probability of a failure occurring before the \( t_{med} \) is 0.5, and the probability of a failure occurring after the \( t_{med} \) is 0.5.

The design life is defined to be the time to failure \( t_R \) that corresponds to a specified reliability \( R \).

\[
R(t_R) = R
\]  \hspace{1cm} (12)

With the specified reliability \( R \) given, the design life \( t_R \) can be calculated.

4.3 Theoretical Reliability Models

Ebeling (1997) uses four different probability models to describe a failure process. These models are: the exponential, normal, lognormal, and Weibull probability distribution. The models are derived theoretically rather than empirically. The Weibull distribution is the candidate for the reliability modeling in this research.

4.3.1 Weibull Probability Distribution

The Weibull distribution is useful in modeling both increasing and decreasing failure rates in reliability modeling. The form of its hazard rate function is:

\[
\lambda(t) = at^b
\]
where the power function $\lambda(t)$ is increasing for $a>0, b>0$ and is decreasing for $a>0, b<0$.

Usually, $\lambda(t)$ is expressed as follow:

$$\lambda(t) = \frac{\beta}{\theta} \left( \frac{t}{\theta} \right)^{\beta-1}, \text{ where } \theta > 0, \beta > 0, t \geq 0,$$  \hspace{1cm} (13)

$$R(t) = e^{-(t/\theta)^{\beta}},$$ \hspace{1cm} (14)

and

$$f(t) = -\frac{\beta}{\theta} \left( \frac{t}{\theta} \right)^{\beta-1} e^{-(t/\theta)^{\beta}}.$$ \hspace{1cm} (15)

Beta ($\beta$) is called the shape parameter as it determines the shape of the failure distribution. Table 6 adapted from (Ebeling, 1997) summarizes the effect of varied values of $\beta$.

<table>
<thead>
<tr>
<th>Event</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 &lt; \beta &lt; 1$</td>
<td>Decreasing failure rate</td>
</tr>
<tr>
<td>$\beta = 1$</td>
<td>Exponential distribution</td>
</tr>
<tr>
<td>$1 &lt; \beta &lt; 2$</td>
<td>Increasing failure rate</td>
</tr>
<tr>
<td></td>
<td>(Concave)</td>
</tr>
<tr>
<td>$\beta = 2$</td>
<td>Rayleigh distribution</td>
</tr>
<tr>
<td>$\beta &gt; 2$</td>
<td>Increasing failure rate</td>
</tr>
<tr>
<td></td>
<td>(Convex)</td>
</tr>
<tr>
<td>$3 \leq \beta \leq 4$</td>
<td>Increasing failure rate, Approaches normal distribution</td>
</tr>
</tbody>
</table>

Table 6 Weibull Shape Parameter Effects
Theta ($\theta$) is called the scale parameter or the characteristic life and affects the mean and the spread of the distribution.

### 4.3.2 Weibull Distribution Summary Measures

The mean time to failure (MTTF) and the variance for a Weibull distribution is given as follow:

$$\text{MTTF} = \theta \Gamma \left(1 + \frac{1}{\beta}\right)$$

$$\sigma^2 = \theta^2 \left\{ \Gamma \left(1 + \frac{2}{\beta}\right) - \left[ \Gamma \left(1 + \frac{1}{\beta}\right) \right]^2 \right\}$$

where $\Gamma(x)$ is defined to be an extension of the factorial to complex and real number arguments. There are statistical tables available to determine the value of $\Gamma(x)$. If the value of $(x)$ is not available in the table, then the following relation can be applied:

$$\Gamma(x) = (x-1)\Gamma(x-1)$$

The median time to failure is given using the following formula:

$$t_{med} = \theta(-\ln 0.5)^{1/\beta}.$$ (18)

The design life is found from:

$$t_r = \theta(-\ln R)^{1/\beta},$$ (19)

where $R$ is the specified level of reliability.

### 4.3.3 Three-Parameter Weibull Probability Distribution

If the time to failure $T$ is greater than $t_o$, $T > t_o$, where $t_o$ is a minimum life, then the three-parameter Weibull distribution can be used. For this model,

$$R(t) = \exp \left[ -\left( \frac{t-t_o}{\theta} \right)^{\beta} \right] \quad t \geq t_o$$ (20)
and

\[
\lambda(t) = \frac{\beta}{\theta} \left( \frac{t - t_0}{\theta} \right)^{\beta-1} \quad t \geq t_0. \tag{21}
\]

The variance of this distribution is the same as the variance of the two-parameter distribution model, however,

\[
\text{MTTF} = t_0 + \theta \Gamma \left( 1 + \frac{1}{\beta} \right) \tag{22}
\]

and

\[
t_{\text{med}} = t_0 + \theta (-\ln 0.5)^{1/\beta}. \tag{23}
\]

4.4 Reliability of Systems

There are two configurations in which components are related in a system. These two configurations are: serial configuration and parallel configuration as shown in Figure 9. For a serial configuration all the components must function for the system to function. In a parallel configuration, at least one component must function for the system to function. In practice, combinations of serial and parallel configurations are employed.

![Figure 9 System Configurations](image-url)
CHAPTER 5

SCENARIO USED FOR RESEARCH

5.1 Definitions of Terms

Definitions of military terms and figures of weapons are presented below and organized in the order they appear in the scenario. Some definitions are adapted from the free, open content, community-built encyclopedia “www.Wikipedia.org”.

- Observation post (OP): An observation post is a position from which soldiers can watch enemy movements and direct artillery fire.
- Reconnaissance (Recon): The military term for the active gathering of information about an enemy, or other conditions, by physical observation. It is part of combat intelligence.
- Platoon: In an army, a platoon is a unit of thirty to forty soldiers typically commanded by a lieutenant assisted by a non-commissioned officer. The platoon is formed by at least two squads (usually three or four squads).
- Infantry: The infantry are ground soldiers who fight primarily with small arms (guns and rifles) and operate within organized military units. “Infantry” also refers to the branch of the military in which these soldiers serve.
- Battalion: A battalion consists of two to six companies typically commanded by a lieutenant colonel. It is the smallest military unit capable of independent operations, but is usually part of regiment or a brigade or both, depending on the organizational model used by that service.
- Military Doctrine: A level of military planning between national strategy and unit-level tactics, techniques, and procedures. It provides a shared thinking way.
• Headquarters: The location where most, if not all, of the important functions of an organization are concentrated. The term is used especially with regards to military organizations and large corporations.

• Company: A company is a military unit, typically consisting of 100-200 soldiers. Most companies are comprised of three or four platoons although the exact number may vary by country, unit type and structure.

• TOW: Tube-launched, optically tracked, wire-guided missile, the heaviest antitank machine missile in the U.S. inventory. Figure 10 is a picture of a TOW.

![TOW Example](image10.png)

• LAV: Light Armored Vehicle. Figure 11 is a picture example of a LAV.

![LAV Example](image11.png)
• A-6 Jet: Marine aircraft, known as an “Intruder”. Figure 12 is a picture of an A-6.

![Figure 12 A-6 Intruder](image)

• M-60 Machine gun: A medium-size machine gun. Figure 13 is a picture of an M-60.

![Figure 13 M-60 Medium-Size Machine Gun](image)

• AT-4: a light, disposable antitank rocket. Figure 14 is a picture of an AT-4.

![Figure 14 AT-4 Antitank Rocket](image)
- **SAW**: Squad Automatic Weapon, a light machine gun. Figure 15 is a picture of SAW.

![Figure 15 SAW Example](image)

- **Close air support (CAS)**: CAS is the use of military aircraft in a ground attack role against targets in close proximity to friendly troops, in support of ground combat operations.

- **Sabot**: A sabot is literally a French wooden shoe. Here it refers to a device named for a shoe used in a firearm or cannon to fire a projectile or bullet that is smaller than the bore diameter of the weapon.

- **A-10**: The A-10 is an US Air Force aircraft designed for close air support of ground forces. It is a simple, effective and hardy single-seat, twin engine jet aircraft designed to attack tanks, armoured vehicles, and other ground targets. Figure 16 is a picture of an A-10 (nick named the Thunderbolt)

![Figure 16 A-10 Thunderbolt](image)
5.2 Command Hierarchies

The hierarchies of command shown from Figure 17 to Figure 21 are aids to understand the scenario and to avoid confusion due to the many scenario characters.

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**Figure 17 Chain of Command (Recon Platoon)**

**Figure 18 Chain of Command (Delta Company)**
At the tactical air Command Center:

Lieutenant General Chuck Horner
(Command of Airforce)

Brigadier General Buster Glosson
(deputy)

Figure 19 Chain of Command (Air Command Center)

Marines Commanders:

General Chuck Krulak
(Head Marines logistics officer)

Lt. Col. Cliff Myers
(Battalion Commander)

Major Jeff Powers
(Operation Officer)

Figure 20 Chain of Command (Marines Commanders)

In the A-6 attack jet:

Lt. Col. Beaman Cummings
(Pilot)

1st Lt. Michael Kies
(bombardier navigator)

Figure 21 Chain of Command (A-6 Attack Jet)
5.3 Scenario Narrative

5.3.1 Introduction

The 1991 Gulf War was a conflict between Iraq and a coalition force of 32 nations led by the United States. Iraq invaded Kuwait on August 2, 1990. The United Nation applied economic sanctions against Iraq immediately after the invasion. The coalition forces freed Kuwait and achieved victory in 1991 with minimum coalition deaths. The main battles involved aerial and ground combat within Kuwait and the borders of Saudi Arabia.

The battle of Khafji was the first major ground engagement of the Gulf War 1991. It took place in the Saudi Arabia city of AL Khafji. As the air portion of Operation Desert Storm drew to a close, Iraqi troops invaded Khafji. US Marines called in for close air support (CAS) while they held off the invaders. A total of 25 US servicemen lost their lives over the course of the three day battle. A total of 75 Iraqi armoured vehicles were destroyed over the course of the engagement. Estimates of Iraqi casualties range upwards of 2,000 soldiers killed. Over 400 Iraqi prisoners were taken in the Khafji area during the period of the battle (January 29th-February 1st 1991) (Morris, 2004). Many decisions were made, and can be analyzed, over the period of the three day battle. Understanding Iraq's objectives was the first step in the Air Force effort to gauge the significance of Khafji. As stated by retired Air Force Gen. Charles A. Horner, the Joint Forces Air Component Commander, the Battle of Khafji was downplayed at the time "because we didn't really understand what the objectives of the Iraqi army were." (Hedges, 2003)

A major concern for the coalition was protecting the colossal Marine logistics complex at Kibrit. Located at an abandoned airfield 30 miles south of the Kuwait border,
it was in the direct line of the enemy assault. Kibrit, the largest fuel and ammunition dump in the Marine Corps’ history, was erected to a previously unheard-of-scale, sprawling over 25 square miles and at one point storing nearly two million gallons of gasoline. Kibrit sprouted up practically overnight in preparation for the ground war and was brazenly situated forward of friendly lines in order to maximize the Marine attack’s forward momentum.

The Iraqi offensive consisted of three heavy divisions striking at four major points along the boarder, Observation Post 6 (OP 6), Observation Post 4 (OP 4), Observation Post 2 (OP 2), and Observation Post 7 (OP 7) as shown in Figure 22.

Figure 22 Enemy Offensive, January 29, 1991 (Morris, 2004)
The battle of Khafji can be decomposed into two parts: the outpost battles and the battle for Khafji. The following scenario (adapted from Morris, 2004) is a brief overview of the outpost battles particularly at Observation Post 4 (OP 4).

5.3.2 Scenario (The Outpost Battle of Khafji)

Figure 23 is an aid to understand the scenario.

![Figure 23 Scenario January, 29, 1991 (Morris, 2004)](image)

January 19, 1991

A group of marines, a recon platoon made their way to OP 4, located in the vicinity of Umm Hjul, located just over the Kuwait line at 179 meters above sea level. The site, a police customs house, was chosen as the recon platoon’s home because of its peculiar location along the Kuwait boarder. Umm Hjul is known to the Saudis as Markaz az Zabr. The geography of Markaz az Zabr provides a distinct disadvantage for the
marine platoon; any forces approaching the OP have the benefit of being in a position to fire down upon them.

In the infantry, visibility is paramount. According to the modern conception of war, almost all fighting positions are selected based upon how well one can observe the likely avenues of enemy approach. The ideal fighting position is a solitary, steeply sloped, uniformly graded hill with an escape route to the rear.

The commander of the recon platoon was Lieutenant Ross (see Figure 22). He wanted his men to work on improving the position despite heavy rain that would impede efforts. An eight foot high horseshoe-shaped berm directly behind the police post was ready and designated as the platoon’s fallback position. The berm was large enough to hold the entire platoon without its small fleet of vehicles (four Humvees and a five-ton truck). The platoon occupied a 500 meter front along the berm. The berm actually extended for several miles to a corresponding earthen wall on the Kuwaiti side.

8:00 P.M. January 29, 1991

January 29th was the night before Lieutenant Ross, his platoon sergeant Gillispie, and the rest of the platoon were to be relieved. Their mission that night was recon, to observe and report any enemy activity and if threatened by a large enough force, evacuate the area with utmost haste. The platoon was divided in three teams: Sergeant Mike Davis’s team, Sergeant John Jestel’s team, and Thomas Manney’s team. Corporal Miguel Roche was the communication chief of the platoon.

Lieutenant Ross and Sergeant Gillispie heard a noise coming from across the desert. In a few minutes they could see enemy tanks headed toward them. Ross went to the foot of the berm to Roche’s communication shed where he told Roche to wake the
soldiers of the platoon and to call and inform battalion about the new situation. Roche punched up a message to headquarters on the DCT, a small electronic pad with numerous pre-formatted messages stored in it. Unknown to Roche, the messages were not getting through to the battalion. Roche then ran to the bunkers to ready the soldiers. Several minutes passed before Ross and Roche realized the enemy was jamming their communications capabilities preventing their messages getting sent to the battalion command.

6 P.M. January 29, 1991

Around four miles northwest from Lieutenant Ross’s position, Captain Roger “Rock” Pollard, the commander of Delta Company, had his section of TOW antitank vehicles ready. These vehicles are considered valuable assets with powerful night scopes. The TOW antitank vehicles were interspersed with his lighter, 25-mm-armed LAVs.

8:20 P.M. January 29, 1991

At 8:20 pm Lance Corporal Dave Burrows observed three moving enemy vehicles and reported this to Sergeant Vitale, the leader of the TOW section. The moving objects were still too far away to deduce the type of vehicles or even determine if they were enemy vehicles. LAV companies at this stage in the war were equipped with first-generation passive night sights, which were practically worthless in this type of situation. Vitale was unconvinced this contact would develop into anything significant; the contacts were headed south, away from OP 4 and were still too far out to be a threat. Nevertheless, the number of objects sighted continued to increase. Vitale informed Captain Pollard of the situation. Pollard and Vitale knew that the recon team in OP 4 was at least three or four kilometers closer to the situation. They were expecting to hear from the recon at OP
4 but the messages had not come. After a few minutes Captain Pollard realized that there were numerous tanks on the far side of the berm moving south.

Pollard requested permission from battalion headquarters to engage the enemy. Standard rules of engagement required permission to engage. Pollard gave Lieutenant Colonel Cliff Myers, the battalion commander, a detailed situation report and was told to wait for the situation to further develop, with air support provided as soon as possible. However, a stream of red tracer appeared from recon’s position meaning a drastic change in the situation had suddenly occurred.

8:45 P.M. January 29, 1991

Ross and Roche continued working the radio to try and obtain air support. They had been trying for almost twenty minutes, but the radio was still not working. The platoon had been more or less abandoned, left out at the observation post for so long that their radio cryptographic data had expired.

Ross realized they would have to evacuate soon. However, he could not leave without informing his chain of command what was happening. The enemy was coming, and commanders back in the rear of the battle space needed to know the situation.

Roche went to the antenna farm at the back of his position to try and solve the radio problem. He checked the batteries and the antenna itself but it seemed like there was no hope. While Ross was with the radio, Gillispie was up on the berm using night vision goggles to observe the approaching enemy, now about a kilometer out. The Marines were ready to evacuate back to the horseshoe. Ross told Gillispie to signal the platoon to move back to the horseshoe. The signal was a red pop-up flare.
9 P.M. January 29, 1991

Lieutenant Ross and his platoon pulled away from the berm covering the 500 meters back to the horseshoe berm. By then Ross had contact with an airborne command and learned a marine A-6 intruder attack aircraft was on the way.

While Ross and the platoon still could not get hold of the light-armored vehicle company, the air support would give them time to regroup before striking out to the south to find a safe site. Furthermore, the aircraft would be able to relay their message to battalion headquarters and request more air support.

Just then a green tracer fire emanating from the second story of the customs house hit the lead tank. It was sergeant Jestel’s M-60 machine gun followed by several resounding AT-4 shots. The enemy tanks returned fire with their 115-mm main guns. The tanks were now only few hundred meters away, practically point-black range for armored combat.

As the force of between ten to fifteen enemy tanks approached, Davis gave the signal to engage. Sergeant Bench decided to use all the AT-4 launchers within his reach, scoring one direct hit. Lance Corporal Anderson, the team’s SAW gunner, had thrown down his SAW to grab an idle M-60 nearby. Bench discarded his M-16, picked up Anderson’s SAW, and began engaging the tanks to his front.

In the customs house, Lance Corporal Jeffery knew that the enemy would be drawn to their position if he and the others tried to do something. Just as one of the vehicles moved into his sights, Jestel and the other Marines unleashed a fusillade of antitank rocket fire. The enemy return fire was ineffective impacting well behind Jeffery’s position.
Soon an odd pause developed, the enemy appeared to be breaking off their attack. Sergeant Jestel yelled for his team to advance on the tanks. They sprinted out to a small clump of sand mounds in front of the house and hastily organized a defensive position.

Back at the horseshoe, Ross and Gillispie watched Jestel’s team in stunned disbelief. They knew the futility of trying to stop the tanks with machine guns and failed to understand why Jestel was shooting at them. Suddenly, the enemy jamming ceased. Ross suddenly had communication capability with Davis’s team. He told Davis to gather Jestel’s team and have them fall back to the horseshoe.

First Lieutenant Michael Kies, the bombardier navigator of the marine A-6 attack jet, received a radio call from the air-support center informing him that a ground unit on the border was in trouble and needed close air support. The pilot was Kies’s squadron commander, Lieutenant Colonel Cummings. The air support center instructed them to change their radio to the ground radio frequency and make contact with the ground unit commander.

Kies contacted Lieutenant Ross and informed him that they were inbound and just a few minutes from their position. At his position Ross directed Kies toward an enemy tank. The A-6 dropped ordinance nearby directly on the target tank and then headed back to the base. The enemy vanguard appeared in disarray, with numerous vehicles breaking off the attack and careening through the gloom in random directions.

The enemy force, initially stunned by the volume of machine-gun fire and the cluster-bomb strike, had regrouped and were pressing on with their attack. They began blasting away at the small generator building behind the customs house and grinding toward the Marines.
With air support outbound away from the battle, but more air support sure to follow, Ross began focusing on getting the light armored vehicles to his position to conduct a battle handover. Rather than surrender ground without a fight, he wanted the LAVs, with their heavier armament and antitank missiles to link up with his platoon and attrite the enemy armored formation in preparation for the coming air strikes. Also, if they could suppress the enemy, and take off some of the pressure of their advance, Ross and his marines could safely escape.

Ross grabbed another radio from Roche and began conversing with Pollard’s second-in-command, Lieutenant William. Ross managed to coax the LAVs forward. Enroute, Lieutenant William requested that Ross mark his position with an infrared strobe to avoid any friendly fire situation. This was a nearly universal control measure, and the LAVs, which had night sights mounted on their hulls, would be able to pick up the infrared flashes. Pollard informed Ross that as the company got closer, they would fire their 25-mm chain guns over the recon platoon to cover their escape.

Ross sent Lance Corporal Pacheco out with a wallet-sized infrared strobe light to the mouth of the horse shoe. As soon as Pacheco activated the beacon, tank rounds began impacting all around the Marines. Noticing the increasingly accurate barrages, Peacheco quickly snapped off the device. It appeared that contrary to all intelligence, the enemy also had night-vision scopes. Ross would have to target the LAVs via radio, a challenging proposition.

Meanwhile, Gillispie began collecting marines to strike at the converging tanks with their AT-4s. Although the AT-4s were not doing damage, they were rattling and confusing the enemy. As they started moving out, Ross spotted them; the last thing that
Ross wanted was for the platoon to get split up again or for half of the platoon to get decisively engaged as the other half was preparing to evacuate.

**Approximately 9:00 P.M. January 29, 1991**

From his position, Pollard knew the enemy was shooting Sabot rounds designed to pierce the thick laminate steel of American tanks. The Sabot rounds were punching straight through the buildings of the observation post and emerging out the other side.

Lieutenant Williams reported to Pollard that Ross’ recon platoon was under fire and that he had requested Delta’s immediate assistance. To Williams, Ross sounded panicky and seemed to have lost control over his men. Ross apparently thought it was no big deal for LAVs to go against the much heavier enemy tanks.

Pollard was now caught in quandary of his life. Scared, tired, mad, confused, frustrated, and with a balefully incomplete understanding of the situation, he now had to decide whether to take his LAVs, which were never designed to get involved in such a tank attack, against the enemy tanks. Pollard had no idea of recon’s true disposition, did not know what had caused recon to open up fire, and did not know what else the enemy had in store for them. Earlier that afternoon, despite a meeting with Ross, Pollard did not find out if Ross had enough transportation for all his marines, and did not know if Ross had an entire platoon on the berm or just a single five-man team. Ross’s platoon was equipped with an older type of radio set meaning the only way that Pollard could talk to Ross was via a relay through Lt. Williams. This relay cost precious time and messages could get distorted as they passed from one end of the chain to the other. Pollard could not ignore recon’s pleas. He had planned to stay a safe distance away and use Vitale’s TOWs to destroy the enemy tanks. TOWs had the capability to destroy vehicles out to
3,750 meters. The longest range of the enemy’s tanks was 3,000 meters. He knew that the enemy could not cross the berm without an intense effort, and the only gap in the berm was the gap at OP 4. Controlling the berm gap became the decisive element to defending OP 4. Pollard figured that while he fought, Lieutenant William could work on obtaining further air support.

Pollard called over to Vitale and informed him that his platoon and Lieutenant Kendall’s Second platoon were to launch up to the border to go get recon and that he (Pollard) would need half of Vitale’s TOW vehicles to follow in trace to provide protective long range fire. As a final preparation, Pollard ordered his logistics train, the fuel truck, the recovery vehicle, the drinking water trailer, and the headquarters Humvees led by First Sergeant Alfonso Villa, to displace back away from the fight.

Pollard along with his second platoon, launched up the border. He left Lieutenant Sadowski’s platoon of six LAVs to hold down the position. Soon after they crossed the start line, things started disorganizing. Vehicle misalignment was not acceptable practice in such a nighttime situation.

Nighttime, January 29, 1991, Riyadh, Saudi Arabia, 250 Miles South of OP 4

At the tactical air command center in Riyadh, the Coalition air headquarters for the war, General H. Norman Schwarzkopf and the commander of air forces, Lieutenant General Chuck Horner, had other concerns. They were working on degrading the enemy’s elite ground force, the Republican Guard, to fifty percent of their initial combat strength.

After midnight, one of Horner’s deputies, Brigadier General Buster Glosson was stunned to hear reports of enemy tanks columns attacking into Saudi Arabia. It looked to
be a major effort, encompassing most of the boarder region from OP 6, in the west, all the way to the town of Khafji on the Coast. Air strikes were being directed toward the border but only in piecemeal fashion. Horner’s air controllers were responding to Marine requests, but there was no real battle plan. No decisive action had been taken for over three hours. None of the air controllers on duty that night had warned Horner or Glosson that a major offensive was under way.

Over at the Light-Armored Infantry battalion command post, twenty miles south of OP 4, operations officer Major Jeff Powers heard from Delta team about the situation. After getting an update from Pollard, he ordered his staff to break down the command post tent and prepare for the fight.

Later, Powers received spot reports from his other company commanders. Bravo company to the south was reporting enemy movement to their front. Charlie company in transit from Khafji to OP 6 was reporting tanks on their horizon. Powers told the Bravo company commander to spread his vehicles out to prepare for saving Kibrit.

Meanwhile, in the second Marine Division sector, 15 miles east of OP 4 at OP 2, the recon Marines at the police post watched the flashes from the fight at OP 4 on the horizon and decided to get out of the area while they could.

General Chuck Krulak, the head Marine logistics officer in the Gulf, had been worried for some time that the enemy would learn of Kibrit and attack the exposed supply base, demolishing the Marines offensive plans. When he heard of the enemy mechanized assault, he was convinced that Kibrit was the objective. He immediately ordered the base to hundred percent alert.
Approximately 9:15 P.M. January 29, 1991

Joshua Brierly the TOW gunner for Green 1 (in Delta group) saw an enemy tank at just 3,000 meters away from him. He reported to his vehicle commander that an enemy main battle tank was less than two miles away. This was just under the range of a soviet T-80 tank. The main plan of the group was to move up to the border and wait for the enemies to approach within the Marines TOW range. The enemies would be destroyed by missiles from vehicles they would never see. At that time, the situation was that the marines were exposed to the enemy fire.

Sergeant Michael Wissman, the commander of Green 1, called over to Vitale informing him that his gunner has a tank at three thousand meters, and was requesting permission to engage.

Vitale was a few hundred meters away, in Red 1. He knew Brierly as a good marine, one of the best in the group at armor identification. Vitale was also thinking how the enemies rolled up so close on them without them knowing, and wondering where the other enemy’s tanks were.

Vitale decided that he had to double check his information. He ordered Jason Brown from Red 1 and Scottie Pruett from Green 4 to conduct a search to confirm Brierly’s distance to target. After two minutes, both confirmed that Brierly’s target did not exist. Brierly’s call from Green 1 did not seem right, it was way too close. Even Sergeant Wissman at the Green 1 has his doubts when Brierly first reported the tank. The enemies were at 6,000 meters at one minute and then somewhere under 3,000 the next minute.
Wissman called again to Vitale asking permission to engage, Vitale switched over to Pollard in Delta 6 and cleared him to fire. Vitale switched back to the TOW net where he ordered Brown who was standing near him, Brierly from Green 1, and Pruett from Green 4 to fire.

At that time, Pollard saw the whole thing. Pollard and 2nd platoon were heading to get recon when he saw Green 2 to his left rear getting ripped apart. Pollard reported back to Battalion that he lost a vehicle, but he did not know that his people had destroyed it.

After the missiles were launched, Vitale noticed that Brown’s missile hit the target at 23 seconds, Pruett’s missile impacted at 25 seconds, but Brierly’s missile hit after only 3 seconds. He knew that something was wrong. When he heard Pollard’s report, he knew that they had just killed Green 2 with Corporal Ismael Cotto, Lance Corporal Daniel Walker, Lance Corporal Dave Snyder, and Private Scott Schroeder in it.

At the berm, Roche and Pacheco noticed that the TOW vehicles suddenly stopped moving back. Lt. Ross was thus presented with a staggering dilemma. Should he and his platoon remain in the horseshoe and hope that LAVs would come to take the pressure, or did they “cut bait” and clear out of this bad scene. Clearing the area would be under the enemies’ fire, and staying there would be waiting for the enemy to attack them especially after their position was cleared to the enemy because of the infrared strobe fiasco. In combat, sometimes action, any action, seems preferable to doing nothing.

Ross told the men to load up. The Humvees started leaving the horseshoe within minutes. Roche was trying all Delta’s frequencies to try and obtain communication with them to let them know they were inbound. As they got closer, mistakenly, the LAVs began firing their 25-mm cannons at recon but recon was able to avoid it.
After the death of Green 2, Pollard and Kendall’s group of LAV-25s pressed on with their attack, leaving the wounded TOW group behind. Pollard yelled over to Williams, “What does recon have for transportation? How many of them do we have to pick up? How close to the buildings do we have to go? Can’t they just meet us halfway?” Enemies’ Sagger missiles were flying up in the air. The Marines began putting a steady steam of 25-mm fire downrange. But firing at the enemy with 25-mm rounds was not solving anything. Pollard needed to resolve this recon question, pull back to the main body of the company, and wait for some serious air support to start leveling the battlefield.

After several minutes, Lt. Williams came back with the answer to Pollard’s question. Recon had five ton vehicle (the 5-ton, 6x6, vehicles are tactical vehicles designed for highway and cross-country terrain) and a few Humvees, and they were heading back for pickup. Soon Pollard started to see the recon vehicles so he called and informed Battalion that recon was out.

Pollard started the withdrawal back to Delta’s main line of resistance. At this time, Lt. Williams began shifting Sadowski’s Platoon south to a new position three thousand meters due west of OP 4. This superior locale allowed them to better suppress the enemy and provide cover for Pollard’s withdrawal back to Delta’s main line of resistance.

Allied aircraft were beginning to filter in. Lt. Williams along with the company’s air controller, Corporal Russell Zawalick, began to direct these planes onto OP 4.
Approximately 9:30 P.M. January 29, 1991

The first flight of aircraft to arrive at OP 4, after the lone A-6 jet, was a two-ship formation of Air Force A-10 Thunderbolts, responding to a request from the LAV battalion. The control of the A-10s was turned over to Zawalick, stationed two feet away from Lt. Williams inside Delta’s antenna-studded command-and-control LAV, a few hundred meters behind the main screen line. When Zawalick began to direct the A-10s onto the enemy columns of tanks, he discovered that A-10s lacked effective night vision equipment with which to acquire targets.

This unfortunate circumstance certainly was not making Zawalick’s life any easier. Actually, as the A-10s checked in, Zawalick attempted to orient them, asking if they could spot the police post buildings, the virtual center of the action. After several passes, the A-10 flight leader radioed back to Zawalick, informing him that they were unable to locate the landmark.

For Zawalick this was a tough decision. He could just point the pilots in the right direction, and hope for the best, knowing that they would blast some enemies, but he knew that if he did so, he ran a serious risk of the A-10s mistaking one of Delta’s LAV for an enemy tank.

Williams came up with the idea of trying to direct the A-10s using the flashes of the LAV’s 25-mm rounds as they ricocheted off the enemy tanks. One of the pilots had mentioned that he could see their rounds impacting. Williams thought that if they could coordinate their fire, then they could adjust the A-10 aircraft off the flashes and bring the aircraft to bear on the enemy in short order. He ordered the company to train their
weapons on the tanks nearest the breach. After a series of runs, the adapted targeting plan worked.

A second pair of A-10s checked aboard. Zawalick tried to bring the flight around for a Maverick missile run, but this night knew no master and was aggravated by the Iraqi jamming and the fact that Delta and its enemies were now only hundreds of yards apart. Earlier they had been able to guide the fliers to targets without difficulty, but now as forces converged, the pilots struggled to make sense of the swirling ground clutter of activity. The battle was entering a new phase, and Williams figured that it was time to fall back to somewhere safer.

An A-10 came around again and told Zawalick that he is going to drop a flare, hoping that Zawalick would be able to direct him based on the bright marker. The blazing cylinder was dropped from the sky, the only problem was that it was laying in the middle of Delta’s screen line, making their position clear for any enemy tank for miles around. The flare fell close to one of the LAVs, “Blaze of Glory”. Sergeant Mongerella was the vehicle commander, and Ron Tull was the vehicle driver. When they noticed the human sized flare, Mongrella ordered Tull to move the vehicle away. He had backed the vehicle up 50 or 60 yards when he saw one of his friends, out in the desert trying to extinguish the flare using a shovel. Thirty second later, the Blaze of Glory was consumed by fire.

Zawalick told the A-10s that he had just marked Delta’s position with his flare. Zawalick then radioed for the A-10s to engage targets 6,000 meters away at an azimuth of 126 degrees magnetic. At this point, Lt. William grabbed Zawalick and told him to shut the A-10s down because Blaze of Glory was hit. Zawalick replied that no one he was
controlling had fired yet. Williams told him to figure out who fired. Zawalick began spinning to all frequencies asking who had just shot, but no one answered.

When Pollard discovered what happened, he first thought that the enemy had hit them. He needed to figure things out. He thought that because of the flare, the enemy had zeroed in on Delta’s position, but seeing as how they were still outside of tank range, he had no idea what they could have hit them with. He asked Vitale to scan for any enemy in the region and the answer was that there were no tanks approaching.

First Sergeant Alfonso Villa, back with the logistics vehicles and Humvees, radioed Pollard asking if there were any survivors from Blaze of Glory. Villa has several corpsmen back with him, and if they were going to mount a recovery effort, they needed to get started immediately. Pollard told him no, that the explosion was too intense to allow any survivors.

Lt. Williams came up on the net and said that they now had aircraft stacked up from OP 4 to Riyadh and that they should evacuate the area and let the air wing handle the situation. At 11:30 PM, Pollard called over to Battalion, who quickly gave him permission to evacuate OP 4.

12:45 A.M. January 30, 1991

Eventually the recon platoon made its way to a safe position well away from the dangers berm. Sergeant Vitale could not just leave without trying to check on Green 2. Delta had started withdraw, but as far as he was concerned, he still had a missing vehicle out there. He could not just walk away. He was hoping that somehow Cotto and his soldiers were still alive, that their radio was dead or that they had experienced a total
electrical meltdown and were just waiting for a pickup. He lit out from Delta lines to go get them.

Because he was trying to travel as much as possible in hunt for Green 2, when Vitale decided to head back to friendly lines, he discovered that he was disoriented.

After he gave up, he began swinging a blue-colored chem-light on a piece of cord to attract the company’s attention. He was found 20 minutes later.

5.4 Scenario Features

The term scenario originated in the performing arts, it means an outline or synopsis of a film or play. In this research, the term scenario means an internally consistent story about how events develop over time (Kirkwood, 1997). The battle of Khafji scenario was chosen because of many reasons. The battle of Khafji scenario was detailed enough to gain a deep understanding of the decision makers values. The scenario covers the smallest thoughts and details about what they cared about. The derived value models and hierarchies captured the values of the decision makers accurately.

The battle of Khafji was also chosen because it included the worst incidents of friendly fire or fratricide between US forces since the Vietnam War (Hedges, 2003). A total of 11 US Marines were killed in two separate incidents on January 29, 1991 at Observation Post 4 (OP 4). The main cause of friendly fire incident can be seen as data flow misinterpretation. These incidents and other events where information was misinterpreted by decision makers in the scenario are modeled using the reliability distributions.

The scenario also includes examples of how the value of information degraded over time. This degradation is captured by an information reliability model which is used
to feed the decision model. In other words, the battle of Khafji scenario contains decisions that were made exploiting information available. This information varied over time due to the dynamic nature of the battle. This variation had a unique affect on the decision situations.
CHAPTER 6

VALUE STRUCTURE AND VALUE-FOCUSED THINKING MODEL

6.1 Introduction

A battlefield decision making scenario is easily classified as a dynamic multi-objective decision making problem, mostly unstructured and highly uncertain. A decision maker in the battlefield decision space deals with dynamically changing information. A future decision may depend on what happened before even if what occurred before was unexpected. Typically, information used to make decisions flows from various sources. Whether this information is reliable or not, motivates the decision maker to use this information to plan, analyze, and decide on a best alternative to achieve the desired objective, such as defeating the enemy. In a battlefield there is really no single decision to make; several sequential decisions are made. Each period of time may receive new information making it sometimes necessary to make a new decision each time. In a battlefield, one decision and its impact, leads to another decision in a sequential fashion.

Multi-objective decision making models provide a means to examine how decision makers make choices among competing alternatives, available or generated alternatives, by weighting the importance of different objectives and then systematically evaluating how well alternative solutions achieve the desired objectives. This research explores such models applied to battlefield decision making.

Military decision making comprises both individual and group decisions. The members of a group may or may not be located at the same physical location through the scenario, but in an ideal case they are aware of one another. Military forces in combat are one of the common examples of decision making groups at different physical locations.
Regardless of whether decisions are made individually or as a group, the decisions are made based on a systematic process. This research proposes the use of value focused thinking as a means of describing that systematic decision making process. What follows in this chapter is the value-focused thinking model of the research decision making scenario. The value-focused thinking decision model is composed of a decision model and a value model. A decision model is the combination of a fundamental objectives hierarchy, a means objectives network, and the attributes used to assess how well alternatives achieve objectives. A value model expands the decision model into a model that can be used quantitatively to evaluate alternatives in a decision situation using the value-focused thinking decision analysis techniques.

Figure 24 present a general form of the decision hierarchy for the military.

```
   Headquarters
    ▼
   Commanders
    ▼
 2-Lt in Command Officers
    ▼
 Team Leaders
    ▼
 Soldiers
```

Figure 24 General Decision Hierarchy for Military

The decision hierarchy in Figure 25 was derived as applicable to the battle of AL Khafji scenario. The hierarchy presents the decision makers modeled in this research.
Different members in the decision hierarchy may have different values, and thus a different VFT model (decision model and a value model) is constructed for most of the members in Figure 25 decision hierarchy.

In this chapter, the battle field collaborative multi-objective decision making is characterized using value focused thinking. Due to the doctrinal military decision making process, there are two different classes of collaborative multi-objective decision situations in the decision hierarchy in Figure 25. One class involves multiple decision makers that must collectively agree on a course of action (examined horizontally through the decision hierarchy). This class relation is embedded in the qualitative derivation of the objectives of the different members in the decision hierarchies. In the second class, one decision maker is the main decision maker, but he accounts for the values of other subordinate members in his decision. The values of each member may be treated equally,
or the main decision maker may assign less weight to the values of other members (examined vertically through the decision hierarchy). This class of relation is embedded in the qualitative derivation of the objectives of the different members in the decision hierarchies. This type of relation applies constraints and restrictions on the use of resources and alternatives by the subordinate members in the decision hierarchy.

Value focused thinking has been used before as a methodology in military application. However, it was never used in combat applications. Parnell, et al. (1998) developed a value-focused thinking model “Foundations 2025” to evaluate which system concepts and technologies for achieving air and space dominance in the year 2025 have the greatest potential to ensure that dominance. The model study was preceded by a similar study in 1993 “Spacecast 2020” reported by Burk and Parnell in 1997 to identify future space system concepts (as referred in Parnell, et al. 1998).
6.2 Decision Models

A decision model is the combination of a fundamental objectives hierarchy, a means objectives network, and the attributes used to assess how well alternatives achieve objectives. Objectives structuring is the main task in building a decision model. The framework for deriving objectives was personal military conceptual experience, and military training and doctrine documents. In the proceeding section, a specified decision model is constructed for each member of the decision hierarchy in Figure 25.

6.2.1 Headquarters

The definition of military objectives according to the Department of Defense (DOD), as mentioned in (US Military Glossary, 2005), is: “the derived set of military actions to be taken to implement National Command Authorities guidance in support of national objectives. Defines the result to be achieved by the military and assigns tasks to commanders”.

Working with this, defense planning begins with basic national level objectives. Examples of basic national level objectives are the political objectives in the documents of the U.S. Constitution. All of national power instruments (political, economic, and military) can be used in achieving political objectives.

Political objectives and military objectives are different in form and structure, but are strongly related. The political objectives describe the destination, while the military objectives describe how to reach the destination militarily.

Political objectives can be limited or unlimited. Unlimited political objectives are usually easily explained. Limited political objectives are usually complicated due to the combination of positive and negative goals. Limited political objectives are usually
supported by limited military objectives; the cost of the war based on unlimited military objectives might be more than the value of the objective (Essays on Air and Space Power, 1997).

The Gulf War however, is an example of an unlimited military strategy applied successfully in pursuit of a limited political objective (Strategy, 2005). The limited political objective was to restore Kuwait’s independence. To achieve this objective it was deemed necessary to destroy all the capability of the enemy forces to resist and eject them from Kuwait by force, essentially an unlimited military objective.

The battle of Al Khafji scenario is a part of the larger Gulf War scenario. To develop the fundamental objectives hierarchies for the different members in the decision hierarchy, or at least for the top level, the general objectives of the Gulf war should be considered.

The strategic objective of the Gulf War scenario was “winning the war”. A strategic objective should provide common guidance to all the generated objectives and later to all the decision opportunities. The fundamental objectives that fall under this strategic objective are considered the Headquarters fundamental objectives for the Gulf War. These fundamental objectives are:

- Deter the Iraqi aggression.
- Restore lost territory (Kuwait).
- Defend the homelands like: Saudi Arabia, UAE, Bahrain, and Qatar (Basically the lands where the coalition forces exist).
- Protect lines of communication.
- Defeat an opponent.
• Win the media war.

The political objectives effects are clear in the list of the Headquarters fundamental objectives for the Gulf War like the political objective of “win the media war”. A media war is a political concern rather than a military concern.

The fundamental objective hierarchy of the general headquarters for the Gulf War is shown in Figure 26.

![Figure 26 Headquarters Fundamental Objectives Hierarchy for the Gulf War](image)

Using the strategic objectives and the fundamental objectives of the Gulf War, with an understanding of their deriving forces, the Headquarters’ strategic objective and fundamental objectives for the battle of Al Khafji are derived. The initial strategic objective for the battle of Al Khafji was to defeat the Iraqi aggression. This strategic objective changed over time to a more specific objective. As the Iraqi aggression resulted in occupying Al Khafji city, the strategic objective changed to restoring the freedom of the city of AL Khafji. Both strategic objectives were guided by the main strategic objective of winning the war; both can be combined into a single strategic objective as “Win the battle”.
The fundamental objectives of the headquarters were derived and are:

- Restore lost territory.
- Deter Aggression.
- Protect lines of Communication.
- Protect Resources “Kibrit”.

The fundamental objective hierarchy of the headquarters for the battle of Al Khafji is shown in Figure 27.

Figure 27 Headquarters Fundamental Objective Hierarchy for the Battle of Al Khafji

A complete decision model for the headquarters was not derived and constructed in this research due to scenario constraints. However, the Headquarters’ fundamental objectives serve as a guide in deriving the fundamental objectives of the lower levels in the decision hierarchy, and to help capturing a complete overview of the values in the decision hierarchy.

The second level in the decision hierarchy is the platoon and group commanders. In the scenario, there are two decision makers in this level:

- 1st Lt. Stephen Ross, Commander of the recon platoon.
- Captain Roger Pollard, Commander of Delta Company.
Separate sets of objectives were generated and organized into fundamental objectives hierarchies and means objectives networks. Attributes are used to measure the achievement of their objectives when examining alternatives.

### 6.2.2 Lt. Stephen Ross

Lt. Ross is a commander of a recon platoon. The mission of a recon platoon in the military is to observe and report any enemy activity and if threatened by a large enough force, to evacuate with utmost haste.

In considering Lt. Ross’s values, one considers values significant enough to consider when evaluating decision alternatives. Using this approach a list of Ross’s objectives, consistent with the decision context (scenario), were derived and are:

- Keep the troops alive.
- Stay alive.
- Achieve the main mission successfully.
- Establish a good communication with the upper chain commanders.
- Establish a good communication with lower officers and soldiers.
- Maintain a high Situation awareness.
- Minimize response time.

This list of objectives includes both means objectives and fundamental objectives. Both kinds of objectives were separated by examining each objective on the list (using the WITI test). This was a critical step because the objectives which are important because they help achieve other objectives (means objectives) were separated from the objectives that are important because they reflect what Lt. Ross really wants to accomplish. The results of the effort are the following:
Fundamental objectives:

- Stay alive
- Keep the troops alive
- Achieve the main mission successfully

Means objectives:

- Establish a good communication with the upper chain commanders.
- Establish a good communication with lower officers and soldiers.
- Maintain a high situation awareness.
- Minimize response time.

The fundamental objectives are organized into a fundamental objectives hierarchy. The upper levels in the hierarchy represent more general objectives, and the lower-levels explain the important elements of the more general levels (Clemen and Reilly, 2001).

For example, the higher level fundamental objective of “Keep the Troops Alive” has two lower-level fundamental objectives “Minimize Number of Injuries” and “Minimize Number of Casualties” that explain what is meant by the higher level objective. Each of the lower-level fundamental objectives describes an aspect of keeping the troops alive. Another lower-level was added as an aspect of those two lower-level objectives distinguishing between injuries to soldiers or team leaders, and similarly distinguishing between death of soldiers or team leaders. Figure 28 displays the fundamental objectives hierarchy for Lt. Stephen Ross.
The means objectives were organized into a network depicting how the means objectives are important to achieve specified fundamental objectives. The fundamental objectives hierarchy and the means objectives network combined together as shown in Figure 29.

Figure 29 Fundamental Objectives Hierarchy and Means Objectives Network for Lt. Ross
Figure 29 shows the relation between the means objectives and the fundamental objectives. The mean objective “Minimize Response Time” helps achieve the fundamental objectives “Stay Alive” and “Achieve the Main Mission Successfully”. If the commander response time to take the right decision is short, the odds to achieve the mission successfully can be higher.

The next step was to derive attributes to measure the achievement of the fundamental objectives. The assignment of attributes to measure the objectives required value judgments. These value judgments, like all other value judgments, can lead to insights from value focused thinking (Keeney, 1994).

There are six fundamental objectives in the lower level of the hierarchy that need attributes to measure the objectives’ achievements.

For the fundamental objective “Stay Alive”, the outcome related to this objective is either staying alive or dead. Two additional levels are added between these two outcomes. The attribute “Life Status” definition includes a verbal description of the four levels of the objective achievement and a numerical indicator assigned to each level. The complete attribute scale is illustrated in Table 7. Level 0 is defined as the most favorable level and level 3 is defined as the most unfavorable level.

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attributes Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Alive without Injuries</td>
</tr>
<tr>
<td>1</td>
<td>Alive with Minor Injuries</td>
</tr>
<tr>
<td>2</td>
<td>Alive with Major Injuries</td>
</tr>
<tr>
<td>3</td>
<td>Dead</td>
</tr>
</tbody>
</table>

Table 7 Attribute “Life Status” for Lt. Ross
The fundamental objective “Keep his Troops Alive” is specified by the lower level objectives: “Minimize Casualties in Soldiers”, “Minimize Casualties in Team Leaders”, “Minimize Injuries of Soldiers”, and “Minimize Injuries of Team Leaders”. A single natural attribute for each of these lower level objectives is available. These natural attributes imply that each death or injury is evaluated equally which is appropriate for the given scenario. Collectively, these four attributes are used to measure the degree to which the higher level fundamental objective “Keep his Troops Alive” is achieved. These four attributes scales are illustrated from Table 8 to Table 11, respectively.

<table>
<thead>
<tr>
<th>Attribute Level</th>
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<td>0 % Dead</td>
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<td>1-25% Dead</td>
</tr>
<tr>
<td>2</td>
<td>26-50% Dead</td>
</tr>
<tr>
<td>3</td>
<td>51-75% Dead</td>
</tr>
<tr>
<td>4</td>
<td>76-100% Dead</td>
</tr>
</tbody>
</table>

Table 8 Attribute “Number of Casualties in Soldiers”

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 Dead</td>
</tr>
<tr>
<td>1</td>
<td>1 Dead</td>
</tr>
<tr>
<td>2</td>
<td>2 Dead</td>
</tr>
<tr>
<td>3</td>
<td>3 Dead</td>
</tr>
</tbody>
</table>

Table 9 Attribute “Number of Casualties in Team Leaders”
<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0% Injured</td>
</tr>
<tr>
<td>1</td>
<td>1-25% Injured</td>
</tr>
<tr>
<td>2</td>
<td>26-50% Injured</td>
</tr>
<tr>
<td>3</td>
<td>51-75% Injured</td>
</tr>
<tr>
<td>4</td>
<td>76-100% Injured</td>
</tr>
</tbody>
</table>

Table 10 Attribute “Number of Injuries in Soldiers”

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 Injured</td>
</tr>
<tr>
<td>1</td>
<td>1 Injured</td>
</tr>
<tr>
<td>2</td>
<td>2 Injured</td>
</tr>
<tr>
<td>3</td>
<td>3 Injured</td>
</tr>
</tbody>
</table>

Table 11 Attribute “Number of Injuries in Team Leaders”
For the objective “Achieve the Main Mission Successfully”, the complete attribute “Mission Achievement” scale is illustrated in Table 12.

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Mission was Perfectly Achieved</td>
</tr>
<tr>
<td></td>
<td>(Information was sent)</td>
</tr>
<tr>
<td>1</td>
<td>Mission was Partially Achieved</td>
</tr>
<tr>
<td></td>
<td>(Information was partially sent)</td>
</tr>
<tr>
<td>2</td>
<td>Mission Failed</td>
</tr>
<tr>
<td></td>
<td>(Information was sent)</td>
</tr>
</tbody>
</table>

Table 12 Attribute “Mission Achievement”

This constructed attribute was developed specifically for the scenario decision context. The mission was to send information to the headquarters. Therefore, to avoid ambiguity and to meet the understandability requirement, the meaning of each level of the scale is described in Table 12. For example, the meaning of “Mission Failed” is explained as (information was not sent). It was necessary to construct this attribute because there is no natural attribute existed to measure the objective “Achieve the Main Mission successfully”.
6.2.3 Captain Roger “Rock” Pollard

Captain Pollard is a commander of a fighting group. His mission includes visualizing the current state and future state, formulating concepts of operations to get from one state to another state, and doing so at least cost. His duties also include: assigning missions to his troops, assigning priorities, allocating resources, selecting the critical time and place to act, and knowing when and how to make adjustments.

In considering Captain Pollard values, one considers values significant enough to consider when evaluating decision alternatives. Using this approach a list of Pollard’s objectives, consistent with the decision context (scenario), were derived and are:

- Stay alive.
- Keep the troops alive.
- Achieve the main mission successfully.
- Re-supply friendly forces.
- Protect Military assets.
- Maintain a high situation awareness.
- Locate and destroy enemy weapons.
- Neutralize enemy radars.
- Stop and prevent artillery attacks against forces.

This list of objectives includes both means objectives and fundamental objectives. Both kinds of objectives were separated by examining each objective on the list (using the WITI test). This was a critical step because the objectives which are important because they help achieve other objectives (means objectives) were separated from the
objectives that are important because they reflect what Capt. Pollard really wants to accomplish. The results of the effort were the following:

Fundamental objectives:

- Stay alive
- Keep the troops alive
- Achieve the main mission successfully
- Protect Military Assets

Means objectives:

- Maintain a high situation awareness.
- Locate and destroy enemy weapons.
- Neutralize enemy radars.
- Stop and prevent artillery attacks against forces.
- Re-supply friendly forces.

The fundamental objectives are organized into a fundamental objectives hierarchy. The upper levels in the hierarchy represent more general objectives, and the lower-levels explain the important elements of the more general levels (Clemen and Reilly, 2001).

The higher level fundamental objective of “Keep the Troops Alive” has two lower-level fundamental objectives “Minimize Number of Injuries” and “Minimize Number of Casualties” that explain what is meant by the higher level objective. Each of the lower-level fundamental objectives describes an aspect of keeping the troops alive. Another lower-level was added as an aspect of those two lower-level objectives distinguishing between injuries to soldiers or officers and team leaders, and similarly
distinguishing between death of soldiers or officers and team leaders. Figure 30 displays the fundamental objectives hierarchy for Captain Pollard.

Figure 30 Captain Pollard, Fundamental Objectives Hierarchy

The means objectives were organized into a network that depicting how the means objectives are important to achieve specified fundamental objectives. The fundamental objectives hierarchy and the means objectives network were combined as shown in Figure 31.
Figure 31 shows the relation between the means objectives and the fundamental objectives for Pollard. The mean objective “Neutralize Enemy Radar” helps achieve the fundamental objectives “Keep his Troops Alive” and “Protect Military Assets”.

The next step was to derive attributes to measure the achievement of the fundamental objectives. There are ten fundamental objectives in the lower level of the hierarchy that need attributes to measure the objectives’ achievements.

For the fundamental objective “Stay Alive”, the outcome related to this objective is either staying alive or dead. Two additional levels are added between these two outcomes. The attribute “Life Status” definition includes a verbal description of the four levels of the objective achievement and a numerical indicator assigned to each level. The complete attribute “Life Status” scale is illustrated in Table 13. Level 0 is defined as the most favorable level and level 3 is defined as the most unfavorable level.
Table 13 Attribute “Life Status” for Capt. Pollard

The fundamental objective “Keep his Troops Alive” is specified by the lower level objectives: “Minimize Casualties in Soldiers”, “Minimize Casualties in Officers and Team Leaders”, “Minimize Injuries of Soldiers”, and “Minimize Injuries of Officers and Team Leaders”. A single natural attribute for each of these lower level objectives is available. These natural attributes imply that each death or injury is evaluated equally which is appropriate for the given scenario. Collectively, these four attributes are used to measure the degree to which the higher level fundamental objective “Keep his Troops Alive” is achieved. These four attributes are illustrated from Table 14 to Table 17, respectively.

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attributes Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Alive without Injuries</td>
</tr>
<tr>
<td>1</td>
<td>Alive with Minor Injuries</td>
</tr>
<tr>
<td>2</td>
<td>Alive with Major Injuries</td>
</tr>
<tr>
<td>3</td>
<td>Dead</td>
</tr>
</tbody>
</table>

Table 14 Attribute “Number of Casualties in Soldiers”
### Table 15 Attribute “Number of Casualties in Officers and Team Leaders”

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 Dead</td>
</tr>
<tr>
<td>1</td>
<td>1 Dead</td>
</tr>
<tr>
<td>2</td>
<td>2 Dead</td>
</tr>
<tr>
<td>3</td>
<td>3 Dead</td>
</tr>
</tbody>
</table>

### Table 16 Attribute “Number of Injuries of Soldiers”

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 % Injured</td>
</tr>
<tr>
<td>1</td>
<td>1-25% Injured</td>
</tr>
<tr>
<td>2</td>
<td>26-50% Injured</td>
</tr>
<tr>
<td>3</td>
<td>51-75% Injured</td>
</tr>
<tr>
<td>4</td>
<td>76-100% Injured</td>
</tr>
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</table>

### Table 17 Attribute “Number of Injuries of Officers and Team Leaders”

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 Injured</td>
</tr>
<tr>
<td>1</td>
<td>1 Injured</td>
</tr>
<tr>
<td>2</td>
<td>2 Injured</td>
</tr>
<tr>
<td>3</td>
<td>3 Injured</td>
</tr>
</tbody>
</table>
The fundamental objective “Protect Military Assets” is specified by the lower level objectives: “Minimize Total Damages in Light vehicles”, “Minimize Total Damages in Heavy Vehicles”, “Minimize Minor Damages in Light Vehicles”, and “Minimize Minor Damages in Heavy Vehicles”. A single natural attribute for each of these lower level objectives is available. These natural attributes imply that each light vehicle is evaluated equally as each heavy vehicle. This value judgment is appropriate for the given scenario. In the scenario, the light vehicles are the LAVs and the heavy vehicles are the TOWs. Collectively, these four attributes are used to measure the degree to which the higher level fundamental objective “Protect Military Assets” is achieved. These four attributes are illustrated from Table 18 to Table 21, respectively.

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0 % Damaged</td>
</tr>
<tr>
<td>1</td>
<td>1-25% Damaged</td>
</tr>
<tr>
<td>2</td>
<td>26-50% Damaged</td>
</tr>
<tr>
<td>3</td>
<td>51-75% Damaged</td>
</tr>
<tr>
<td>4</td>
<td>76-100% Damaged</td>
</tr>
</tbody>
</table>

Table 18 Attribute “Number of Total Damages in Light Vehicles”
<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 % Damaged</td>
</tr>
<tr>
<td>1</td>
<td>1-25% Damaged</td>
</tr>
<tr>
<td>2</td>
<td>26-50% Damaged</td>
</tr>
<tr>
<td>3</td>
<td>51-75% Damaged</td>
</tr>
<tr>
<td>4</td>
<td>76-100% Damaged</td>
</tr>
</tbody>
</table>

Table 19 Attribute “Number of Total Damages in Heavy Vehicles”

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 % Damaged</td>
</tr>
<tr>
<td>1</td>
<td>1-25% Damaged</td>
</tr>
<tr>
<td>2</td>
<td>26-50% Damaged</td>
</tr>
<tr>
<td>3</td>
<td>51-75% Damaged</td>
</tr>
<tr>
<td>4</td>
<td>76-100% Damaged</td>
</tr>
</tbody>
</table>

Table 20 Attribute “Number of Minor Damages in Light Vehicles”

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 % Damaged</td>
</tr>
<tr>
<td>1</td>
<td>26-50% Damaged</td>
</tr>
<tr>
<td>2</td>
<td>51-75% Damaged</td>
</tr>
<tr>
<td>3</td>
<td>76-100% Damaged</td>
</tr>
</tbody>
</table>

Table 21 Attribute “Number of Minor Damages in Heavy Vehicles”
The complete attribute “Mission Achievement” scale for the objective “Achieve the Main Mission Successfully” is illustrated in Table 22.

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Mission was Perfectly Achieved</td>
</tr>
<tr>
<td></td>
<td>(Recon is Helped)</td>
</tr>
<tr>
<td>1</td>
<td>Mission was Partially Achieved</td>
</tr>
<tr>
<td></td>
<td>(Recon is Partially Helped)</td>
</tr>
<tr>
<td>2</td>
<td>Mission Failed</td>
</tr>
<tr>
<td></td>
<td>(Failed to Help Recon)</td>
</tr>
</tbody>
</table>

Table 22 Attribute “Mission Achievement”

This constructed attribute was developed specifically for the research scenario decision context. Pollard’s mission was to help Lt. Ross’s recon platoon. To avoid ambiguity and to meet the understandability requirement, the meaning of each level of the scale is described as illustrated in Table 22. For example, the meaning of “Mission was Perfectly Achieved” was explained as (Recon was Helped). It was necessary to construct this attribute because there is no natural attribute existed to measure the objective “Achieve the Main Mission successfully”.

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6.2.4 Second in Command Officers

1st Lt. Scott Williams is the second officer in command of Delta Company, and Sergeant Gillispie is second in command for the recon platoon. Due the doctrine nature of the military, their decision models (fundamental objectives hierarchy, mean objectives network, and attributes) are considered the same as the decision models of their commanders. The driving forces to assign weights to the attributes and to the objectives might be different.

6.2.5 Teams Leaders

Sergeant Mike Davis is a team leader in the recon platoon and Sergeant Nick Vitale is a team leader in the Delta Company. Their missions include leading, and motivating soldiers into action to accomplish missions. They serve as the connection point between the commanders and the soldiers.

In considering the team leader (either Sgt. Nick Vitale or Sgt. Mike Davis) values, one considers values significant enough to consider when evaluating decision alternatives. Using this approach a list of a team leader’s objectives, consistent with the decision context (scenario), were derived and are:

- Stay alive.
- Keep the troops alive
- Achieve the assigned mission
- Help other groups
- Achieve implied tasks
- Follow engagement regulations
- Maintain a high situation awareness
• Minimize response time

This list of objectives includes both means objectives and fundamental objectives. Both kinds of objectives were separated by examining each objective on the list (using the WITI test). This was a critical step because the objectives which are important because they help achieve other objectives (means objectives) were separated from the objectives that are important because they reflect what a team leader really wants to accomplish. The results of the effort were the following:

Fundamental objectives:

• Stay alive
• Keep the troops alive
• Achieve the assigned Mission

Means objectives:

• Help other groups
• Achieve implied tasks
• Follow engagement regulations
• Maintain a high situation awareness
• Minimize response time

The fundamental objectives are organized into fundamental objectives hierarchy. The upper levels in the hierarchy represent more general objectives, and the lower-levels explain the important elements of the more general levels (Clemen and Reilly, 2001).

For example, the higher level fundamental objective of “Keep the Troops Alive” has two lower-level fundamental objectives “Minimize Number of Injuries” and “Minimize Number of Casualties” that explain what is meant by the higher level
objective. Each of the lower-level fundamental objectives describes an aspect of keeping the troops alive. Figure 32 displays the fundamental objectives hierarchy for each of the team leaders.

![Fundamental Objectives Hierarchy](image)

Figure 32 Team Leaders, Fundamental Objectives Hierarchy

The means objectives were organized into a network depicting how the means objectives are important to achieve specified fundamental objectives. The fundamental objectives hierarchy and the means objectives network were combined together as shown in Figure 33.
The next step was to derive attributes to measure the achievement of the fundamental objectives. There are four fundamental objectives in the lower level of the hierarchy that need attributes to measure the objectives’ achievements.

For the fundamental objective “Stay Alive”, the outcome related to this objective is either staying alive or dead. Two additional levels are added between these two outcomes. The attribute “Life Status” definition includes a verbal description of the four levels of the objective achievement and a numerical indicator assigned to each level. The complete attribute scale is illustrated in Table 23. Level 0 is defined as the most favorable level and level 3 is defined as the most unfavorable level.
The fundamental objective “Keep the Soldiers Alive” is specified by the lower level objectives: “Minimize Injuries of Soldiers” and “Minimize Casualties in Soldiers”. A single natural attribute for each of these lower level objectives is available. These natural attributes imply that each death or injury is evaluated equally which is appropriate for the given scenario. Collectively, these two attributes are used to measure the degree to which the higher level fundamental objective “Keep the Soldiers Alive” is achieved. These two attribute scales are illustrated in Table 24 and Table 25, respectively.

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Alive without Injuries</td>
</tr>
<tr>
<td>1</td>
<td>Alive with Minor Injuries</td>
</tr>
<tr>
<td>2</td>
<td>Alive with Major Injuries</td>
</tr>
<tr>
<td>3</td>
<td>Dead</td>
</tr>
</tbody>
</table>

Table 23 Attribute “Life Status” for Team Leaders

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 % Injured</td>
</tr>
<tr>
<td>1</td>
<td>1-25% Injured</td>
</tr>
<tr>
<td>2</td>
<td>26-50% Injured</td>
</tr>
<tr>
<td>3</td>
<td>51-75% Injured</td>
</tr>
<tr>
<td>4</td>
<td>76-100% Injured</td>
</tr>
</tbody>
</table>

Table 24 Attribute “Number of Injuries in Soldiers”
<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 % Dead</td>
</tr>
<tr>
<td>1</td>
<td>1-25% Dead</td>
</tr>
<tr>
<td>2</td>
<td>26-50% Dead</td>
</tr>
<tr>
<td>3</td>
<td>51-75% Dead</td>
</tr>
<tr>
<td>4</td>
<td>76-100% Dead</td>
</tr>
</tbody>
</table>

Table 25 Attribute “Number of Casualties in Soldiers”

The complete attribute “Mission Achievement” scale for the objective “Achieve the Assigned Mission” is illustrated in Table 26.

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attribute Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Mission was Perfectly Achieved</td>
</tr>
<tr>
<td>1</td>
<td>Mission was Partially Achieved</td>
</tr>
<tr>
<td>2</td>
<td>Mission Failed</td>
</tr>
</tbody>
</table>

Table 26 Attribute “Assigned Mission Achievement”

This constructed attribute was developed to accommodate the dynamic nature of the scenario decision context facing the team leaders. Their mission was changing along the time horizon of the scenario.
6.2.6 Soldiers

On the battlefield, soldiers make decisions depending on their sense of the state of the battlefield. In fact, most of what infantry soldiers do on the battlefield involve varying degrees of sensing. This includes the specific functions of searching, acquiring and tracking targets. Accordingly, the soldier’s sensed perception of the battlefield plays a critical role in his decision process and resulting actions (Tollefson, Kwin, Martin, Boylan, and Foote, 2004). On the other hand, sometimes constraints apply to the available or derived alternatives which affect the nature of the soldier’s list of objectives. For example, soldiers have constraints on the direction of their movement as decided by their commander. These constraints are often problem or scenario specific.

In considering a soldier’s values, one considers values significant enough to consider when evaluating decision alternatives. Using this approach a list of a soldier’s objectives, consistent with the research decision context (scenario), were derived and are:

- Stay alive.
- Complete assigned personal task.
- Help other soldiers.
- Protect personal weapons.
- Minimize response time.
- Achieve implied tasks.
- Establish good relations with commanders.
- Follow rules of engagement regulations.
- Follow military regulations for safety.
This list of objectives includes both means objectives and fundamental objectives. Both kinds of objectives were separated by examining each objective on the list (using the WITI test). This was a critical step because the objectives which are important because they help achieve other objectives (means objectives) were separated from the objectives that are important because they reflect what a soldier really wants to accomplish. The results of the effort were the following:

Fundamental objectives:

- Stay alive
- Protect personal weapons
- Establish good relations with commanders
- Complete assigned personal task

Means objectives:

- Follow rules of engagement regulations
- Follow military regulations for safety
- Minimize response time
- Help other soldiers
- Achieve implied tasks
The fundamental objectives are organized into a fundamental objectives hierarchy as shown in Figure 34.

![Figure 34 A Soldier, Fundamental Objectives Hierarchy](image)

The means objectives were organized into a network that shows how the means objectives are important to achieve specified fundamental objectives. The fundamental objectives hierarchy and the means objectives network were combined together as shown in Figure 35.

![Figure 35 Fundamental Objectives Hierarchy and Means Objectives Network for a Soldier](image)
The next step was to derive attributes to measure the achievement of the fundamental objectives. There are four fundamental objectives in the lower level of the hierarchy that need attributes to measure the objectives’ achievements.

For the fundamental objective “Stay Alive”, the outcome related to this objective is either staying alive or dead. Two additional levels are added between these two outcomes. The attribute “Life Status” definition includes a verbal description of the four levels of the objective achievement and a numerical indicator assigned to each level. The complete attribute scale is illustrated in Table 27. Level 0 is defined as the most favorable level and level 3 is defined as the most unfavorable level.

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attributes Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Alive without Injuries</td>
</tr>
<tr>
<td>1</td>
<td>Alive with Minor Injuries</td>
</tr>
<tr>
<td>2</td>
<td>Alive with Major Injuries</td>
</tr>
<tr>
<td>3</td>
<td>Dead</td>
</tr>
</tbody>
</table>

Table 27 Attribute “Life Status” for Soldiers

For the fundamental objective “Protect Personal Weapons”, the outcome related to this objective is either the weapon is protected or the weapon is damaged or lost. The attribute “Weapon Status” is illustrated in Table 28.

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attributes Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Protected</td>
</tr>
<tr>
<td>1</td>
<td>Damaged or lost</td>
</tr>
</tbody>
</table>

Table 28 Attribute “Weapon Status”
The complete attribute “Relation Status” scale for the objective “Establish Good Relations with Commanders” is shown in Table 29.

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attributes Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Excellent Relation</td>
</tr>
<tr>
<td></td>
<td>(Compliments is Received)</td>
</tr>
<tr>
<td>1</td>
<td>Neutral</td>
</tr>
<tr>
<td></td>
<td>(Neither Compliments or Complaints is received)</td>
</tr>
<tr>
<td>2</td>
<td>Poor Relation</td>
</tr>
<tr>
<td></td>
<td>(Complaints is received)</td>
</tr>
</tbody>
</table>

Table 29 Attribute “Relation Status”

This constructed attribute was developed specifically for the scenario decision context. There is no natural attribute existed to measure the objective “Establish Good Relations with Commanders”. To avoid ambiguity and to meet the understandability requirement, the meaning of each level is described in Table 29. For example, the meaning of an “excellent” relation is measured as whether a compliment was received, a complaint was received, or neither was received.

The complete attribute “Personal Task Completion” scale for the objective “Complete Assigned Personal Task” is illustrated in Table 30.

<table>
<thead>
<tr>
<th>Attribute Level</th>
<th>Description of Attributes Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Achieved Perfectly</td>
</tr>
<tr>
<td>1</td>
<td>Partially Achieved</td>
</tr>
<tr>
<td>2</td>
<td>Failed</td>
</tr>
</tbody>
</table>

Table 30 Attribute “Personal Task Completion”
This constructed attribute was developed to accommodate the dynamic nature of the scenario decision context that would face a soldier. The soldier’s personal task was changing along the time horizon of the scenario.

6.3 Decision Context: Decision Situation Identification and Alternatives Development

6.3.1 General Discussion

Keeney (1994) defined a decision context as “the set of alternatives appropriate to consider for a specific decision situation”. A decision context is composed of a decision situation and the alternatives appropriate for this situation. However, the decision situation is a description for a course of events with specific considerations. These considerations might be constraints or restrictions. Figure 36 highlights this matter.

![Figure 36 A Decision Context Components](image)

A decision maker must choose a context that captures the decision situation. The considerations in the decision situation must give the decision maker the authority and the available resources to make the decision. If those criteria do not fit the decision situation is incorrectly identified.
Decision situations are created in the normal course of events and by the actions of others (Keeney, 1994). However, not all decisions are created by outside forces. It is worthwhile to transfer a decision problem into a decision opportunity. Decision opportunities occur because of decision maker control over the situation. There are two ways to identify decision opportunities, by either transferring a decision problem into a decision opportunity or by creating a decision opportunity from scratch.

Identifying decision opportunities is applicable to combat. In combat, transferring problems into opportunities is applicable in a defensive act, while creating decision opportunities from scratch is applicable in an offensive act.

The decision maker can take advantage of a decision problem by transferring it into a decision opportunity. A decision opportunity may alleviate the decision problems or avoid future decision problems. Therefore, identifying a decision opportunity is analogous to prevention, while solving a decision problem is analogous to a cure (Kenney, 1994).

Creating a decision opportunity can be established by broadening the decision context. However, broadening the decision context is not always possible in battlefield situations because of the nature of military doctrine. Military doctrine applies constraints to the decision makers and these constraints often narrow the freedom of generating alternatives in order to broaden the decision context.

Identifying a decision context involves a systematic process of developing alternatives and arranging resources and limitations with respect to objectives accomplishment. Working with this, alternatives development is required for decision problems and decision opportunities.
Alternatives in battlefields can usually be defined as action, or a course of actions as the result of estimating the strategic situation. Taking no action is also an action; sometimes taking no action and waiting for the situation to develop is the best action.

Military objectives, and consequently alternatives, require control over resources. Both are influenced by the availability of resources. If alternatives are not compatible with the available resources, then there is a higher risk of not achieving the specified objectives.

A decision maker must determine any limitations to their freedom of action (generating alternatives) which might influence task accomplishment (Achieving objectives). These limitations are constraints. There are two kinds of constraints, either restrictions on resources, or restrictions on the types of alternatives. In a battlefield, the restrictions on resources are barriers like lack of time, troops, weapons, or supplies. The restrictions on the type of alternatives include doctrinal considerations. An example is reconnaissance is not allowed beyond the forward line of troops before midnight. In battlefield, restrictions on resources limit what a decision maker can do, while restrictions on the types of alternatives are things the decision maker can not do.

6.3.2 Scenario Decision Contexts

Four decision situations, and their related considerations, were generated based on the battle of Khafji scenario. The considerations were used to clarify the limitations and constraints of the scenario. A set of alternatives was then developed for each decision situation based on the values of the decision maker and the considerations of the decision situation. Keeney (1994) suggested guidelines to aid developing alternatives. The principle was to develop alternatives that best achieve the decision maker values
specified for the decision context. Each alternative was developed exhibiting the following characteristics:

- **Feasibility:** each alternative must consider and comply with the constraints of the decision situation.
- **Usability:** each alternative must (potentially) perform well with respect to the objectives in the decision model.

Each decision situation along with its alternatives shaped a decision context for each different decision problem. There are four decision contexts considered.

**Decision Context 1:**

Decision maker: Lt. Ross, commander of recon platoon.

Location: The Berm (Recon platoon location).

Time: 8:45 P.M.

Decision situation: at 8:10 P.M. Ross saw enemy tanks heading toward the border. He tried to communicate with headquarters but failed. At 8:20 P.M. he found out that the enemy was jamming their communication capabilities. He tried to repair the radio but it didn’t work.

Considerations:

- The recon platoon consisted of four Humvees and a five-ton truck.
- The recon platoon mission was to observe and report any enemy activity, and to evacuate the area with utmost haste if threatened by a large enough force, where it is Ross’s call to assess the threat level.
• The geography of the platoon location provides a distinct disadvantage; forces approaching the platoon have the benefit of being in a position to fire down upon them.

Alternatives:
• Escape and try to restore communication capability.
• Wait and try to restore communication capability.
• Pull back to horse-shoe berm and try to restore communication capability.
• Pull back to horse-shoe berm and try to restore communication capability. If communication is not restored, send some soldiers back to Delta team.

Decision Situation 2:

Decision makers: Sergeant Mike Davis, Team Leader
L. Corporal Anderson, Soldier
Sergeant Luis Bench, Soldier.

Location: The Berm (Recon platoon location).
Time: 9:00 P.M.

Decision situation: Sergeant Davis received a signal to engage (Wrong interpretation). L. Corporal Anderson and Sergeant Luis Bench are in his team.

Considerations:
• The signal was to pull back to the horse-shoe berm, but Sergeant Davis misinterpreted the signal.

Alternatives for Sergeant Mike Davis:
• Engage the enemy.
• Do not engage the enemy.
Alternatives for L. Corporal Anderson and Sergeant Luis Bench considering that Sergeant Mike Davis the team Leader gave the signal to engage:

- Engage the enemy
- Do not engage the enemy.

**Decision Situation 3:**

Decision maker: Captain Roger “Rock” Pollard, Commander of Delta Company.

Location: 3.7 miles away from recon platoon.

Time: 9:07 P.M.

Situation: Lt. William reported to Capt. Pollard that recon platoon was under fire and had requested Delta’s assistance.

Considerations:

- The Company consists of 19 LAVs and 10 TOWs.
- TOWs had the capability to destroy vehicles out to 3,750 meters. The longest range for enemy tanks was 3,000 meters.
- Pollard had no idea of recon’s deposition (number of soldiers and vehicles).
- Pollard had no idea that recon managed to get air support.

Alternatives:

- Call and wait for air support then move to help recon.
- Move up the company and help recon with the uncertainty of recon disposition.
- Figure out recon’s disposition, and then move up the required soldiers and vehicles to help them.
**Decision Situation 4:**

Decision maker: Sergeant Nick Vitale, TOWs team leader.

Location: 3.5 miles away from recon platoon.

Time: 9:15 P.M.

Situation: Joshua Brierly, the TOW gunner for Green 1 reported an enemy tank 1.8 miles (2900 meters) away from him. Joshua’s vehicle commander reported to Vitale and requested permission to engage. At 9:18 P.M. Joshua’s vehicle commander requested permission to engage again.

Considerations:

- The plan was to stay on safe distance and use Vitale’s TOWs to destroy the enemy tanks.
- Vitale considered how the enemies were 6,000 meters away at one minute and then somewhere less than 3,000 meters the next minute.
- Vitale considered that if the target is an object in the desert rather than an enemy vehicle, firing at it might lead the enemy to observe their movement to the berm.
- Vitale knew Brierly as a good soldier and one of the best in the group at armor identification.

Alternatives:

- Ignore Joshua and wait for further situation development.
- Double check Joshua’s information and act accordingly.
- Clear Firing Order.
6.4 Value Models

6.4.1 General Discussion

Usually, a value model is developed via direct discussion between a decision analyst and the individual whose values are being quantified. The analyst focuses the discussion to elicit information about the value judgments needed for quantifying a decision model (Keeney, 1994). In this research, I will play the role of both, the analyst and the individual. Throughout the research, the entire individual’s (decision maker’s) attitudes toward risk were considered neutral.

After the decision models (fundamental objectives hierarchies, means objectives networks, and attributes) were defined and the alternatives were developed, there was a need to expand the decision models into value models to quantitatively evaluate the competing alternatives.

In all the decision contexts, there is no alternative that yields a best outcome with respect to all the possible outcomes related to all objectives. One alternative may be better achieving an objective while another alternative is better achieving a different objective. A systematic analysis may produce preference for one alternative over its competitors. Thus, tradeoffs among the attributes must be considered to determine the best alternative. The alternatives are ranked only if the attributes are combined into a single index of the overall desirability of an alternative. In other words, there needs to be a general structure to combine the various attributes in some proper manner. Therefore, a single dimensional value functions and weights were determined.
After determining the single dimensional value functions and the weights, the form of the final value function is:

$$v(X_a, ..., X_n) = w_a v_a(X_a) + w_b v_b(X_b) + ... + w_n v_n(X_n)$$

where $X_a, ..., X_n$ are different attributes, $w_a, ..., w_n$ are the weights on the attributes, and $v_a(X_a), ..., v_n(X_n)$ are the single dimensional value functions over each of the attributes. The value function scales to accommodate any number of attributes, $n$.

Using the value model (value function), the alternatives were examined to decide on the alternative to best accomplish the objectives. If none of the alternatives are good, then the best alternative is the best of a poor lot (Kirkwood, 1997).

### 6.4.2 Determining Single Dimensional Value Functions

Piecewise linear single dimensional value functions were determined for the attributes of each decision maker’s fundamental objectives. Each single dimensional value function varies between 0 and 1 over the range of scores of an attribute. Table 31 through Table 34 shows the single dimensional values for the attribute score levels of the decision makers.
<table>
<thead>
<tr>
<th>Attribute</th>
<th>Score</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Status</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.858</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.572</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Number of Casualties in Soldiers</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.858</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.572</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.143</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Number of Casualties in Team Leaders</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Number of Injuries in Soldiers</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.858</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.572</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.143</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Number of Injuries in Team Leaders</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Mission Achievement</td>
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<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 31 Single Dimensional Values for Lt. Ross
<table>
<thead>
<tr>
<th>Attribute</th>
<th>Score</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Status</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.858</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.572</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Number of Casualties in Soldiers</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.858</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.572</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.143</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Number of Casualties in Team Leaders &amp; Officers</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Number of Injuries in Soldiers</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.858</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.572</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.143</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
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<tr>
<td>Number of Injuries in Team Leaders</td>
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<td>1</td>
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<tr>
<td></td>
<td>1</td>
<td>0.75</td>
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<td>0.5</td>
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<tr>
<td></td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Number of Total Damages in Light Vehicles</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.858</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.572</td>
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<tr>
<td></td>
<td>3</td>
<td>0.143</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Number of Total Damages in Heavy Vehicles</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.875</td>
</tr>
<tr>
<td></td>
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<td>0.625</td>
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<td></td>
<td>3</td>
<td>0.125</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Number of Minor Damages in Light Vehicles</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.858</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.715</td>
</tr>
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<td></td>
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<td>0.286</td>
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<td>4</td>
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</tr>
<tr>
<td>Number of Minor Damages in Heavy Vehicles</td>
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</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Mission Achievement</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 32 Single Dimensional Values for Captain Pollard
### Table 33 Single Dimensional Values for a Team Leader

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Score</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Status</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.858</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.429</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Number of Injuries in Soldiers</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.875</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.625</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Number of Casualties in Soldiers</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Assigned Mission Achievement</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

6.4.3 Assigning Weights

There are always some attributes that are more important than others. Thus, weights on different attributes for each decision maker were assigned as illustrated from Table 35 to Table 38.
The weight of an attribute is equal to the increment in value received when moving the score on that attribute from the least preferred level to the most preferred level.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Status</td>
<td>0.15</td>
</tr>
<tr>
<td>Number of Casualties in Soldiers</td>
<td>0.20</td>
</tr>
<tr>
<td>Number of Casualties in Team Leaders</td>
<td>0.20</td>
</tr>
<tr>
<td>Number of Injuries in Soldiers</td>
<td>0.15</td>
</tr>
<tr>
<td>Number of Injuries in Team Leaders</td>
<td>0.15</td>
</tr>
<tr>
<td>Mission Achievement</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Table 35 Weights for Lt. Ross Objectives’ Attributes

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Status</td>
<td>0.10</td>
</tr>
<tr>
<td>Number of Casualties in Soldiers</td>
<td>0.10</td>
</tr>
<tr>
<td>Number of Casualties in Officers and Team Leaders</td>
<td>0.15</td>
</tr>
<tr>
<td>Number of Injuries in Soldiers</td>
<td>0.05</td>
</tr>
<tr>
<td>Number of Injuries in Officers and Team Leaders</td>
<td>0.10</td>
</tr>
<tr>
<td>Number of Total Damages in Light Vehicles</td>
<td>0.10</td>
</tr>
<tr>
<td>Number of Total Damages in Heavy Vehicles</td>
<td>0.10</td>
</tr>
<tr>
<td>Number of Minor Damages in Light Vehicles</td>
<td>0.05</td>
</tr>
<tr>
<td>Number of Minor Damages in Heavy Vehicles</td>
<td>0.05</td>
</tr>
<tr>
<td>Mission Achievement</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Table 36 Weights for Captain Pollard Objectives’ Attributes
<table>
<thead>
<tr>
<th>Attributes</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Status</td>
<td>0.3</td>
</tr>
<tr>
<td>Number of Injuries in Soldiers</td>
<td>0.2</td>
</tr>
<tr>
<td>Number of Casualties in Soldiers</td>
<td>0.3</td>
</tr>
<tr>
<td>Assigned Mission Achievement</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Table 37 Weights for the Team Leaders Objectives’ Attributes

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Status</td>
<td>0.4</td>
</tr>
<tr>
<td>Personal Weapon Status</td>
<td>0.2</td>
</tr>
<tr>
<td>Relation Status</td>
<td>0.1</td>
</tr>
<tr>
<td>Personal Task Completion</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 38 Weights for a Soldier Objectives’ Attributes

6.4.4 Assigning Probabilities

Decision makers assign probabilities to the outcome of an alternative related to each attribute. Kirkwood (1997) reported general procedures and considerations in electing probabilities. Table 39 to Table 42 shows the probability of yielding a certain score on the attribute scale when a certain alternative is chosen, and the single dimensional value of that score. Table 39 to Table 42 corresponds to decision context 1 through decision context 4, respectively.

Decision Context 1:

Table 39 shows the probability of yielding a certain score on the attribute scale when a certain alternative is chosen, and the single dimensional value of that score. For
example, Alternative 1 has a 0.90 probability of having a score of 0 and a 0.10 probability of having a score of 1 for the life status attribute. A score of 0 has a single dimensional value of 1 and a score of 1 has a single dimensional value of 0.858.

Alternatives:

- Alternative 1: Escape and try to restore communication capability.
- Alternative 2: Wait and try to restore communication capability.
- Alternative 3: Pull back to horse-shoe berm and try to restore communication capability.
- Alternative 4: Pull back to horse-shoe berm and try to restore communication capability. If communication is not restored, send few soldiers back to Delta team.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Alternatives</th>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
<th>Alternative 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Status</td>
<td>Prop.</td>
<td>0.90</td>
<td>0.10</td>
<td>0.25</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Score</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Value</td>
<td>1</td>
<td>0.85</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>Number of Casualties in Soldiers</td>
<td>Prop.</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Score</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Value</td>
<td>0.85</td>
<td>0.57</td>
<td>0.57</td>
<td>0.57</td>
</tr>
<tr>
<td>Number of Casualties in Team Leaders</td>
<td>Prop.</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Score</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Value</td>
<td>0.75</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Number of Injuries in Soldiers</td>
<td>Prop.</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Score</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Value</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>Number of Injuries in Team Leaders</td>
<td>Prop.</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Score</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Value</td>
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<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Mission Achievement</td>
<td>Prop.</td>
<td>0.75</td>
<td>0.25</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Score</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Value</td>
<td>1</td>
<td>0.66</td>
<td>0.66</td>
<td>0.66</td>
</tr>
</tbody>
</table>

Table 39 Probabilities and Single Dimensional Values for Decision Context 1
Alternatives
Decision Context 2:

Table 40 shows the probability of yielding a certain score on the attribute scale when a certain alternative is chosen, and the single dimensional value of that score. For example, Alternative 2 has a 0.7 probability of having a score of 3 and a 0.3 probability of having a score of 1 for the life status attribute of Sergeant Mike Davis. A score of 3 has a single dimensional value of 0 and a score of 1 has a single dimensional value of .858 on that attribute. The same table interpretation is applied for the soldier portion of the table.

Alternatives:

Alternatives for Sergeant Mike Davis:

- Alternative 1: Engage the enemy.
- Alternative 2: Do not engage the enemy.

Alternatives for L. Corporal Anderson and Sergeant Luis Bench considering that Sergeant Mike Davis, the team Leader, gave the signal to engage:

- Alternative 1: Engage the enemy
- Alternative 2: Do not engage the enemy.
### Decision Context 3:

Table 41 shows the probability of yielding a certain score on the attribute scale when a certain alternative is chosen, and the single dimensional value of that score. For example, Alternative 1 has a 1.00 probability of having a score of 0. A score of 0 has a single dimensional value of 1 on that attribute.

Alternatives:
- Alternative 1: Call and wait for air support then move to help recon.

<table>
<thead>
<tr>
<th>Decision Maker</th>
<th>Attributes</th>
<th>Alternatives</th>
<th>Alternative 1</th>
<th>Alternative 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sergeant Mike Davis</td>
<td>Number of Injuries in Soldiers</td>
<td>Prop</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Score</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value</td>
<td>0</td>
<td>0.858</td>
</tr>
<tr>
<td></td>
<td>Number of Casualties in Soldiers</td>
<td>Prop</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Score</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Assigned Mission Achievement</td>
<td>Prop</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Score</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value</td>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Life Status</td>
<td>Prop</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Score</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value</td>
<td>0</td>
<td>0.858</td>
</tr>
<tr>
<td></td>
<td>Personal Weapon Status</td>
<td>Prop</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Score</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Relation status</td>
<td>Prop</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Score</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Personal Task Completion</td>
<td>Prop</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Score</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Value</td>
<td>0.5</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 40 Probabilities and Single Dimensional Values for Decision Context 4 Alternatives
- Alternative 2: Move up the company and help recon with the uncertainty of recon deposition.
- Alternative 3: Figure out recon’s deposition, and then move up the required soldiers and vehicles to help them.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Life Status</th>
<th>Number of Casualties in Soldiers</th>
<th>Number of Casualties in Team Leaders &amp; Officers</th>
<th>Number of Injuries in Soldiers</th>
<th>Number of Injuries in Team Leaders &amp; Officers</th>
<th>Number of Total Damages in Light Vehicles</th>
<th>Number of Total Damages in Heavy Vehicles</th>
<th>Number of Minor Damages in Light Vehicles</th>
<th>Number of Minor Damages in Heavy Vehicles</th>
<th>Mission Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Status</td>
<td>Value</td>
<td>Prop.</td>
<td>Score</td>
<td>Value</td>
<td>Prop.</td>
<td>Score</td>
<td>Value</td>
<td>Prop.</td>
<td>Score</td>
<td>Value</td>
</tr>
<tr>
<td>Prop.</td>
<td>1</td>
<td>1</td>
<td>0.2</td>
<td>1</td>
<td>0.858</td>
<td>0.2</td>
<td>0.858</td>
<td>0.5</td>
<td>0.75</td>
<td>0.858</td>
</tr>
<tr>
<td>Score</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td>1</td>
<td>0.858</td>
<td>0.3</td>
<td>0.858</td>
<td>1</td>
<td>0.75</td>
<td>0.858</td>
</tr>
<tr>
<td>Value</td>
<td>1</td>
<td>1</td>
<td>0.8</td>
<td>1</td>
<td>1.0, 0.858</td>
<td>0.8</td>
<td>1.0, 0.858</td>
<td>1</td>
<td>0.75</td>
<td>1.0, 0.858</td>
</tr>
<tr>
<td>Number of Casualties in Soldiers</td>
<td>Prop.</td>
<td>0.8</td>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
<td>0.2</td>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Score</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Value</td>
<td>1</td>
<td>0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
</tr>
<tr>
<td>Number of Casualties in Team Leaders &amp; Officers</td>
<td>Prop.</td>
<td>0.8</td>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
<td>0.2</td>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Score</td>
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<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Value</td>
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<td>1.0, 0.75</td>
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<td>1.0, 0.75</td>
<td>1.0, 0.75</td>
<td>1.0, 0.75</td>
<td>1.0, 0.75</td>
<td>1.0, 0.75</td>
</tr>
<tr>
<td>Number of Injuries in Soldiers</td>
<td>Prop.</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0.4</td>
<td>0.6</td>
<td>0.4</td>
<td>0.6</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Score</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Value</td>
<td>1</td>
<td>0.858</td>
<td>0.858</td>
<td>0.858</td>
<td>1.0, 0.858</td>
<td>0.858</td>
<td>1.0, 0.858</td>
<td>0.858</td>
<td>1.0, 0.858</td>
<td>0.858</td>
</tr>
<tr>
<td>Number of Injuries in Team Leaders &amp; Officers</td>
<td>Prop.</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
<td>0.4</td>
<td>0.6</td>
<td>0.4</td>
<td>0.6</td>
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<td>0.6</td>
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<tr>
<td>Score</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Value</td>
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<td>0.75</td>
<td>0.75</td>
<td>1.0, 0.75</td>
<td>0.75</td>
<td>1.0, 0.75</td>
<td>0.75</td>
<td>1.0, 0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Number of Total Damages in Light Vehicles</td>
<td>Prop.</td>
<td>0.9</td>
<td>0.1</td>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Score</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Value</td>
<td>1</td>
<td>0.858</td>
<td>0.858</td>
<td>1.0, 0.858</td>
<td>0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
</tr>
<tr>
<td>Number of Total Damages in Heavy Vehicles</td>
<td>Prop.</td>
<td>0.8</td>
<td>0.2</td>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Score</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Value</td>
<td>1</td>
<td>0.858</td>
<td>1.0, 0.858</td>
<td>0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
</tr>
<tr>
<td>Number of Minor Damages in Light Vehicles</td>
<td>Prop.</td>
<td>0.8</td>
<td>0.2</td>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Score</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Value</td>
<td>1</td>
<td>0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
<td>1.0, 0.858</td>
</tr>
<tr>
<td>Number of Minor Damages in Heavy Vehicles</td>
<td>Prop.</td>
<td>0.8</td>
<td>0.2</td>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Score</td>
<td>0</td>
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<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Value</td>
<td>1</td>
<td>0.834</td>
<td>1.0, 0.834</td>
<td>0.834</td>
<td>1.0, 0.834</td>
<td>1.0, 0.834</td>
<td>1.0, 0.834</td>
<td>1.0, 0.834</td>
<td>1.0, 0.834</td>
<td>1.0, 0.834</td>
</tr>
<tr>
<td>Mission Achievement</td>
<td>Prop.</td>
<td>0.8</td>
<td>0.1</td>
<td>0.15</td>
<td>0.15</td>
<td>0.8</td>
<td>0.1</td>
<td>0.8</td>
<td>0.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Score</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Value</td>
<td>1</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Table 41 Probabilities and Single Dimensional Values for Decision Context 3 Alternatives

156
Decision Context 4:

Table 42 shows the probability of yielding a certain score on the attribute scale when a certain alternative is chosen, and the single dimensional value of that score. For example, Alternative 1 has a 0.3 probability of having a score of 0, a 0.35 probability of having a score of 2, and a 0.35 probability of having a score of 3 for the life status attribute. A score of 0 has a single dimensional value of 1, a score of 2 has a single dimensional value of 0.429 and a score of 3 has a single dimensional value of 0 on that attribute.

Alternatives:

- Ignore Joshua and wait for further situation development.
- Double check Joshua’s information and act accordingly.
- Clear Firing Order.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Life Status</th>
<th>Number of Injuries in Soldiers</th>
<th>Number of Casualties in Soldiers</th>
<th>Assigned Mission Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prop.</td>
<td>.3</td>
<td>.35</td>
<td>.35</td>
</tr>
<tr>
<td></td>
<td>Score</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Value</td>
<td>1</td>
<td>.429</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 42 Probabilities and Single Dimensional Values for Decision Context 4 Alternatives
6.4.5 Evaluating Alternatives

Usually, military leaders intuitively assign advantages and disadvantages for each course of action (Alternative) to objectively and logically analyze the advantages and the disadvantages of each alternative against the advantages and disadvantages of the others (Leading Situations, 2006). This procedure does not yield the best alternative always. Sometimes, the alternative with the most advantages or the fewest disadvantages is not the best alternative to achieve the objectives.

Using the value model (value function) the alternatives were evaluated to suggest the alternative that best accomplish the objectives. The expected value was calculated for each alternative in each decision context using the following function:

\[
\text{Expected Value} = E[v(X_a, \ldots, X_c)] = P_a w_a v_a(X_a) + P_b w_b v_b(X_b) + \ldots + P_n w_n v_n(X_n)
\]

where \(P_a, \ldots, P_c\) are the probabilities of the attribute level (certain outcome) occurrence when a certain alternative is selected.

6.4.6 Results

Using the expected value analysis, the value number of each alternative is shown in Table 43.

The procedure is specified so that an alternative that has the least preferred level on all of the attributes will have a value of zero. Similarly, an alternative that has the most preferred level on all of the attributes will have a value of one. The value number for a certain alternative gives the proportion of distance, in a value sense, that the alternative is from the alternative with a value of zero to the alternative with a value of one.
Table 43 Decision Context Solutions (Evaluating Alternatives)

**Decision context 1:**

The analysis shows that for decision context 1 alternative 4 was the best available alternative among the others. Alternative 4 was to pull back to the horse-shoe berm and to try to restore the communication capability and then send a few soldiers back to Delta team if communication was not restored. This alternative was compatible with the scenario decision; Lt. Ross ordered Gillispie to signal the platoon to move back to the horseshoe.

**Decision context 2:**

The analysis shows that for decision context 2 alternative 2 was the best available alternative among the others for the decision context of Sgt. Mike Davis. Alternative 2 was not to engage the enemy. In the scenario, Sgt. Davis engaged the enemy with his platoon.
For a soldier, the analysis shows that alternative 1 was the best available alternative among the others. Alternative 1 was to engage the enemy. In the scenario, the soldiers engaged the enemy.

**Decision context 3:**

The analysis shows that for decision context 3 alternative 1 was the best available alternative among the other alternatives. Alternative 1 was to call and wait for air support before going to help recon. If the decision maker (Captain Pollard) was aware of the incoming air support, so this alternative would not been considered neither evaluated. The best alternative in this case is alternative 3, figure out recon’s deposition and then move up the required soldiers and vehicles to help them, which is rated the second preferred after alternative 1.

The decision maker (Captain Pollard), in the scenario, took 12 LAVs and 5 TOWs and planned to stay on a safe distance to use Vitale’s TOWs to destroy the enemy tanks. His decision was compatible with alternative 3.

**Decision context 4:**

The analysis showed that for decision context 4 alternative 2 was the best available alternative among the other alternatives. Alternative 2 was to double check Joshua’s information and act accordingly. The decision maker in the scenario cleared an order to fire even though his double check turned out to contradict Joshua’s information.
6.5 Summary

Decision analysis provides a practical approach to a quantitative analysis of decisions under uncertainty (Kirkwood, 1992). Value focused-thinking decision analysis focuses on how to study decision making on the basis of the decision maker’s values. The flow chart in Figure 37 presents a decision analysis process for modeling combat situations.

Figure 37 Decision Analysis Process for Combat situations
The process in Figure 37 is compatible with the five activities of value-focused thinking decision analysis presented in Table 2.

First, a generic decision model (fundamental objectives hierarchy, means objectives network, and attributes) is developed for a decision maker in a combat scenario. Then, the scenario is divided into decision situations. The decision model (fundamental objectives hierarchy, means objectives network, and attributes) should be compatible with each decision situation, or the decision model would be edited to accommodate the decision situation requirements.

A battlefield decision making is a dynamic multi-objective decision making problem. A future decision may depend on what happened before even if what happened before was unexpected. This dynamic nature is transferred to a set of static decision situations. Each decision situation is composed of course of events and considerations. The considerations might contain and capture the previous decision outcome making each decision situation a single decision problem on its own.

A set of alternatives is developed after identifying the decision situation that is compatible with the decision model. Finally, a value model is developed for each decision context to evaluate alternatives.
CHAPTER 7

INFORMATION AND RELIABILITY OF INFORMATION MODEL

7.1 General Discussion

Obtaining and controlling information has been, and will continue to be, critical in the conduct of warfare (Deckro, 2001). Information is a critical part of military operations, has been since the earliest days of organized combat and has continued in criticality through the current days of modern army. It is critically important to include models of combat information in designing and evaluating any combat decision making process and devising tactics for employment. Little has been done to establish a clear relationship between information and the outcome of military operations or combat (Perry, 2000).

In a battlefield, a commander’s courses of actions (alternatives) are derived after identifying the problem and gathering information. A decision maker in a battlefield encounters a dynamic information environment. During combat, individuals gather information from a variety of sources, other individuals or the environment, and then determine what information is reliable and useful, and what information is not. This information is an input to their internal decision model. Actually, this information introduces the decision situation to the decision maker. The information may be incomplete, excessive, and subjective. If decision makers are given false information, it may lead them to incorrect problem identification and therefore to inadequate or inappropriate decisions. Similarly, if the decision maker misinterprets the information, they may identify the wrong decision situation and therefore develop inadequate or inappropriate decisions.
The value of information in the battlefield degrades temporally. An example is the information sent to aircraft to attack a certain mobile target. By the time the aircraft are in a position to act on that information, the information may no longer be as precise or as valuable. The information was not wrong, but temporally it was no longer precise or useful enough, since the target might be on a significant distance from its original location. This degradation process forces decision makers to make and execute decisions within the constraints of a fixed time frame window. The probability of information usefulness degradation along time can be modeled using reliability concepts, but has yet to be so modeled. Delaying the information can also be costly. On October 22\textsuperscript{nd} 2000, ten days after the explosion aboard the USS Cole in Yemen, General Tommy Franks briefed the Senate Armed Services Committee. He was explaining why the Cole had been in Yemen even though there was intelligence that the risk was high that day. He described the decision making process and noted that the information was not received aboard the Cole until after the ship had been attacked (Franks, 2004).

Reliability studies are of interest to the military. The technological advances in equipment create integration issues as well as special maintenance and repair issues. Therefore, it is essential to model equipment reliability. For example, Thomas (2004) presented a method for determining the reliability of a logistics network for supporting contingency operations. The method was based on the interference of random load and capacity of the distribution links of a supply chain. Conditions of risk are considered using various assumed distributions, and uncertainty based on maximum entropy distributions.
Although there are a good deal of research and models in the reliability area, current studies and models do not model the reliability of information and fail to explicitly link decision making and information models. This is a concern given there is a clear correlation between the decision making process and the information feeding that process. In this chapter, battlefield information is defined, a new reliability of information concept is defined and developed, and then the concept is applied to the battle of Khafji decision situation scenario to develop information models that capture the decision makers’ information.

7.2 Battlefield information

Information in the battlefield can be defined as what is transmitted from an event to a decision maker. The transmitted information is what subsequently shapes the decision process. Since the definition specifies an event as the source of information, an event might be sensed directly by the decision maker whose decision problem is being addressed or might be sensed by another individual who then transmits the information to the decision maker whose decision problem is being addressed. In other words, the information can be transmitted indirectly or directly from the event to the decision maker.

Battlefield information possesses several attributes: accuracy, completeness, precision, and relevancy. Following are some definitions of these information attributes (adapted from Hamill, et al., 2002).

- **Accuracy**: information that conveys the true situation.
- **Completeness**: all necessary information required to cover the situation.
- **Precision**: information that has the required level of details.
- **Relevancy**: information that applies to the mission, task, or situation at hand.
The accuracy, completeness, and precision attributes are considered a subset of quality information, while the relevancy attribute is considered a subset of valuable information. Figure 38 highlights this matter.

Figure 38 Information Attributes

7.3 Reliability of Information

There are two meanings for the word “Reliability”. The first meaning is a common language scene of “reliable” as something that can be counted on. The second meaning is the technical version found in the mathematical theory of reliability and reliability engineering: the probability that an item continues to function as is intended as time passes (Tortorella and Driscoll, 2005). Reliability engineering is a relatively new discipline. The increased degree of complexity in technology is a key factor in the growth of the reliability engineering field.

The reliability concept assumes that failures will occur randomly over time. This random process can be modeled using probability distributions, where the failure events or the non-failure events can be predicted statistically. Probabilistic models are used to model many military systems. For example, Aviv and Kress (1997) presented the use of probabilistic models to represent Shoot-Look-Shoot (SLS) tactics for a single shooter.
Shoot-Look-Shoot (SLS) is a firing tactic which includes firing, damage assessing and subsequent firing. For a single shooter, the tactic represents sequential engagements where the shooter may occasionally assess the damage inflicted on a certain target before acquiring and shooting again at previous or alternative targets. Aviv and Kress defined effectiveness criteria for the SLS tactics and constructed representative probabilistic models. The efficiency of the SLS tactic was evaluated in situations where the availability of damage information is not certain. The evaluations were performed with respect to the expected number of kills criterion.

This section reviews literature and approaches used to model the reliability of information based on the available literature of modeling the reliability of physical components and systems.

### 7.3.1 Reliability of Information Definition

Reliability as defined in Ebeling (1997) is “The probability that a component or system will perform a required function for a given period of time when used under stated operating conditions”. This definition is applied to physical components or systems.

Working with Ebeling’s (1997) definition, the reliability of information can be defined as “the probability that the data/information sensed by the decision maker will keep a value (the value that makes it useful) for a given period of time before it loses its usefulness, under stated conditions”. Information reliability is the probability of non-failure of the information value over time.

The cognition of information conveyed depends upon the abilities of the receiving decision maker. This human process further depends on the circumstances of the
situation, as well as the personality, training, and experience of the decision maker (Shupenus and Barr, 1999). Working with the reliability of information definition, we find, it is applicable to situations where the information is correctly interpreted when sensed by the decision maker, while it is not applicable to the situations where the information is misinterpreted by the decision maker. In other words, the correct interpretation of information by the decision maker is a stated condition to make the definition of the concept applicable. Also, it is assumed that there is no deterioration or distortion as the information passes through from its origin to the decision maker.

Information in the battlefield possesses two main attributes: value and quality. Information has value if it adds new significant information to the decision maker to enhance his knowledge of the combat situation. On the other hand, information quality depends on the accuracy, precision, and the completeness of that information. The quality of information is related to the quality of the source of this information. A source of high quality will likely deliver high quality information while a source of low quality will likely deliver low quality information.

Valuable information is not always of high quality. For example, a commander might receive information (valuable information) about the location of an enemy unit. This information is valuable, but might be inaccurate (low quality). Conversely, high quality information might have no value. For example, a commander might receive information about the result of another battle that took place out of his unit control radius; in this case, the information is of high quality but has no value for the decision maker.

The definition of reliability of information is applicable whether the information is of a high quality or low quality as long as the information has value. The valuable
information is information that can withstand a large amount of error and can positively contribute to the decision maker knowledge. On the other hand, the concept is not applicable to information that is not valuable regardless whether this is due to irrelevancy or misinterpretation of the information.

Table 44 highlights the situations where the reliability of information concept is applicable or not applicable.

<table>
<thead>
<tr>
<th>Reliability of Information</th>
<th>Applicable to</th>
<th>Not Applicable to</th>
</tr>
</thead>
<tbody>
<tr>
<td>- High quality valuable information</td>
<td>- Low quality valuable information</td>
<td>- Not valuable (irrelevant or misinterpreted) information whether its of a high quality or low quality</td>
</tr>
</tbody>
</table>

Table 44 Reliability of Information Applicability

7.3.2 Reliability of Information Concept

The reliability of information addresses the probability of information usefulness over time. The value of the information degrades along time as does the probability of usefulness degrades along time. The reliability concept does not really model the degradation of the information value along time; it really models the probability of the usefulness of information along time. In other words, the reliability of information concept looks at the value of information as either valuable or not valuable at a certain point in time without capturing the value of the information itself. This value is neither modeled nor recorded. For example, the value of information might be \( x \) at time \( t_1 \), and then its value might be \( \frac{x}{2} \) at time \( t_2 \). The reliability of information examines the
probability of the usefulness (valuable to the decision maker) of that information at time $t_1$ or at time $t_2$ whether the value of information was ($x$) or \( \left( \frac{x}{2} \right) \).

In this research, at any time the decision maker receives a single piece of information that shapes his decision situation, they are not required to rank or prioritize the information.

Ebeling (1997) discussed three requirements to determine reliability in an operational sense:

- First, the definition of failure must be made specific by establishing an unambiguous description of the failures; the failure must be defined relative to the system performed function.
- Second, the unit of time must be specified.
- Third, the system should be observed under normal performance.

Applying these requirements to the reliability of information concept, failure is described as the case where the information is not useful or has no value to the decision situation. The unit of time along the degradation process is specified according to each decision situation. Finally, the normal performance condition is illustrated by the condition of the right interpretation of the relevant information.

As mentioned earlier, the reliability of information is defined as “the probability that the data/information sensed by the decision maker will keep a value (the value that makes it useful) for a given period of time before it loses its usefulness, under stated conditions”, or the probability of non-failure of the information value over time.

Mathematically,

$$ R(t) = P(T \geq t) $$

(1)
where $T \geq 0$ is a continuous random variable representing the time to information failure.

For a given value of time ($t$), the reliability is the probability that the time to failure ($T$) is greater than or equal to that given value of time ($t$). $R(t)$ is a probability and hence the usual axioms of probability hold,

$$R(t) \geq 0, \quad R(0) = 1, \quad \text{and} \quad \lim_{t \to \infty} R(t) = 0.$$ 

The reliability of information is a positive number between 0 and 1. The reliability of information at $t = 0$ ($t_o$, time when the information was sensed by the decision maker) is always 1, so the probability of valuable or useful information is always 1 when the information is first received by the decision maker given that it is relevant and correctly interpreted when received. Finally, the reliability of information approaches zero as the time approaches $\infty$.

Define $F(t)$ to be the probability that a failure occurs before time $t$,

$$F(t) = 1 - R(t) = P[T < t] \quad (2)$$

and

$$f(t) = \frac{dF(t)}{dt} \quad \text{or} \quad f(t) = -\frac{dR(t)}{dt}. \quad (3)$$

$F(t)$ is the cumulative distribution function (CDF) of the failure distribution, and $f(t)$ is the probability density function (PDF) of the failure distribution.

The failure rate, or hazard rate function, provides an instantaneous (at time $t$) rate of failure (Ebeling, 1997).

$$\lambda(t) = \frac{dR(t)}{dt} = \frac{1}{R(t)} \cdot \frac{f(t)}{R(t)}. $$ \quad (4)

Since the reliability of information degrades over time, the Weibull distribution is selected as the mathematical distribution to initially model the reliability of
information. The Weibull distribution is one of the most powerful probability distributions in reliability. It is used to model both increasing and decreasing failure rates. Other distributions are useful too such as the normal distribution which used to model the fatigue and wear out phenomena, or the right triangular distributions. The weibull is chosen because of its flexibility and the ease of controlling its parameters. The four reliability functions in equations (1) to (4) are expressed, respectively, as the following:

\[ R(t) = e^{-(t/\theta)^\beta} , \quad (5) \]

\[ F(t) = 1 - e^{-(t/\theta)^\beta} , \quad (6) \]

\[ f(t) = -\frac{\beta}{\theta} \left( \frac{t}{\theta} \right)^{\beta-1} e^{-(t/\theta)^\beta} , \quad (7) \]

and \( \lambda(t) = \frac{\beta}{\theta} \left( \frac{t}{\theta} \right)^{\beta-1} , \) where \( \theta > 0, \beta > 0, t \geq 0 \). \quad (8) \]

Beta (\( \beta \)) is called the shape parameter as it determines the shape of the failure distribution. Theta (\( \theta \)) is called the scale parameter or the characteristic life and effects the mean and the spread of the distribution.

The mean time to failure (MTTF) and the variance for a Weibull distribution is given as follows:

\[ \text{MTTF} = \theta \Gamma\left(1 + \frac{1}{\beta}\right) \quad (9) \]

\[ \sigma^2 = \theta^2 \left\{ \frac{1}{\Gamma\left(1 + \frac{2}{\beta}\right)} - \left[ \frac{1}{\Gamma\left(1 + \frac{1}{\beta}\right)} \right]^2 \right\} \quad (10) \]

where \( \Gamma(x) \) is defined to be an extension of the factorial to complex and real number arguments. The median time to failure is given using the following formula:
\[ t_{med} = \theta(-\ln 0.5)^{1/\beta} \]  

(11)

### 7.3.3 Reliability of Information Application

The reliability of information concept can be used to model the information used by decision makers in a battlefield decision making situation.

A reliability function is fit to each decision situation scenario considering that the distribution starts at \( t_o \) (when the information was sensed by the decision maker) and ends at \( t_\infty \) (when the information fails or has no value). The procedure is the following:

- Consider a Weibull distribution as a mathematical form for the hazard rate function and the other reliability functions.
- Assign \( t_o \) where the information was sensed by the decision maker.
- Assume a value for \( \beta \) in a logical manner. A convex hazard rate function distribution as in Figure 39 fits a decision situation with fast dynamic events. The hazard rate function of a fast dynamic decision situation increases in an increasing rate. The value of \( \beta \) that satisfies this is \( 2 \leq \beta \leq 3 \).

![Figure 39 Convex Hazard Rate Function](image)
A convex hazard rate function distribution as in Figure 40 fits a decision situation with slower, more stable events. The hazard rate function of a slower decision situation increases in a decreasing rate. The value of $\beta$ that satisfies this is $1 < \beta < 2$.

![Figure 40 Concave Hazard Rate Function](image)

Table 45 adapted from (Ebeling, 1997) summarizes the effect of varied values of $\beta$ on the failure rate distribution.

<table>
<thead>
<tr>
<th>Event</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 \leq \beta &lt; 1$</td>
<td>Decreasing failure rate</td>
</tr>
<tr>
<td>$\beta = 1$</td>
<td>Exponential distribution</td>
</tr>
<tr>
<td></td>
<td>Constant Failure Rate</td>
</tr>
<tr>
<td>$1 &lt; \beta &lt; 2$</td>
<td>Increasing failure rate</td>
</tr>
<tr>
<td></td>
<td>(Concave)</td>
</tr>
<tr>
<td>$\beta = 2$</td>
<td>Rayleigh distribution</td>
</tr>
<tr>
<td>$\beta &gt; 2$</td>
<td>Increasing failure rate</td>
</tr>
<tr>
<td></td>
<td>(Convex)</td>
</tr>
<tr>
<td>$3 \leq \beta \leq 4$</td>
<td>Increasing failure rate</td>
</tr>
<tr>
<td></td>
<td>Approaches normal distribution</td>
</tr>
</tbody>
</table>

Table 45 Weibull Shape Parameter effects
• Assume a $t_\infty$, where the reliability of information is almost zero, as the time when
the information have no value, and then find the corresponding value of theta ($\theta$)
using the following equation:

$$\theta = \frac{t_\infty}{\left( -\ln(R(t_\infty)) \right)^\frac{1}{\beta}}$$

(12)

Equation (12) is derived from equation (5).

• Using the values of $\beta$ and $\theta$, fit the reliability distributions.

7.4 Reliability of Information Modeling

Decision makers can assign values for beta ($\beta$) and theta ($\theta$). The parameters
values should be assigned via a direct discussion between the analyst and the decision
maker. The analyst should focus the discussion to elicit information about the values of
the parameters; $\beta$ and $\theta$. The decision maker might not be aware of the nature or the
meaning of $\theta$ and $\beta$ as distribution parameters. The following are questions that might be
asked by the analyst to aid in eliciting the parameters values from the decision maker.

To find the value of $\beta$, the analyst can ask the direct question “Do you expect the
events to be of a fast dynamic nature or of a slow stable nature?” The answer to this
question assigns the value range of $\beta$. The answer to this question is subjective, so a
constructed attribute of the nature of events might be helpful.

To find the value of $\theta$, the decision maker has to estimate the time when the
information fails; the information no longer has value. Using this time in equation (12)
yields $\theta$. The information failure should occur when the decision maker believes the
information in no longer helpful as a means to achieve his objectives. The question for
the decision maker might be “After how many units of time, you expect that the
information will have no value with respect to your objectives?” In order to assign the value of \( \theta \), first assign the failure time according to a base line case. A base line case is the case where no action is taken in response to the information sensed or received. Practically, the decision maker should assign the failure time considering that no action or course of actions was taken after the information was sensed.

7.5 Reliability of Information Models

The reliability of information concept can be applied to model the information for the decision makers in the battle of Khafji scenario. Usually the reliability of information model is developed via direct discussion between the decision maker and a decision analyst. In this research, I will play the role of both, the analyst and the decision maker. The framework of assigning the parameters to develop the reliability of information models was personal military conceptual experience.

While developing the reliability of information model for each decision maker in each decision situation, the information is illustrated, the time unit is specified, and the reliability of information conceptual conditions are considered.

**Decision Situation 1:**

Decision maker: Lt. Ross, commander of recon platoon.

Location: The Berm (Recon platoon location).

Decision situation: At 8:10 P.M. Ross saw enemy tanks heading toward the border. He tried to communicate with headquarters but failed. At 8:20 P.M. he found out that the enemy was jamming their communication capabilities. He tried to repair the radio but it still did not work.
Considerations:

- The recon platoon consisted of four Humvees and a five-ton truck.
- The recon platoon mission was to observe and report any enemy activity, and to evacuate the area with utmost haste if threatened by a large enough force. It was Ross’s call to assess the threat level.
- The geography of the platoon location provided a distinct disadvantage; forces approaching the platoon will have the benefit of being in a position to fire down upon them.

Information: Enemy tanks were heading toward the border while the communication capabilities were not available (Valuable information / High quality).

Time Unit: minutes.

\( t_o = 0 \) minutes (8:20 P.M.)

\( t_w = 80 \) minutes (9:40 P.M.)

\( \beta = 1.5 \)

Assume \( R(80) = 0.009 \). Since the Weibull distribution reaches zero at infinite, 0.9% is considered significantly close to 0% in terms of reliability, but is by no means a unique choice.

Solving for \( \theta \):

\[
\theta = \frac{t}{\left\{-\ln(R(t))\right\}^{1/\beta}} = \frac{80}{\left\{-\ln(0.009)\right\}^{1/1.5}} = 28.5 \text{ minutes.}
\]

The mathematical form of the reliability of information is:

\[
R(t) = e^{-\left(t/28.5\right)^{2.0}}.
\]
Figure 41 displays the reliability of information function $R(t)$ for decision situation 1.

![Figure 41](image)

Figure 41 $R(t)$ for Decision Situation 1

The mathematical form of the cumulative distribution function (CDF) of the failure distribution, $F(t)$, is:

$$F(t) = 1 - e^{-\left(\frac{t}{28.5}\right)^{1.5}}.$$  

Figure 42 displays the cumulative distribution function $F(t)$ for decision situation 1.

![Figure 42](image)

Figure 42 $F(t)$ for decision situation 1

The mathematical form of the probability density function (PDF) of the failure distribution, $f(t)$, is:

$$f(t) = \frac{28.5}{1.5} \left( \frac{t}{28.5} \right)^{0.5} e^{-\left(\frac{t}{28.5}\right)^{1.5}}.$$
Figure 43 displays the probability density function \( f(t) \) for decision situation 1.

![Figure 43 f(t) for decision situation 1](image1)

The mathematical form of the hazard rate function \( \lambda(t) \) is:

\[
\lambda(t) = \frac{1.5}{28.5} \left( \frac{t}{28.5} \right)^{0.5}.
\]

Figure 44 displays the hazard rate function \( \lambda(t) \) for decision situation 1.

![Figure 44 \( \lambda(t) \) for decision situation 1](image2)

The mean time to failure is:

\[
MTTF = \theta \Gamma \left( 1 + \frac{1}{\beta} \right) = 25.7445 \text{ minutes}.
\]
The failure distribution variance is:

\[
\sigma^2 = \theta^2 \left\{ \Gamma \left(1 + \frac{2}{\beta} \right) - \left[ \Gamma \left(1 + \frac{1}{\beta} \right) \right]^2 \right\} = 302.3515171
\]

Another measure of central tendency of the failure distribution is the median time to failure:

\[
t_{med} = \theta (-\ln 0.5)^{1/\beta} = 22.295 \text{ minutes}
\]

**Decision Situation 2:**

Decision makers: Sergeant Mike Davis, Team Leader

Location: The Berm (Recon platoon location).

Decision situation: Sergeant Davis received a signal to engage (Wrong interpretation).

L. Corporal Anderson and Sergeant Bench were in his team.

Considerations:

- The signal was to pull back to the horse-shoe berm, but Sergeant Davis misinterpreted the signal.

Information: The information was in the form of a signal to pull back to the berm.

The decision maker (Sergeant Mike Davis) misinterpreted the information so the reliability of information concept is not applicable to model this information.
**Decision Situation 3:**

Decision maker: Captain Roger “Rock” Pollard, Commander of Delta Company.

Location: 3.7 miles away from recon platoon.

Situation: At 9:07 P.M. Lt. William reported to Capt. Pollard that recon platoon was under fire and requested Delta’s assistance.

Considerations:

- The Company consisted of 19 LAVs and 10 TOWs.
- TOWs had the capability to destroy vehicles out to 3,750 meters. The longest range for enemy tanks was 3,000 meters.
- Pollard had no idea of recon’s deposition (number of soldiers and vehicles).
- Pollard had no idea that recon managed to get air support.

Information: Recon platoon is under fire, and had requested Delta’s assistance (Valuable information / less quality).

Time Unit: minutes.

\( t_0 = 0 \) minutes (9:07 P.M.)

\( t_\infty = 30 \) minutes (9:37 P.M.)

\( \beta = 2.5 \)

Assume \( R(30) = 0.009 \)

Solving for \( \theta \):

\[
\theta = \frac{t}{\left\{-\ln(R(t))\right\}^{1/\beta}} = \frac{30}{\left\{-\ln(0.009)\right\}^{1/2.5}} = 16.14 \text{ minutes}.
\]

The mathematical form of the reliability of information is:

\[
R(t) = e^{-\left(t/16.14\right)^{2.5}}.
\]
Figure 45 displays the reliability of information function $R(t)$ for decision situation 3.

![Figure 45 R(t) for decision situation 3](image)

The mathematical form of the cumulative distribution function (CDF) of the failure distribution, $F(t)$, is:

$$F(t) = 1 - e^{-\frac{1}{16.14}t^{1.5}}.$$

Figure 46 displays the cumulative distribution function $F(t)$ for decision situation 3.

![Figure 46 F(t) for decision situation 3](image)

The mathematical form of the probability density function (PDF) of the failure distribution, $f(t)$, is:

$$f(t) = -\frac{16.14}{2.5} \left( \frac{t}{16.14} \right)^{1.5} e^{-\frac{t}{16.14}}.$$
Figure 47 displays the probability density function $f(t)$ for decision situation 3.

![Figure 47](image)

Figure 47 $f(t)$ for decision situation 3

The mathematical form of the hazard rate function $\lambda(t)$ is:

$$\lambda(t) = \frac{2.5}{16.14} \left( \frac{t}{16.14} \right)^{1.5}.$$  

Figure 48 displays the hazard rate function $\lambda(t)$ for decision situation 3.

![Figure 48](image)

Figure 48 $\lambda(t)$ for decision situation 3

The mean time to failure is:

$$\text{MTTF} = \theta \Gamma \left( 1 + \frac{1}{\beta} \right) = 14.32 \text{ minutes}.$$
The failure distribution variance is:

\[ \sigma^2 = \theta^2 \left[ \Gamma \left( 1 + \frac{2}{\beta} \right) - \left[ \Gamma \left( 1 + \frac{1}{\beta} \right) \right]^2 \right] = 37.55094 \]

Another measure of central tendency of the failure distribution is the median time to failure:

\[ t_{med} = \theta (-\ln 0.5)^{1/\beta} = 13.9391 \text{ minutes.} \]

**Decision Situation 4:**

Decision maker: Sergeant Vitale, TOWs team leader.

Location: 3.5 miles away from recon platoon.

Situation: at 9:15 P.M. Corporal Brierly, the TOW gunner for Green 1 reported an enemy tank 1.8 miles (2900 meters) away. Brierly’s vehicle commander reported to Vitale and requested permission to engage. At 9:18 P.M. Brierly’s vehicle commander requested permission to again engage.

Considerations:

- The plan was to stay a safe distance and use Vitale’s TOWs to destroy the enemy tanks.
- Vitale considered how the enemies were 6,000 meters away at one minute and then somewhere less than 3,000 meters the next minute.
- Vitale considered that if the target is an object in the desert rather than an enemy vehicle, firing at it might lead the enemy to observe their movement to the berm.
- Vitale knew Brierly as a good soldier and one of the best in the group at armor identification.

Information: enemy tank in range (Valuable information / Low quality).
Time Unit: seconds.

\( t_o = 0 \) seconds (9:15 P.M.)

\( t_\infty = 300 \) seconds (9:20 P.M.)

\( \beta = 2.5 \)

Assume \( R(300) = 0.009 \)

Solving for \( \theta \):

\[
\theta = \frac{t}{\left(-\ln(R(t))\right)^{1/\beta}} = \frac{300}{\left(-\ln(0.009)^{1/2.5}\right)} = 161.4 \text{ seconds.}
\]

The mathematical form of the reliability of information is:

\[
R(t) = e^{-(t/161.4)^{2.5}}.
\]

Figure 49 displays the reliability of information function \( R(t) \) for decision situation 4.

![Figure 49](image)

Figure 49 \( R(t) \) for decision situation 4

The mathematical form of the cumulative distribution function (CDF) of the failure distribution, \( F(t) \), is:

\[
F(t) = 1 - e^{-(t/161.4)^{2.5}}.
\]
Figure 50 displays the cumulative distribution function $F(t)$ for decision situation 4.

![Figure 50](image_url)

Figure 50 $F(t)$ for decision situation 4

The mathematical form of the probability density function (PDF) of the failure distribution, $f(t)$, is:

$$f(t) = \frac{161.4}{2.5} \left( \frac{t}{161.4} \right)^{1.5} e^{-\left(\frac{t}{161.4}\right)^{1.5}}.$$

Figure 51 displays the probability density function $f(t)$ for decision situation 4.

![Figure 51](image_url)

Figure 51 $f(t)$ for decision situation 4

The mathematical form of the hazard rate function $\lambda(t)$ is:

$$\lambda(t) = \frac{2.5}{161.4} \left( \frac{t}{161.4} \right)^{1.5}.$$
Figure 52 displays the hazard rate function $\lambda(t)$ for decision situation 4.

The mean time to failure is:

$$MTTF = \theta \left( 1 + \frac{1}{\beta} \right) = 143 \text{ seconds.}$$

The failure distribution variance is:

$$\sigma^2 = \theta^2 \left\{ \left[ \Gamma \left( 1 + \frac{2}{\beta} \right) - \left[ \Gamma \left( 1 + \frac{1}{\beta} \right) \right]^2 \right \} = 3755.09.$$  

Another measure of central tendency of the failure distribution is the median time to failure:

$$t_{med} = \theta (\ln 0.5)^{1/\beta} = 139.39 \text{ seconds.}$$
CHAPTER 8
AN INTEGRATED INFORMATION-BASED, VALUE-FOCUSED THINKING MODEL

8.1 General Discussion

Military decisions are always made based on models. These models might be as simple as a conceptual model in the mind of the decision maker. These conceptual mental models are based on experience and self-confidence. However, as the use of modeling and computer tools have grown, so has the need to employ quantitative and qualitative analysis to build better computational models of the decision making process (Hughes, 1994). The value-focused thinking (VFT) mode is an example of these models. However, the VFT model falls short in capturing some important characteristic of the decision making process in reality, the use of information.

Col. Boyd in 1978 (as referred in Beene, 1998) described the decision cycle in a battlefield context, particularly the decision process of a fighter aircraft pilot. His concept of the Observe-Orient-Decide-Act (O-O-D-A) cycle of decision making has become a standard tool for enunciating the phases on which each decision depends. He models decision makers in a battlefield operating according to the decision structure illustrated in Figure 53.

![Figure 53 Boyd’s Observe-Orient-Decide-Act (O-O-D-A) Loop](image-url)
The Observe phase involves taking in information, such as sensor or intelligence information. The Orient phase involves updating of an internal model of the situation including noting any changes. The Decide phase involves considering each known course of action available to the decision maker in light of the information (or situational assessment) within the decision maker mental model. The Act phase involves putting into action the decided course of action.

Combat can be viewed as a sequence of different events, as was presented in chapter 6. To better model these events there is need to incorporate improved information about men, materials, and engagement processes (Hughes, 1994). A lack of knowledge regarding present states of a situation might have a severe cost in terms of future outcomes.

In reality, the decision maker tries to take the proper action during an event, or after an event has occurred. The VFT modeling captures this picture, but it does not capture other decision making process characteristics such as the decision maker assessing the quality of the information source and the reliability of the information, which in turn shapes his decision problem, before generating and considering alternatives and taking any actions.

In this chapter, an integrated model for capturing the battlefield decision making process is derived. The model is based on value-focused thinking decision making analysis, while assessing the quality of the information source, and incorporating information reliability modeling. This chapter refers to this model as the Integrated Model. The Integrated Model is defined, and then applied to model the battle of Khafji decision situation scenarios.
8.2 Introduction

To make use of the decision modeling techniques for battlefield modeling, information that creates a complete or almost a complete picture of the present situation is needed. The picture requires data regarding the weapons, modes of movement, existing terrain and weather, and location and motion of all physical elements on the battlefield. Even assuming perfect data, there remain uncertainties about the future. What is needed is a modeling process that considers the decision maker’s evaluation of the received information, and produces a methodology for evaluating alternatives based on the decision maker’s objectives (values) and his evaluation of the information.

The Integrated Model presented here was derived based on, and capturing, an aggregate view of the following scenario. The information is sent to the decision maker from variety of sources. This information introduces the decision maker to the decision problem. The decision maker assesses the quality of that information source. A source of high quality will likely deliver high quality information while a source of low quality will likely deliver low quality information. After assessing the quality of the information’s source, the decision maker assesses the reliability of that information. Finally, after assessing the information’s source quality and the information reliability, the decision maker derives alternatives (courses of action) and makes decisions based on his objectives and his assessment of the information’s source quality and information reliability.
8.3 Source Quality $Q_s$

The battlefield is a dynamic environment where events constantly change. Information must not only be provided to the decision maker, but also must be rich enough to overcome the uncertainties and be useful enough to support decision making. The United States Army Field Manual (USA FM, 1996), entitled “Information Operations”, directs commanders and planners to carefully assess the quality of the information sources before its use because the sources of information are imperfect and susceptible to distortion and deception. The source of information in a battlefield might be an individual or an environment source. In some cases, as here, the assessment of quality is subjective. The quality assessment is not an easy process, and is not well defined, especially when assessing the quality of human intelligence sources (HUMINT). The probability distribution provides a good way of modeling the behavior of information along time, but it does not capture the quality of that information source. Current methods of evaluating information sources are subjective and require considerable user expertise (Noble, 2004). The assessment process depends on the skill of the individual, meaning the resulting assessment is proportional to the individual knowledge.

Assessing quality of the information source raises several issues with respect to the decisions the commander might take. If he suspects deception, intentional or unintentional, he may assign less quality to the source of information. If he trusts the source of information, he may assign a higher quality to that source.

A good deal of research to assess the quality of information sources or open information sources (internet) in particular is available. For example, Bovens and Hartmann (2001) developed a probabilistic criterion to assess the reliability (quality) of
information sources. In their research, they stipulate that all information sources are unreliable: more reliable than randomization, but short of being fully reliable. Another stipulation was the independence of the source. Independent sources gather information by observing the facts that they report on, but they are not influenced by other reports from other sources. Other research on this area include Pon and Cardenas (2005), Parssian, Sumit, and Jacob (2004), and Noble (2004).

The research to date, in general, considers the following three considerations (Noble, 2004):

- The actual historical quality of the information source on similar events.
- The reports consistency with confirmed facts.
- The source consistency with the information available from other sources.

The above three considerations might not be applicable to the battlefield environment in this research; historical data about the sources quality are not available and are hard to develop. The research considers one piece of information at a time, so it is not applicable to compare a source consistency with other different sources.

In this research, the quality of the information source \((Q_s)\) is a number between 0 and 1 representing the probability that the source delivers a sufficient level of quality information. The level of quality is defined as information that is complete, accurate, and precise enough to support the decision maker action on that information, if the information is relevant (value attribute) to his decision problem. The source of information quality is defined as the probability that the source can provide information that meets the required information quality attributes: completeness, precision, and accuracy. Mathematically,
A: event, source can provide information of sufficient level of quality.

\[ Q_s = P(A) \]

It is critical to distinguish between information reliability and an information’s source quality. The information reliability is a dynamic value that captures the changes which might take place concerning the value of information along time, while the source of information quality is a static value that captures the attainment probability, the ability of attaining the information attributes: completeness, precision, accuracy.

### 8.4 Information Joint Probability

Let \( R(t) \) be the reliability of information, defined as the probability that the data/information sensed by the decision maker retains value (the value that makes it useful) for a given period of time, after which it loses its usefulness, under stated conditions. The reliability \( R \) at a time \( t \) is the probability that the information has a value at time \( t \).

\( Q_s \) is the quality of the information source and defined as the probability that the source can provide information that meets the required information quality attributes: completeness, precision, and accuracy.

Both measures are independent events. The information joint probability concept defines the probability that the information has value at a certain time and the source of this information delivers a sufficient level of quality information. Mathematically, by defining the events \( A \) and \( B \) as the following:

\[ A = \text{event, source can provide information of sufficient level of quality.} \]
\[ B = \text{event, the information is useful (has a value) at a certain time } t. \]
then the quality of the information source and the reliability of information can be
defined as the following, respectively:

\[ P (A) = Q_s \]

\[ P (B) = R (t) \]

with the joint probability as:

\[ J (t) = Q_s \cdot R (t) = P (A) \cdot P (B) = P (A \cap B) \]

This point probability \( Q_s \) serves as a scaling factor for the reliability of
information distribution resulting in a new (non reliability) distribution \( J (t) \). The
mathematical form of this joint probability distribution is as follow:

\[ J(t) = Q_s e^{-(t/\theta)^\gamma} \]

**8.5 Desired Joint Probability Level and Alternatives Development**

When considering the decision making process, it is important that the model of
that process includes the required tasks (evaluate alternatives) consistently with respect to
the information available (fed to the process). The decision analysis model should aid the
decision maker in taking the appropriate action at the appropriate time.

An event must be detected and the information must be received before any action
is taken. In order for a decision maker to gain value from a detection and information
received, the decision must be made and executed quickly, accurately, and at sufficient
level. Time is a crucial factor in battlefields and must be considered in the analysis tools.

Decision makers differ in their attitudes toward risk. Decision makers prefer to
make a decision and execute it before a certain point in time. This point of time varies
among decision makers and represents the decision maker’s accepted level of risk
associated with the level of the joint probability at that time. In other words again, a
decision maker would prefer to act upon the information available within a certain probability level of information’s usefulness considering the source quality. For example, a decision maker may prefer to execute a decision, acting upon information, before the joint probability of information decreases below 70%. The Required Information Life (RIL) is used to model this temporal aspect of information. The RIL is defined to be the time to failure $t_R$ that corresponds to a specified joint probability $J$.

Given a desired Joint probability $J$,

$$J(t) = Q_s e^{-(t/\theta)\beta} = J$$

the RIL is found from

$$t_R = \theta\left(-\ln\frac{J}{Q_s}\right)^{1/\beta}$$

where $J$ is the desired joint probability, $Q_s$ is the source quality, $\theta$ and $\beta$ are the distribution parameters, and $t_R$ is the time when there is $(1-R)\%$ probability that the information failed.

The speed of performing the mission, evaluating alternatives and making a decision, is critical to success. With the RIL assessed, the decision maker should derive and develop alternatives that consider $t_R$. For example, a commander is considering a retreat from a certain location if no backup forces arrived to the location. In this case, the alternative “withdraw the troops in 20 minutes if backup forces did not show up” is more detailed and specified than the alternative “wait for the backup, and then withdraw forces if the backup did not show up”. The 20 minutes time is the RIL in this case.

The detailed alternatives also allow for an initial screening of proposed alternatives. For example, sometimes executing the decision embedded in a certain
alternative is impossible within the time window frame contained in that certain alternative.

In the VFT model, the set of alternatives is usually developed for each decision situation based on the values of the decision maker and the considerations of the decision situation. A principle in the VFT model was to develop alternatives that best achieve the decision maker values specified for the particular decision context. Each alternative was developed exhibiting the following characteristics:

- Feasibility: each alternative must consider and comply with the constraints of the decision situation.
- Usability: each alternative must (potentially) perform well with respect to the objectives in the decision model.

In the Integrated Model, the set of alternatives is developed for each decision situation based on the values of the decision maker, the considerations of the decision situation, and the reliability of information. Each alternative must be developed exhibiting the two typical characteristics, feasibility and usability, to which we now add another characteristic: time.

- Time: each alternative must consider the time factor with respect to the reliability of the information shaping that decision situation.
8.6 Integrated Model

Research in the decision making field has shown that individuals tend to make common decision making mistakes. A goal of the Integrated Model is to capture and shape the battlefield decision making process and improve the possibility of making a good battlefield decision. Guaranteeing a good decision making process is the closest we can get to assuring good decision outcomes (Russo and Schoemaker, 1990). The Integrated Model is based on VFT decision making analysis, source quality assessment, and information reliability modeling. The model examines the process of decision making systematically based on how each part of the process contributes to make better decisions. In this section, the integrated model is defined and developed, and its advantages compared to the strict VFT model are discussed.

8.6.1 Integrated Model Process

The integrated model provides a practical approach to quantitatively analyze battlefield decisions. The model focuses on how to study decision making on the basis of the decision maker’s values and his evaluation of the information (source quality and information reliability) driving the decision. The flow chart in Figure 54 presents the integrated model process for modeling combat decision situations. The three main activities in the integrated model process are:

- Developing a Generic Decision Model
- Identifying the Decision Context
- Developing the Value Model

Each activity with its subordinate steps is presented in the following sections.
Developing a Generic Decision Model

A decision model is a combination of a fundamental objectives hierarchy, a means objectives network, and attributes to measure the achievement of the objectives.
Specify Values

Values are what a decision maker cares about; it is the area of concern. Values are specified via a direct discussion between the decision maker and an analyst.

Derive Objectives

Objectives are the specific statements of something that the decision maker desires to achieve. Objectives are derived via a direct discussion between the decision maker and an analyst.

Derive Attributes

Attributes are used to measure the achievement of the objectives.

- Identifying the Decision Context

A decision context is composed of a decision situation and the alternatives appropriate for the situation. A decision situation is a description of a course of events with specific considerations. These considerations might be constraints or restrictions. Figure 55 highlights this matter.

![Figure 55 A Decision Context Components](image)

A decision maker must identify the decision situation correctly and derive alternatives that capture and consider that decision situation to avoid type III error, correctly solving the wrong problem.
Identify Decision Situation

Decision situations are created through the normal course of events and the actions of others (Keeney, 1994). The integrated model assumes that the decision situation is shaped by the battlefield information received by the decision maker. The battlefield information is defined as what is transmitted from an event to a decision maker. This transmitted information shapes the decision process. The decision model (fundamental objectives hierarchy, means objectives network, and attributes) should be applicable to the decision situation or it must be changed to consider the values of the decision maker for this specific situation.

Assign Source Quality

When a decision maker receives the information that shapes his decision problem, his mind processes that information automatically and without awareness of details of the process (Russo and Schoemaker, 1990). Assigning a quality value for the source of that information is one of the unconscious details that should be explicitly addressed in a model to avoid relying inappropriately on trusting the information or anchoring on convenient facts.

Recall the basic assumption, a source with a high quality will likely deliver high quality information while a source with low quality will likely deliver low quality information. This $Q_s$ measure is a number between 0 and 1 and is defined as the probability that the source can provide information that meets the required information quality attributes: completeness, precision, and accuracy. The $Q_s$ value can be derived via a direct discussion between the decision maker and the analyst. The decision maker will assign the value based on his awareness of the source situation. The assessment
process of the $Q_s$ should be defined at the time this information was created. In other words, the quality of the source of information is assessed at the time of the information creation to avoid complications. The complications might arise from a misunderstanding of assessing the quality of information instead, or by mistakenly assessing the quality of the source considering the distortion on the way. This number $Q_s$ will serve as a scaling factor for the reliability of information distribution as shown later.

**Assign Information Reliability**

Decision makers assign values for beta ($\beta$) and theta ($\theta$); the parameters of the Weibull failure distribution. The parameters values should be assigned via a direct discussion between the analyst and the decision maker.

To find the value of $\beta$, the analyst can ask the direct question “Do you expect the events to be of a fast dynamic nature or of a slow stable nature?”

To find the value of $\theta$, the decision maker estimates the time when the information fails; the information no longer has value. Substitute this time value in following equation to find the value of $\theta$:

$$\theta = \frac{t_\infty}{\left\{-\ln(R(t_\infty))\right\}^{\beta}}.$$

In order to assign the value of $\theta$, first assign the failure time according to a base line case. A base line case is the case where no action is taken in response to the information sensed or received. Practically, the decision maker should assign the failure time considering that no action or course of actions were taken after the information was sensed.
Assign Desired Level of Joint Probability

After assigning the source quality and the information reliability, the decision maker assigns the desired level of joint probability based on the risk he is willing to assume. The desired level of joint probability is derived via a direct discussion between an analyst and the decision maker. The question to decision maker could be “What the lowest joint probability of valuable information and the source ability to deliver quality information, you are welling to act upon?”

With the desired level assigned, RIL is used to calculate the time to failure $t_R$ that corresponds to the desired joint probability $J$.

Given a desired joint probability $J$,

$$J(t) = Q_s e^{-\beta t} = J$$

the RIL is found from

$$t_R = \theta \left( -\ln \frac{J}{Q_s} \right)^{1/\beta}$$

Generate Alternatives

Identifying a decision context involves a systematic process of developing alternatives and arranging resources and limitations with respect to objective accomplishment. Keeney (1994) suggested guidelines to help in developing alternatives. The principle underlying the guidelines is to develop alternatives that best achieve the decision maker values specified for the decision context. These alternatives should now also account for the time values associated with the required level of information joint probability specified by the decision maker. The result is a set of alternatives that best achieve the decision maker values, and detailed enough to include the time factor.
Initial Evaluation

The set of generated alternatives allow for an initial evaluation of alternatives based on the applicability of the time window frame for the action proposed by the alternative.

• Developing the Value Model

Capturing the essence of the decision situation, assessing the source quality, and assigning a reliability measure for the information shaping the decision situation is not enough to make the best decision. There is a need for a systematic approach to choose among competing alternatives. A value model helps clarify any complex matter related to values. A value model $v$ assigns a number $v(x)$ to each consequence $x = (x_1, ..., x_N)$, where $x_i$ is a level of attribute $X_i$ measuring objective $O_i$. This number, $v(x)$, measures the desirability of the consequences of an alternative and can be used to evaluate and choose among the alternatives. The next three steps are essential in building a value model.

Determine Single Dimensional Value Functions

Specify the value increments between the attribute levels. The value increment refers to the degree to which the decision maker prefers high levels on an attribute scale to the lower levels on that attribute scale.

Assign Weights

In reality, not all attributes are of equal importance. Weights are used to highlight this difference. The weight of an attribute is equal to the increment in value of moving the level on that attribute between its least preferred level to its most preferred level.
**Assign Probabilities**

Before eliciting probability values to each possible level (outcome) in all the different attributes in the decision problem, it is helpful to organize the different attributes’ levels into an event space. Kirkwood (1997) presents procedures for determining and eliciting probabilities from decision makers.

**Evaluate Alternatives**

The decision model defines what is important to the decision maker. The value model (value function) measures, and ranks, each alternative with respect to the decision model. After determining the single dimensional value functions and the weights, the form of the final value function becomes:

\[ v(X_a, X_b, X_c) = w_a v_a(X_a) + w_b v_b(X_b) + w_c v_c(X_c) \]

where \( X_a, X_b, \) and \( X_c \) are different attributes, \( w_a, w_b, \) and \( w_c \) are the weights on the three attributes, and \( v_a(X_a), v_b(X_b), \) and \( v_c(X_c) \) are the single dimensional value functions over each of the three attributes. The value function scales to accommodate any number of attributes beyond the three shown in the example.

To determine the expected value for each alternative in a decision problem, the value function is calculated as:

\[ \text{Expected value for an alternative} = E \left[ w_a v_a(X_a) + w_b v_b(X_b) + w_c v_c(X_c) \right] \]

**8.6.2 Integrated Model Advantages**

There is a clear correlation between the decision making process and the value of information feeding that process. In the battlefield, the decision maker decides to take an action once the information is received. The period after an event is detected, information is received, and before making a decision is critical to the decision making process.
because this is the point at which any potential compromise can be minimized and contained. The compromise may take the form of assessing the source quality or the information reliability. Current models like the VFT model fail to capture this aspect of the process.

In a battlefield decision making model, before making decisions, the process of evaluating the source quality and mapping the information value must be considered. The Integrated Model addresses these critical processes. In other words, the Integrated Model shifts the decision making process from a value-based process to a value-and-information-based process. The model incorporates both information reliability and the source quality in the decision making process. The reliability model and the source quality are directly involved in generating and evaluating alternatives. The model generates more detailed alternatives, and allows for initial screening of these alternatives.

Usually, decision makers begin to gather information and reach conclusions based on a mental model decision framework (Russo and Schoemaker, 1990). Sometimes, decision makers fail to consciously define the problem. For the most part analytical models of decision makers have ignored most of this decision making process. The Integrated Model overcomes this lack of problem definition by addressing each phase in the decision problem in a systematic way.

The integrated model is one step towards solving the decision making modeling dilemma. Decision makers will continue to struggle with how to make the best decisions. This integrated model captures the real life situations in combat and provides a quantitative tool to help generate detailed alternatives and evaluate them. The Integrated Model is next applied to the battle of Khafji scenario.
8.7 Battle of Khafji Integrated Models

The integrated model approach was used to model the four decision problems derived from the battle of Khafji scenario. The same decision models (fundamental objectives hierarchy, means objectives network, and attributes), for each decision maker, developed for the VFT model in chapter 6 are used in the Integrated Model. The framework of deriving objectives was based on in depth scenario knowledge, personal military experience, military training, and doctrine documents.

Modeling the source quality and the reliability of information is usually developed via direct discussion between a decision analyst and the individual decision maker whose values are being quantified. In this research, the values for source quality assessment and the reliability modeling were derived from engineering principles, military doctrine, and personal experience based on an in-depth understanding of the modeled scenario. The individuals in the scenario are considered risk neutral.

A set of alternatives was developed for each decision situation based on the values of the decision maker, the considerations of the decision situation, the source quality assessment, and the reliability of information. Keeney (1994) suggests guidelines for developing alternatives. The principle is to develop alternatives that best achieve the decision maker values specified for the decision context. Each alternative was developed exhibiting the following characteristics:

- Feasibility: each alternative must consider and comply with the constraints of the decision situation.
- Usability: each alternative must perform well with respect to some of the objectives in the decision model.
• Time: each alternative must consider the time factor with respect to the reliability of the information shaping that decision situation.

**Decision Problem 1**

Decision maker: Lt. Ross, commander of recon platoon.

Location: The Berm (Recon platoon location).

Decision situation: At 8:10 P.M. Ross saw enemy tanks heading toward the border. He tried to communicate with headquarters but failed. At 8:20 P.M. he found out that the enemy was jamming their communication capabilities. He tried to repair the radio but it still did not work.

Considerations:

• The recon platoon consisted of four Humvees and a five-ton truck.

• The recon platoon mission was to observe and report any enemy activity, and to evacuate the area with utmost haste if threatened by a large enough force. It was Ross’s call to assess the threat level.

• The geography of the platoon location provided a distinct disadvantage; forces approaching the platoon had the benefit of being in a position to fire down upon them.

Source quality: 1

Information: Enemy tanks were heading toward the border while the communication capabilities were not available (Valuable information / High quality).

Time Unit: Minutes.

\[ t_o = 0 \text{ minutes (8:20 P.M.)} \]

\[ t_\infty = 80 \text{ minutes (9:40 P.M.)} \]
$\beta = 1.5$

Assume $R(80) = 0.009$

Solving for $\theta$:

$$\theta = \frac{t}{\{-Ln(R(t))\}^{1/\beta}} = \frac{80}{\{-Ln(0.009)\}^{1/1.5}} = 28.5 \text{ minutes}$$

The mathematical form of the reliability of information is:

$$R(t) = e^{-(t/28.5)^{1.5}}$$

Figure 56 displays the reliability of information function $R(t)$ for decision situation 1.

![Figure 56](image)

Figure 56 $R(t)$ for Decision Situation 1

The mathematical form of the joint probability distribution is:

$$J(t) = 1 \cdot e^{-(t/28.5)^{1.5}}$$
Figure 57 displays the information joint probability $J(t)$ for decision situation 1.

Desired joint probability level: 0.7

Required life time: $t_R = \theta(-\ln \frac{J}{Q_s})^{1/\beta} = 28.5*(-\ln \frac{0.7}{1})^{1/1.5} = 14$ minutes

A set of alternatives was then developed for this decision situation based on the values of the decision maker, the considerations of the decision situation, the source quality, and the reliability of information.

Alternatives:

- Escape from the area in less than 14 minutes and try to restore communication capability.
- Wait and try to restore communication capability.
- Pull back to horse-shoe berm within 14 minutes and try to restore communication capability.
- Pull back immediately to horse-shoe berm and try to restore communication capability. If communication is not restored in 10 minutes, send some soldiers back to Delta team.
Initial evaluation: Alternative 2 “wait and try to restore communication capability” should be dropped from the set of alternatives. The decision should be executed before 14 minutes to avoid undesired consequences, which alternative 2 does not satisfy.

Value Model: The value model is the same as developed in chapter 6, except that alternative 2 is not evaluated.

Appendix A examines the Weibull distribution parameters sensitivity, more specifically the effect of varied parameters values on the RIL calculations in this decision problem. Appendix B includes a discussion on the effects of using the right triangular distribution for modeling the reliability of information in this decision problem.

Decision Problem 2

Decision makers: Sergeant Mike Davis, Team Leader

Location: The Berm (Recon platoon location).

Decision situation: Sergeant Davis received a signal to engage (Wrong interpretation). L. Corporal Anderson and Sergeant Bench were in his team.

Considerations:

- The signal was to pull back to the horse-shoe berm, but Sergeant Davis misinterpreted the signal.

Information: The information was in the form of a signal to pull back to the berm.

The decision maker (Sergeant Mike Davis) misinterpreted the information so the reliability of information concept is not applicable to model this information.
Decision problem 3

Decision maker: Captain Roger “Rock” Pollard, Commander of Delta Company.

Location: 3.7 miles away from recon platoon.

Situation: At 9:07 P.M. Lt. William reported to Capt. Pollard that recon platoon was under fire and requested Delta’s assistance.

Considerations:

- The Company consisted of 19 LAVs and 10 TOWs.
- TOWs had the capability to destroy vehicles out to 3,750 meters. The longest range for enemy tanks was 3,000 meters.
- Pollard had no idea of recon’s deposition (number of soldiers and vehicles).
- Pollard had no idea that recon managed to get air support.

Source Quality: 0.8

Information: Recon platoon is under fire, and had requested Delta’s assistance (Valuable information / less quality).

Time Unit: Minutes.

\( t_o = 0 \) minutes (9:07 P.M.)

\( t_\alpha = 30 \) minutes (9:37 P.M.)

\( \beta = 2.5 \)

Assume \( R(30) = 0.009 \)

Solving for \( \theta \):

\[
\theta = \frac{t}{\left(-\ln(R(t))\right)^{\frac{1}{\beta}}} = \frac{30}{\left(-\ln(0.009)\right)^{\frac{1}{2.5}}} = 16.14 \text{ minutes}
\]
The mathematical form of the reliability of information is:

\[ R(t) = e^{-(t/16.14)^{2.5}} \]

Figure 58 displays the reliability of information function \( R(t) \) for decision situation 3.

![Figure 58 R(t) for decision situation 3](image)

The mathematical form of the joint probability distribution is:

\[ J(t) = 0.8 * e^{-(t/16.14)^{2.5}} \]

Figure 59 displays the information joint probability \( J(t) \) for decision situation 3.

![Figure 59 J(t) for Decision Situation 3](image)

Desired joint probability level: 0.75

Required life time: \[ t_R = \theta \left( -\ln \left( \frac{J}{Q_x} \right) \right)^{1/\beta} = 16.14 * \left( -\ln \left( \frac{0.75}{0.8} \right) \right)^{1/2.5} = 6 \text{ minutes} \]
A set of alternatives was then developed for this decision situation based on the values of the decision maker, the considerations of the decision situation, the source quality, and the reliability of information.

Alternatives:

- Call and wait for air support then move to help recon.
- Move up the company immediately and go to help recon with the uncertainty of recon disposition.
- Determine recon’s disposition in less than 6 minutes, and then move up the required soldiers and vehicles to help them.

Initial evaluation: Alternative 1 “Call and wait for air support then move to help recon” should be dropped from the set of alternatives. The decision should be executed in less than 6 minutes to avoid undesired consequences which alternative 1 does not satisfy.

Value Model: The value model is the same as developed in chapter 6, except that alternative 1 is not evaluated.

Decision Problem 4

This decision problem highlights the situation where the decision maker might suspect that he is being deceived, so he may choose to wait until more reliable (quality) information is available. If he does not suspect deception, then he may act as before, producing different, and perhaps less desirable, outcomes.

Decision maker: Sergeant Vitale, TOWs team leader.

Location: 3.5 miles away from recon platoon.

Situation: at 9:15 P.M. Corporal Brierly, the TOW gunner for Green 1 reported an enemy tank 1.8 miles (2900 meters) away. Brierly’s vehicle commander reported to Vitale and
requested permission to engage. At 9:18 P.M. Brierly’s vehicle commander requested permission to again engage.

Considerations:

- The plan was to stay a safe distance and use Vitale’s TOWs to destroy the enemy tanks.
- Vitale considered how the enemies were 6,000 meters away at one minute and then somewhere less than 3,000 meters the next minute.
- Vitale considered that if the target is an object in the desert rather than an enemy vehicle, firing at it might lead the enemy to observe their movement to the berm.
- Vitale knew Brierly as a good soldier and one of the best in the group at armor identification.

Source quality: 0.8

Information: Enemy tank in range (Valuable information / Low quality).

Time Unit: Seconds.

\( t_o = 0 \) seconds (9:15 P.M.)

\( t_\infty = 300 \) seconds (9:20 P.M.)

\( \beta = 2.5 \)

Assume \( R(300) = 0.009 \)

Solving for \( \theta \):

\[
\theta = \frac{t}{\left\{ -\ln(R(t)) \right\}^{\frac{1}{\beta}}} = \frac{300}{\left\{ -\ln(0.009) \right\}^{\frac{1}{2.5}}} = 161.4 \text{ seconds}
\]

The mathematical form of the reliability of information is:

\[
R(t) = e^{-\left(t/161.4 \right)^{2.5}}
\]
Figure 60 displays the reliability of information function $R(t)$ for decision situation 4.

![Figure 60 $R(t)$ for decision situation 4](image)

The mathematical form of the joint probability distribution is:

$$J(t) = 0.8 * e^{-(t / 161.4)^{2.5}}$$

Figure 61 displays the information joint probability $J(t)$ for decision situation 4.

![Figure 61 $J(t)$ for Decision Situation 4](image)

Desired joint probability level: 0.75

Required life time: $t_R = \theta ( - \ln \frac{J_{\theta}}{Q_s} )^{1/\beta} = 161.4 * ( - \ln \frac{0.75}{0.8} )^{1/2.5} = 54$ seconds

$= 0.9$ minutes
A set of alternatives was then developed for this decision situation based on the values of the decision maker, the considerations of the decision situation, the source quality, and the reliability of information.

Alternatives:

- Ignore Brierly and wait for situation development.
- Double check Brierly’s information and act accordingly in less than 54 seconds.
- Clear Firing Order in less than 54 seconds.

Initial evaluation: Alternative 1 “Ignore Joshua and wait for situation development” should be dropped from the set of alternatives. The decision should be executed in less than 54 seconds to avoid undesired consequences, and alternative 1 does not satisfy that. Alternative 2 “Double check Brierly’s information and act accordingly in less than 54 seconds” and alternative 3 “Clear firing order in less than 54 seconds” are the effectively same, except that alternative 2 gives a chance to double check the information, which is more desirable, so alternative 3 could be dropped from the set of alternatives.

Value Model: If alternative 3 is dropped, then there is no need to build a value model; alternative 2 is the best decision. If alternative 3 is not dropped, then the value model is the same as in chapter 6 except that alternative 1 will not be evaluated.
8.8 Summary

The Integrated Model incorporates the newly developed concept of information reliability with VFT and the concept of source quality assessment in modeling techniques.

The three major activities in the employing Integrated Model process are:

- Developing a Generic Decision Model
- Identifying the Decision Context
- Developing the Value Model

A decision model is a combination of a fundamental objectives hierarchy, a means objectives network, and attributes to measure the achievement of the objectives.

A decision context is composed of a decision situation and the alternatives appropriate for the situation. The Integrated Model helps in generating a set of alternatives that account for the time values in its details. The assigned source quality and the assigned information reliability contribute to the estimate of these time values.

A source quality is defined as the probability that the information source can provide information that meets the required information quality attributes: completeness, precision, and accuracy. The reliability of information is defined as the probability that the data/information sensed by the decision maker retains value (the value that makes it useful) for a given period of time, after which it loses its usefulness, under stated conditions. The reliability \( R \) at a time \( t \) is the probability that the information has a value at time \( t \).

These two concepts, independent probabilities, are combined together in a new concept called the joint probability. The joint probability is defined as the probability that
the information has value at a certain time and the source of this information delivers a sufficient level of quality information. The decision maker’s required level of joint probability is used to back calculate the required information life RIL, or in other words, the time values that should be included in the alternatives details.

The set of generated alternatives in the Integrated Model allow for an initial evaluation of alternatives based on the applicability of the time frame for the action proposed by the alternative. A value model help clarify any complex matter related to values. It is a systematic approach to choose among competing alternatives.

The Integrated Model addresses the critical processes of assigning the information source quality and the reliability of information. It shifts the decision making process from a value-based process to a value-and-information-based process. In the Integrated Model, the reliability model and the source quality are directly involved in generating and evaluating alternatives. The model generates more detailed alternatives, and allows for initial screening of these alternatives.
CHAPTER 9
EXTENSIONS TO INTEGRATED MODEL

9.1 Introduction

The tremendous advance in information technologies (IT) afford decision makers the capability to quickly fuse data from multiple sources, make informed decisions, and convey those decisions to necessary units and soldiers at the highest speed possible (Hamill, et al., 2002).

More information helps only to the extent that it is used intelligently (Russo and Schoemaker, 1990); vast amounts of data may only confuse matters. The Integrated Model techniques can be extended and employed to systematically address this aspect.

9.2 Extended Cases

The Integrated Model assumes that each piece of information shapes the decision situation of a decision maker. In other words, the Integrated Model examines a snapshot picture of the situation. The decision situations in the battle of Khafji scenario were compatible with that assumption. In this chapter, the Integrated Model techniques are briefly discussed while relaxing that assumption. Figure 62 presents different cases beyond the single piece of information case. Each case is discussed with respect to the employment of the Integrated Model techniques. These discussions set the direction for further research in this area.
The different cases in Figure 62 assume receipt of valuable information by the decision maker. Figure 62 distinguishes between two main cases: two pieces of information received at different times, and two pieces of information received at the same time. In Figure 62, the relevancy attribute, when two pieces of information are received at different times, refers to the relevancy of the new information to the decision situation as shaped by the past information. When two pieces of information are received at the same time, the relevancy attribute refers to the relevancy between the two pieces of information.
9.2.1 New Information / Same Source / Related to Old Information / Agreement

If new information agrees with old information and is received from the same source and the same source quality $Q_s$, then the Integrated Model remains the same.

If the assessed source quality $Q_s$ of the new information is better than the assessed source quality $Q_s$ for the old information, then the RIL is longer. Similarly, if the assessed source quality $Q_s$ of the new information is less than the assessed source quality $Q_s$ for the old information, then the RIL is shorter. This aspect might have a critical effect over the alternative details whether this primary alternative, derived for the old decision situation, was executed or not. If the primary alternative was not executed, the alternative is edited to adopt the new RIL. Similarly if the primary alternative was executed, any second phase of the alternative is updated with the new RIL.

9.2.2 New Information / Same Source / Related to Old Information / Contradiction

When new information, from the same source as the old information, is received contradicting the old information, the Integrated Model techniques are employed based on the execution situation of the primary alternative which was derived for the decision situation shaped by the old information.

If the primary alternative was executed, then the new information will shape a new decision problem. On the other hand, if the primary alternative was not executed, the information source quality $Q_s$ value will decide between the two contradictory decision problems. This situation, contradictory information, is the most complicated and unfortunate situation because the decision maker has to make a choice between two decision situations. The $Q_s$ value decides what situation is framed and analyzed. If the
$Q_j$ value for both of the information pieces is equal, then the decision maker’s attitude toward risk impacts the decision rule.

An example of contradicting information is “The approaching enemy vehicles are tanks” while the old information was “The approaching enemy vehicles are LAVs”.

9.2.3 New Information / Same Source / Related to Old Information / Completion

When new information from the same source of the old information is received in a form of update information completing the old information, the Integrated Model techniques are employed based on the execution situation of the primary alternative which was derived for the decision situation shaped by the old information.

If the primary alternative was executed, then the new information will shape a new decision problem. On the other hand, if the primary alternative was not executed, both pieces of the information should be combined to shape one decision problem.

An example of completion information is “There are two more enemy tanks at area X”. It is critical to distinguish between the contradictory information and the completion information. For example, if the old information states that there are 3 enemy tanks approaching the friendly troops’ location, and the new information states that there are 5 enemy tanks approaching the location, then the new information is in a form of update information, completing the old information, not contradicting it. The new information does not contradict the approaching of the 3 enemy tanks, but it updates the number of the enemy tanks.
9.2.4 New Information / Same Source / Unrelated to Old Information

If the new information is unrelated to the old information received from the same source, then this information will shape a new decision situation. The Integrated Model techniques are employed to shape and analyze a new different decision situation.

9.2.5 New Information / Different Source / Related to Old Information / Agreement

If new information agrees with old information but is received from different source and the source quality $Q_s$ is the same, the Integrated Model remains the same without any additions.

If the new information source quality $Q_s$ is better than the old information source quality $Q_s$, then the RIL is longer. Similarly, if the new information source quality $Q_s$ is less than the old information source quality $Q_s$, then the RIL is shorter. This aspect might have a critical effect over the alternative details whether this primary alternative, derived for the old decision situation, was executed or not. If the primary alternative was not executed, the alternative is edited to adopt the new RIL, and similarly if the primary alternative was executed, any second phase of the alternative is updated with the new RIL.

9.2.6 New Information / Different Source / Related to Old Information / Contradiction

When new information from a different source is received and contradicting the old information, the Integrated Model techniques are employed based on the execution situation of the primary alternative which was derived for the decision situation shaped by the old information.
If the primary alternative was executed, then the new information will shape a new decision problem. On the other hand, if the primary alternative was not executed, the information source quality $Q_s$ will decide between the two decision problems. The $Q_s$ value decides what situation is framed and analyzed. If the $Q_s$ value for both information pieces is equal, then the decision maker’s attitude toward risk influences the decision rule.

9.2.7 New Information / Different Source / Related to Old Information / Completion

When new information from a different source is received in a form of update information completing the old information, the Integrated Model techniques are employed based on the execution situation of the primary alternative which was derived for the decision situation shaped by the old information.

If the primary alternative was executed, then the new information will shape a new decision problem. On the other hand, if the primary alternative was not executed, both pieces of the information should be combined to shape one decision problem.

9.2.8 New Information / Different Source / Unrelated to Old Information

If the new information is unrelated to the old information received from a different source, then this information will shape a new decision situation. The Integrated Model techniques are employed to shape and analyze a new different decision.

9.2.9 New Information / Different Two Sources / Related to Old Information

If two pieces of new information, related to the old information, are received from different two sources, these two pieces of information might be of any combination of the possible relations: agreement, contradiction, and completion. The Integrated model techniques in these cases are employed as a combination of different cases.
9.2.10 New Information / Different Two Sources / Unrelated to Old Information

If two pieces of new information, unrelated to the old information, are received from different two sources, these two pieces of information will shape a new decision situation if they are related to each other, or will shape two new different decision situations if they are unrelated to each other. In the case of two different decision situations, it is important to prioritize the pieces of information.

9.2.11 Two Pieces of Information at the Same Time / Related / Agreement

When two pieces of information are received at the same time and there is agreement between them, then these two pieces are combined to shape one decision situation.

9.2.12 Two Pieces of Information at the Same Time / Related / Contradiction

When two pieces of contradictory information are received at the same time, the information source quality $Q_i$ will decide between the two decision problems. If the $Q_i$ value for both information pieces is equal, then the decision maker’s attitude toward risk influences the decision rule.

9.2.13 Two Pieces of Information at the Same Time / Related / Completion

When two pieces of information are received at the same time and they complement each other, then these two pieces of information are combined to shape one decision situation.

9.2.14 Two Pieces of Information at the Same Time / Unrelated

When two pieces of unrelated information are received at the same time, then each piece of information shapes a different decision situation. The Integrated Model
techniques will be employed to shape and analyze two different decision problems. In such a situation, it is important to prioritize the pieces of information.

9.3 Ranking Information

Information ranking or decision problems’ prioritization is required whenever there are two unrelated pieces of information that shapes two different decision situations at the same time. Different pieces of information are ranked by considering the time dynamics of the information and how quickly the information becomes outdated and of limited use. The rate of change in value over time is information dependent. In other words, the value of information can be ranked or prioritized according to the value of theta ($\theta$) or according to the possible outcomes associated with the VFT model being fed with this information.

Ranking the information according to the value of theta ($\theta$) is justified since theta ($\theta$) affects the mean and the spread of the failure distribution. Therefore, some value of information degrades faster than the value of other information. Ranking the information according to the related possible outcomes associated with the VFT model being fed with this information is justified by the fact that different information has different effect on the outcome of a certain decision situation. If this difference between the outcome without considering the information and the outcome considering the information is recorded, then the information can be ranked according to the value of this difference.

Doyle (1998) remarked “the age of information is best related to the potential cycles of change for a given piece of information and its use”. If information changes frequently, then it is implied to have more impact than information that changes less frequently. By using this concept, information can be prioritized.
9.4 Summary

Decision makers in battlefields receive different pieces of information that shape their decision situations. These pieces of information can be received at the same time or at different times. Any two pieces of information can be either related or unrelated. If two pieces of information are related, then there relation might be agreement, contradiction, or completion of old information. The Integrated Model techniques can be used to model these different situations. This chapter organized and discussed different scenarios of receiving information in battlefields and the employment of the Integrated Model techniques. Further research is required in the areas of information ranking when two valuable but unrelated pieces of information are available at the same time, shared awareness between different sources of information, and combining different pieces of information from the same or different sources to shape one decision problem.
CHAPTER 10

CONCLUSION AND FUTURE AVENUES

10.1 Conclusion

The process of decision making in battlefields takes place under unpredictable and rapidly changing conditions. Battlefield decisions may involve risks especially when there is uncertainty about the consequences of the decision. Any decision made may result in consequences that may affect a large number of people and a vast array of resources.

Leaders throughout the military hierarchy are concerned with ways to employ means to achieve their objectives. Due to the criticality of the decisions and the importance of deploying good strategies, a systematic structured approach to problem solving and decision making is needed. A good deal of research in the area of multi-objective decision making modeling provide a means to examine how decision makers make choices among competing alternatives by weighting the importance of different objectives and then systematically evaluating how well alternative solutions achieve the desired objectives. This research explored applying the value-focused thinking model to battlefield decision making using the battle of Khafji scenario. The research developed a general VFT model to apply to different battlefield situations. In developing the VFT model, the research views the combat as a sequence of different events and therefore presented a methodology for dividing the dynamic decision situations of a battlefield scenario into a group of static decision situations. While developing decision models for the VFT model, the research generated value hierarchies that represent the basic objectives of different individuals in the military chain of command. This value hierarchy
might be used as a generic hierarchy for similar cases or scenarios with few editions if required.

The VFT model coupled with modern technology, particularly computer simulations, can provide improved training experiences. However, the VFT model alone still falls short in capturing all the details in the battlefield decision making process.

The decision maker in a battlefield also encounters a dynamic information environment. During combat, individuals gather and consider information from a variety of sources to determine what information is or is not reliable and useful. This research defined the battlefield information as “what is transmitted from an event to a decision maker”. The battlefield information is particularly uncertain. The uncertainty of the battlefield information depends on many factors, including the source quality, reliability, and age of information. This research examined how each piece of information shapes the decision situation of the decision maker.

The temporal value of each piece of information can and should be modeled when modeling decisions. In battlefields, the value of information degrades over time. The probability of degradation over time can be modeled using a probability distribution. This research modeled the probability of information usefulness over time using reliability concepts. As such, this research defined a new reliability of information concept and defined it as “the probability that the data/information sensed by the decision maker retains value (the value that makes it useful) for a given period of time, after which it loses its usefulness, under stated conditions”. The concept was applied to the battle of Khafji decision situation scenario to develop information models that capture the decision makers’ information. Reliability studies are of interest to the military. Although there is a
good deal of research and models in the reliability area, current studies and models do not model the reliability of information. The new reliability of information concept was a unique contribution of this research effort.

There is a clear correlation between the decision making process and the value of information feeding that process. Current decision making models, including the VFT model, do not consider information degradation in this manner and in fact fail to explicitly link decision making and the information models developed in the research. This research initiated the means to overcome this deficiency.

In creating models, the commander’s approach must be understood and specified. This model approach is needed to not only understand the actual decision making process but also to create better models of the process. As mentioned earlier, the VFT model falls short in capturing some important characteristic of the decision making process in reality, the use of information. In a battlefield, a commander’s courses of actions (alternatives) are derived after identifying the problem and gathering information. In reality, the decision maker tries to take the proper action during an event, or after an event has occurred. The VFT modeling captures this aspect, but it does not capture other decision making process characteristics such as the decision maker assessing the quality of the information source and the reliability of the information, both of which shape his decision problem, before generating and considering alternatives or taking any actions.

This research developed an integrated model for capturing the battlefield decision making process based on value-focused thinking decision making analysis, while assessing the quality of the information source, and incorporating information reliability
modeling. The research defined the Integrated Model in general, and then applied it to model the battle of Khafji decision situation scenario.

The Integrated Model was based on VFT decision making analysis, source quality assessment, and information reliability modeling. The research defined the source quality as “the probability that the source can provide information that meets the required information quality attributes: completeness, precision, and accuracy” and proposed a methodology for assessing it. Based on the source quality and the reliability of information a new concept called the joint probability was developed. The joint probability is defined as “the probability that the information has value at a certain time and the source of this information delivers a sufficient level of quality information”. The decision maker’s required level of joint probability is used to back calculate the required information life RIL, or in other words, the time values that should be included in the alternatives details.

An advantage of the Integrated Model is that the set of generated alternatives in the Integrated Model allow for an initial evaluation of alternatives based on the applicability of the time window frame for the action proposed by the alternative.

In general, the Integrated Model shifts the decision making process from a value-based process to a value-and-information-based process. In other words, the Integrated Model is a modeling process that considers the decision maker’s evaluation of the received information, and produces methodology for evaluating alternatives based on the decision maker’s objectives (values) and his evaluation of the information. The model was theoretical, but detailed enough to generate a computational model presenting its process.
Finally, in summarizing the research, this research examined a decision making model applicable to the battlefield space, a reliability of information model, and then a combined model to capture both of the individual models. The decision making model exploited the value-focused thinking paradigm. The reliability model captured the probability of information usefulness degradation considerations. The combined model, Integrated Model, provided a means to capture and examine the dynamics of battlefield decision making. Each effort represents a novel approach and a unique contribution of this research.

Time pressure and stress are key characteristics in the battlefield decision making process. These characteristics affect the decision makers’ performance (Maule and Hockey, 1993). A deep understanding of the Integrated Model can be used to enhance decision making and improve the ability of the decision maker to learn from an event and adapt to the new situation resulting from the event. It can also be incorporated as an aid to decision makers to help them learn from any mistakes made in the decision making process to better control future decisions.

The techniques within the Integrated Model highlight the importance of consistently updating the information. The lack of recent reports might reverse the effect of previous reports, for instance, the enemy location.

The Integrated Model is one step towards solving the decision making modeling dilemma. Decision makers will continue to struggle with how to make the best decisions. This Integrated Model captures the real life situations in combat and provides a quantitative tool to help generate detailed alternatives and evaluate them.
10.2 Future Avenues

The decision makers modeled in this research were assumed risk neutral when the value function calculations were incorporated. In a future research, the decision makers’ attitudes toward risk could be recorded where the utility theory should be incorporated. The affect of using the expected utility theory on the models outcome could be examined and investigated.

A computational model could be derived based on the theoretical integrated model developed in this research. The SIMULINK package in MATLAB could be used or graphical-based simulation software as ARENA. The simulations can also be used to generate data to validate and verify the theoretical model. Validation refers to testing the agreement of a model with reality while verification refers to testing the model for internal consistency (Clayton, 1997).

The Integrated Model shifts the decision making from a value-based process to a value-and-information-based process, by linking the value-focused thinking procedure with the reliability modeling techniques. Game theory studies strategic situations where players (Decision Makers) choose from different actions in an attempt to maximize their returns. Rasmussen (1989) defined game theory as “the study of the ways in which strategic interactions among rational players produce outcomes with respect to the preferences (or utilities) of those players, none of which might have been intended by any of them”. The correlation between the game theory and the reliability modeling can be investigated and recorded.

In battlefields, an event must be detected before any action can be taken. An event that is detected and classified incorrectly, or not at all, could impede the ability of the
organization to properly respond. A remark pertinent to the Integrated Model is that it is important to detect events as soon as possible since earlier detection will allow earlier reaction, and potentially minimize any negative impact of the event or maximize any beneficial impact. Detection is defined as “the ability of an individual or a system to detect an event” (Beauregard, Deckro, and Chambal, 2002). The relation of this aspect with the decision making process can be investigated. A further level of this aspect, could investigated and its relation with the decision making process, is the accountability defined as the ability to correctly classify detected events.

There are two versions of probability: the classical probability and the fuzzy probability. This research interprets the probability in the classical way; random variables are distinct. Thus, it is a relative frequency interpretation of probability given repeated trails of a battle or a situation. Fuzzy probability is based on the notion that many events can not be stated in a mutual exclusive fashion (Hughes, 1994). An example of a fuzzy probability is the probability related to the event “I won the Battle but lost more soldiers than the enemy did”. Fuzzy probability provides for results which are characterized by related functions, so a fraction of the result belongs to one event and a fraction to others. The use of the fuzzy probability in the decision making models and its affects on the techniques could be investigated.

In battlefields, we can not predict that the orders will be acted as intended even when the troops execute with the best motives what they believe are their orders (Hughes, 1994). This aspect can be modeled and linked to the decision making process by further considering the probability of information misinterpretation.
APPENDIX A
PARAMETER SENSITIVITY ANALYSIS FOR MODELING THE RELIABILITY OF INFORMATION IN DECISION PROBLEM 1

The information reliability models developed in this research make various distributional and parameterization assumptions. The work in this appendix examines the sensitivity of the Weibull distribution parameterizations. Table 46 summarizes the effect of changing the value of $t_\infty$, to change the value of $\theta$, on the RIL calculations for decision problem 1. The analysis is performed while keeping the value of $\beta$ constant at 1.5. Analyses for the other decision problems are similar and not presented.

<table>
<thead>
<tr>
<th>$t_\infty$ (minutes)</th>
<th>$\theta$ (minutes)</th>
<th>RIL (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>24.9</td>
<td>12.5</td>
</tr>
<tr>
<td>71</td>
<td>25.26</td>
<td>12.7</td>
</tr>
<tr>
<td>72</td>
<td>25.62</td>
<td>12.9</td>
</tr>
<tr>
<td>73</td>
<td>25.97</td>
<td>13</td>
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<tr>
<td>74</td>
<td>26.33</td>
<td>13.2</td>
</tr>
<tr>
<td>75</td>
<td>26.68</td>
<td>13.4</td>
</tr>
<tr>
<td>76</td>
<td>27.04</td>
<td>13.6</td>
</tr>
<tr>
<td>77</td>
<td>27.4</td>
<td>13.8</td>
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<td>27.75</td>
<td>13.9</td>
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<td>14.1</td>
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<td>80</td>
<td>28.5</td>
<td>14.3</td>
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<tr>
<td>81</td>
<td>28.8</td>
<td>14.5</td>
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<tr>
<td>82</td>
<td>29.2</td>
<td>14.7</td>
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<tr>
<td>83</td>
<td>29.5</td>
<td>14.8</td>
</tr>
<tr>
<td>84</td>
<td>29.89</td>
<td>15</td>
</tr>
<tr>
<td>85</td>
<td>30.2</td>
<td>15.2</td>
</tr>
<tr>
<td>86</td>
<td>30.6</td>
<td>15.4</td>
</tr>
<tr>
<td>87</td>
<td>30.96</td>
<td>15.6</td>
</tr>
<tr>
<td>88</td>
<td>31.31</td>
<td>15.7</td>
</tr>
<tr>
<td>89</td>
<td>31.67</td>
<td>15.9</td>
</tr>
<tr>
<td>90</td>
<td>32.03</td>
<td>16.1</td>
</tr>
</tbody>
</table>

Table 46 Varied Values of $\theta$ effects on Decision Problem 1
The effect of varied values of $\theta$ on the RIL calculations in decision problem 1 is negligible. Each 10 minutes of change on the assumed $t_\infty$ value, changes the resulting RIL by only 2 minutes. In the scenario modeled, this RIL change is likely insignificant.

Table 47 summarizes the effect of varied values of $\beta$ on the RIL calculations in decision problem 1. The analysis is performed with $\theta$ value held constant at 28.5 minutes. The current model uses two parameter values for $\beta$, $\beta=1.5$ for slow paced events and $\beta=2.5$ for fast paced events.

<table>
<thead>
<tr>
<th>$\beta$</th>
<th>RIL (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.15429</td>
</tr>
<tr>
<td>1.1</td>
<td>11.15198</td>
</tr>
<tr>
<td>1.2</td>
<td>12.05787</td>
</tr>
<tr>
<td>1.3</td>
<td>12.88164</td>
</tr>
<tr>
<td>1.4</td>
<td>13.63237</td>
</tr>
<tr>
<td>1.5</td>
<td>14.31831</td>
</tr>
<tr>
<td>1.6</td>
<td>14.94676</td>
</tr>
<tr>
<td>1.7</td>
<td>15.52415</td>
</tr>
<tr>
<td>1.8</td>
<td>16.05607</td>
</tr>
<tr>
<td>1.9</td>
<td>16.54744</td>
</tr>
<tr>
<td>2.1</td>
<td>17.42502</td>
</tr>
<tr>
<td>2.2</td>
<td>17.81822</td>
</tr>
<tr>
<td>2.3</td>
<td>18.18497</td>
</tr>
<tr>
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<td>18.52779</td>
</tr>
<tr>
<td>2.5</td>
<td>18.84889</td>
</tr>
<tr>
<td>2.6</td>
<td>19.15023</td>
</tr>
<tr>
<td>2.7</td>
<td>19.43353</td>
</tr>
<tr>
<td>2.8</td>
<td>19.70036</td>
</tr>
<tr>
<td>2.9</td>
<td>19.95207</td>
</tr>
</tbody>
</table>

Table 47 Different values of $\beta$ effects on Decision Problem 1

The RIL calculation is very sensitive to the assigned value of $\beta$ over the full range of $\beta$ values. However, given the proposed approach of using either $\beta=1.5$ or $\beta=2.5$, the impact on RIL is not as significant.
Table 48 simultaneously examines the $t_\infty$ and the $R(t_\infty)$ assumptions. For $R(t_\infty)$, the values include the modeled value of 0.009 and orders of magnitude multiples of 0.01.

<table>
<thead>
<tr>
<th>$t_\infty$</th>
<th>RIL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R(t_\infty)=0.009$</td>
</tr>
<tr>
<td>70</td>
<td>24.91</td>
</tr>
<tr>
<td>71</td>
<td>25.27</td>
</tr>
<tr>
<td>73</td>
<td>25.98</td>
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<tr>
<td>74</td>
<td>26.33</td>
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<td>75</td>
<td>26.69</td>
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<td>76</td>
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<td>89</td>
<td>31.67</td>
</tr>
<tr>
<td>90</td>
<td>32.03</td>
</tr>
</tbody>
</table>

Table 48 Different values of $t_\infty$ and $R(t_\infty)$ effects on the RIL for Decision Problem 1

Table 48 data indicate decreasing RIL as $R(t_\infty)$ decreases. $R(t_\infty)$ is as the assumed reliability of information at $t_\infty$, which is close to zero. The more precise the assumption of $R(t_\infty)$, the shorter the resulting RIL. The value employed in the research, $R(t_\infty)=0.009$, provides a reasonably conservative approach. Future computational research should empirically examine the impact of more precise values of $R(t_\infty)$. 
APPENDIX B
MODELING THE RELIABILITY OF INFORMATION IN DECISION PROBLEM 1 USING THE RIGHT TRINGULAR DISTRIBUTION

The information reliability model developed in this research uses a Weibull distribution. Other distributions are possible. The work in this appendix examines the information reliability model sensitivities to the Weibull assumption specifically examining a right triangular distribution alternative. The right triangular distribution is useful in modeling increasing failure rates in reliability studies. The four reliability functions in terms of the triangular distribution are expressed as the following:

\[ R(t) = 1 - \frac{at^2}{2} \]

\[ F(t) = \int_0^t f(t')dt' = \frac{at^2}{2} \]

\[ f(t) = at, \quad 0 \leq t \leq \sqrt{\frac{2}{a}} \]

\[ \lambda = \frac{f(t)}{R(t)} = \frac{2at}{2 - at^2} \]

Decision Problem 1

The information in decision problem 1 can be modeled using the right triangular distribution. The decision maker must assign the value of \( t_\infty \) indicating when the information has no value. Using the \( t_\infty \) value, the right triangular distribution parameter \( a \) is then calculated using the following formula:

\[ a = \frac{2}{t_\infty^2} \]
For the research scenario, decision problem 1, the $t_\infty$ value was set equal to 80 minutes, and hence:

$$a = \frac{2}{80^2} = 0.000313$$

The mathematical form of the reliability of information is:

$$R(t) = 1 - \frac{0.000313t^2}{2}$$

Figure 63 displays the reliability of information function $R(t)$ for decision situation 1.

![Figure 63](image)

Figure 63 $R(t)$ for Decision Situation 1 (Right Triangular Distribution)

The mathematical form of cumulative distribution function (CDF) of the failure distribution, $F(t)$, is:

$$F(t) = \int_0^t f(t')dt' = \frac{0.000313t^2}{2}$$
Figure 64 displays the cumulative distribution function $F(t)$ for decision situation 1.

![Cumulative Distribution Function](image)

**Figure 64 $F(t)$ for Decision Situation 1 (Right Triangular Distribution)**

The mathematical form of the probability density function (PDF) of the failure distribution, $f(t)$, is:

$$f(t) = 0.000313t$$

Figure 65 displays the probability density function $f(t)$ for decision situation 1.

![Probability Density Function](image)

**Figure 65 $f(t)$ for Decision Situation 1 (Right Triangular Distribution)**

The mathematical form of the hazard rate function $\lambda(t)$ of the failure distribution is:

$$\lambda = \frac{f(t)}{R(t)} = \frac{2 \times 0.000313t}{2 - 0.000313t^2}$$
Figure 66 displays the hazard rate function $\lambda(t)$ for decision situation 1

![Hazard Rate Function](image)

Figure 66 $\lambda(t)$ for Decision Situation 1 (Right Triangular Distribution)

**RIL Calculations**

If the desired level of joint probability is 0.7, the RIL is:

$$t_r = \sqrt{\frac{2Q_x - 2J}{Q_x a}} = \sqrt{\frac{(2*1) - (2*0.7)}{1*0.000313}} = 43.8 \text{ minutes.}$$

Recall that the Weibull distribution yielded an RIL of 14 minutes. The mathematical distribution used to model the reliability of information can have a significant effect on the required information life calculations. Not only is the RIL difference likely to have statistically significance, the 29 minutes difference is a practical difference. The weibull assumption used in this research provides a reasonable first model. However, the sensitivity regarding this distribution assumptions means further research is required addressing the choice of distribution and modeling implications of the distribution choice.
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