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THESIS

SURVEILLANCE AND INTERDICTION MODELS: A GAME-THEORETIC APPROACH TO DEFEND AGAINST VBIEDS

by

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June 2010

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14. ABSTRACT

This thesis develops a model for surveillance and interdiction operations by combining a tactical Unmanned Aerial Vehicle (UAV) to detect a threat with a ground force to interdict that threat. The scenario models the defense of a fixed facility such as a Forward Operating Base against an enemy attack in the form of a Vehicle Borne Improvised Explosive Device (VBIED). UAVs are increasingly more important in the military, and significant improvements in quantity and capability allow even tactical units to employ this tool, yet little research has been done on effective employment techniques at this level. Additionally, VBIEDs are a significant threat, but the primary counter-VBIED technique is simply hardened perimeter defenses, and little work has been done to detect and interdict a VBIED before it reaches the target. This research project addresses both deficiencies. Through spreadsheet and decision theory analysis, the factors that impact UAV and ground force employment are examined and effective strategies to employ the two together are considered. Then through Game Theory, the strategic interactions between attack and defender are modeled to examine how changes in the conditions can impact the optimal strategy choices for each side.

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SURVEILLANCE AND INTERDICTION MODELS: A GAME-THEORETIC APPROACH TO DEFEND AGAINST VBIEDS

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List of Acronyms and Abbreviations

ASW	Anti-Submarine Warfare
ATF	Bureau of Alcohol, Tobacco, and Firearms
C-IED	Counter-Improvised Explosive Device
COIN	Counter Insurgency
DHS	Department of Homeland Security
FOB	Forward Operating Base
GAMS	General Algebraic Modeling System
IED	Improvised Explosive Device
JIEDDO	Joint Improvised Explosive Device Defeat Organization
NPS	Naval Postgraduate School
OPTEMPO	Operations Tempo
QRF	Quick Reaction Force
SOF	Special Operations Force
SOP	Standing Operating Procedure
TD	Threshold Distance
TOC	Tactical Operations Center
UAV	Unmanned Aerial Vehicle
USSOCOM	United States Special Operations Command
VBIED	Vehicle Borne Improvised Explosive Device

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CHAPTER 1:
Introduction

On August 18, 2008, the Taliban in Afghanistan launched a double Vehicle Borne Improvised Explosive Device (VBIED) attack against a U.S. military base in Khost Province [1]. The first vehicle detonated at the gate, killing ten people and wounding thirteen others. The second vehicle also made it to the gate area, but the defenders detected the threat and shot the driver before the bomb detonated. That base, Forward Operating Base (FOB) Salerno, is a large facility and serves as a hub of coalition activity, and so it had the infrastructure and resources to defend against the attack. Even though the first vehicle exploded at the gate, no significant damage inside the base was reported, and the casualties were all local Afghans. However, if this attack happened at a smaller base, or if a larger vehicle was used to deliver a bigger bomb, greater casualties and damage should be expected in this type of attack. At a smaller facility without the standoff distance that FOB Salerno has, a large VBIED could potentially cause casualties and damage throughout the entire base, even if it detonates outside the base at the entry gate. In that case, relying on the perimeter to secure the facility is not enough—the defenders need to be able to detect and interdict such an attack before it reaches the gate.

In both Iraq and Afghanistan, coalition forces have moved out of the large FOBs and into smaller bases in order to integrate better with the local population. This reverses an earlier strategy, in which force protection was more of a primary concern that led the military to base its units in the security of large FOBs. Although this was an effective force protection strategy, it failed to facilitate the primary counter-insurgency (COIN) mission. Effective COIN strategy requires winning the support of the local population, and in an effort to accomplish this, commanders began pushing units off of the large FOBs and into smaller outposts to better interact with the locals. While this is a good and effective COIN strategy, it does dramatically increase the risk and creates some force protection problems. These units are no longer tucked away safe within a large base. On these smaller outposts, the entry gate might well be within the blast range of even a medium-sized VBIED. Special Operations Forces (SOF) in particular often operate from team houses located within a village or town and may have no standoff distance to their perimeter to provide protection from a VBIED. In these cases, being able to detect and interdict a VBIED attack before it reaches the facility is important and will be much more effective than simply relying on hardened defenses to absorb an attack.

1.1 The IED Threat

Improvised Explosive Devices (IED) are the greatest threat to the U.S. military in both Iraq and Afghanistan. In the Joint IED Defeat Organization's (JIEDDO) 2008 annual report, the agency director LTG Thomas Metz states: "In Iraq and Afghanistan, the most effective weapon employed against coalition forces during 2008 continued to be the Improvised Explosive Device (IED)" [2, p. 3]. Even beyond those theaters, the report comments that "IEDs remain the weapon of choice for terrorists worldwide in 2008 requiring limited skills and giving them the ability to conduct spectacular attacks for a relatively small investment" (p. 5). IEDs were always the greatest threat in Iraq, and although slower to catch on in Afghanistan, IED use there began to significantly increase in 2008 and accounted for about three quarters of all enemy attacks that year. In response to this threat, the United States has put a tremendous amount of resources and effort into countering IEDs.

JIEDDO has the lead in the Counter-IED (C-IED) effort for the U.S. This organization began in 2003 as an Army IED Task Force, then became a joint task force, then finally reached its current structure as a joint organization directed by a 3-star general in February 2006 under DoD Directive 2000.19E [3, 4]. JIEDDO's evolution and rising importance is partly due to its success, but is also directly related to the increasing significance of the IED threat. In 2008, JIEDDO approved over $4 billion of funding for C-IED efforts, and its annual reports highlight many new technologies, research, and systems that JIEDDO has supported the development of [5, 2]. Obviously the C-IED effort is important and the United States continues to improve capabilities to deal with this threat.

Although IEDs can come in many varieties, the dominant threat is roadside bombs of some sort designed to attack a convoy driving past. This particular IED threat has rightly received most of the attention and effort given to defeating IEDs. However, there are also other types of IED threats that, although not as prolific, are still dangerous. In particular, Vehicle Borne IEDs are a major threat that is difficult to defeat. In general terms, VBIEDs include any explosive attack delivered by a vehicle, though common usage usually limits the term to cars or trucks and often implies a suicide attack in which the driver or other triggerman detonates the vehicle as soon as it arrives at the target. A more inclusive definition, though, would also count non-suicide attacks in which the driver parks the vehicle and leaves the scene before detonating the bomb. Most often, these attacks are against fixed facilities, although there have been VBIED attacks against moving convoys as well [3].

VBIEDs have the potential to be extremely devastating attacks. Since the bombs are assembled in a secure area (rather than in the open as in the case of roadside IEDs), the attackers have the time and opportunity to construct as large a bomb as the vehicle will carry. Also, since the bomb is delivered and detonated by a human, VBIEDs are sometimes referred to as smart weapons, and they have proven to be particularly difficult to defeat. Despite the significant impacts that a VBIED can have, relatively little work has been done to counter VBIED attacks other than the widespread hardening of facilities with primitive techniques such as dirt and concrete barriers. Of the dozens of C-IED efforts including research, initiatives, and new technologies mentioned in both the 2007 and 2008 JIEDDO reports, none are specifically aimed at VBIEDs. In fact, the term "VBIED" is used only once in the 2007 report, and then just in the acronym list, and not at all in the 2008 report. Given the lack of attention paid to VBIEDs, one might conclude that this particular type of attack is not a threat at all, at least compared to the roadside IED which receives the vast majority of C-IED efforts.

On the contrary, VBIED attacks against fixed facilities are a significant threat. Almost all terrorist attacks that result in high casualties are from some sort of VBIED. A Department of Homeland Security (DHS) document states, "Gauging by the number of casualties and amount of property damage, VBIEDs have been the most successful means of terrorist attack both domestically and internationally" [6, p. 4]. The 1983 attacks in Lebanon, first against the U.S. Embassy and then later against the Marine Barracks, were both done with VBIEDs and resulted in over 300 Americans killed. The 1998 U.S. embassy bombings in Africa were also VBIED attacks, again killing hundreds and wounding over 4,000 people [7]. The 1996 bombing of the Khobar Towers in Saudi Arabia was a VBIED attack that killed 19 Air Force personnel and wounded hundreds of others. The worst homegrown terrorist incident in the U.S., the 1995 Oklahoma City bombing, was a VBIED attack that killed 168 people and destroyed or structurally damaged over 300 buildings and shattered glass in over 250 additional buildings [8, p. 6]. This incident in particular demonstrates the potential destructive capability of a VBIED, and why this threat, even if not as common as other IED attacks, is still a major concern. Other VBIED attacks include the bombing of the USS Cole (sometimes called a Water Borne IED) and the 1993 World Trade Center attack, and even the 2001 World Trade Center attacks could be considered a type of VBIED in which a vehicle delivered an explosive attack against a facility. In Iraq and Afghanistan, the U.S. military has learned the lessons of these past attacks and has put up sufficient defenses around the large FOBs to ensure protection against such attacks, and so the VBIED threat against the military in these theaters has not been as great as other

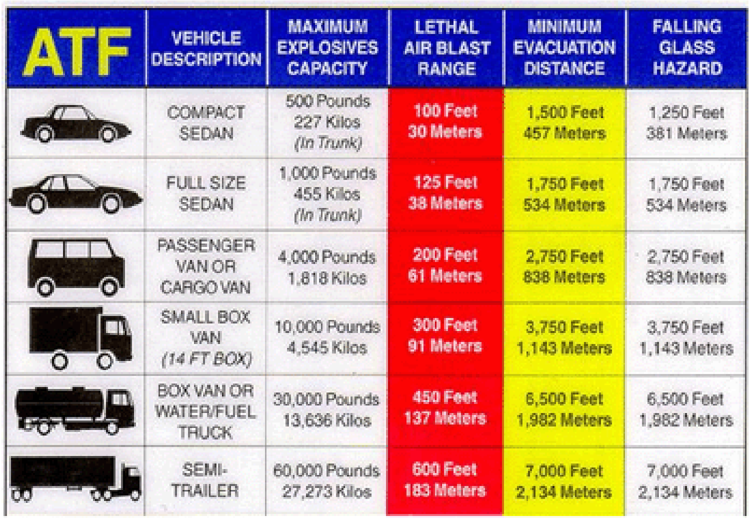
IED attacks against more exposed convoys on the roads. However, VBIEDs are still occurring regularly in both countries against softer targets that are not as well defended. These attacks are usually against host nation facilities such as government buildings or recruiting stations, or even against civilian targets such as markets. However, as U.S. forces continue to move out of the security of large FOBs and into smaller outposts to mix in more with the local population, they will lose their primary defense against VBIEDs and the threat of those attacks might then increase.

The VBIED concept is a very old idea that has withstood the test of time because it is so effective. In an article on the subject, Henry Morgenstern writes:

> Since the times of the Trojan Horse, the idea of taking an object that can breach a security system because it is familiar or desirable and using it to deliver a payload to enemy forces is a well-known tactic. The Vehicle Borne Improvised Explosive Device (VBIED) is but the latest such incarnation of a very old theme – but with a deadly, sometime mass destructive force. [9]

VBIEDs are an attractive technique for terrorists and insurgents because they can deliver a large amount of explosives and create a spectacular attack that can have impacts far beyond the immediate target. The propaganda effect from such an attack is often worth more to the terrorists than the actual damage from the attack, creating a strategic effect from an otherwise tactical level operation. For instance, the 1983 VBIED attacks in Lebanon directly resulted in the United States pulling its forces out of the country. Also, one large attack will receive more attention than many small attacks over time. During the height of the Iraq war, roadside IEDs were a daily occurance, but they frequently received only a passing mention in the news, if they got reported at all. A larger, more "spectacular" attack such as could be accomplished with a VBIED would garner headlines and media attention and create the propaganda effect that the insurgents desire. Even a small vehicle can deliver enough explosives to create a major event, and large vehicles can create a blast big enough to damage a wide area, even if protected. Figure 1.1 shows the Bureau of Alcohol, Tobacco, and Firearm's (ATF) table of car bomb sizes and radius of the explosion. Given the potential destruction possible with a VBIED, it is easy to see why terrorists have turned to it as a weapon of choice.

As mentioned, the primary counter measure to VBIEDs is to harden the facility, such as installing blast walls, increasing stand-off distance, and using security access points to control



ATF	VEHICLE DESCRIPTION	MAXIMUM EXPLOSIVES CAPACITY	LETHAL AIR BLAST RANGE	MINIMUM EVACUATION DISTANCE	FALLING GLASS HAZARD
	COMPACT SEDAN	500 Pounds 227 Kilos (In Trunk)	100 Feet 30 Meters	1,500 Feet 457 Meters	1,250 Feet 381 Meters
	FULL SIZE SEDAN	1,000 Pounds 455 Kilos (In Trunk)	125 Feet 38 Meters	1,750 Feet 534 Meters	1,750 Feet 534 Meters
	PASSENGER VAN OR CARGO VAN	4,000 Pounds 1,818 Kilos	200 Feet 61 Meters	2,750 Feet 838 Meters	2,750 Feet 838 Meters
	SMALL BOX VAN (14 FT BOX)	10,000 Pounds 4,545 Kilos	300 Feet 91 Meters	3,750 Feet 1,143 Meters	3,750 Feet 1,143 Meters
	BOX VAN OR WATER/FUEL TRUCK	30,000 Pounds 13,636 Kilos	450 Feet 137 Meters	6,500 Feet 1,982 Meters	6,500 Feet 1,982 Meters
	SEMI-TRAILER	60,000 Pounds 27,273 Kilos	600 Feet 183 Meters	7,000 Feet 2,134 Meters	7,000 Feet 2,134 Meters

Figure 1.1: ATF Car Bomb Table [From 10]: This chart shows the potential explosive size of a VBIED for various vehicle sizes. For each vehicle, the typical maximum explosive capacity and the corresponding expected lethal blast range and damage range are shown.

entry and search vehicles. For the most part, these are old technologies, and relatively little new work has been done in this area. Some new technology for improving vehicle searches, such as scanners that can detect hidden explosives, have been developed and deployed to high value locations. However, even these are a last line of defense, allowing a potential VBIED right up to the gate of the targeted facility. For the most part, all of these counter-VBIED actions are defensive, designed to protect a facility and better absorb an attack, or make the target too "hard" and deter the attackers from choosing that target, but likely sending them to attack a softer target. Relatively little work has been done to improve the ability to detect and interdict a VBIED before it reaches its intended target. In 2009, the DHS issued a Research/Focus Area document dedicated to VBIED detection [6]. This paper highlights the counter-VBIED challenges and why defeating this threat is so difficult, and it shows that DHS is moving forward with more advanced counter-VBIED efforts. So far, the military seems to be content with using perimeter security to defend against VBIEDs and is putting most of its resources and effort into countering other IED attacks. This strategy has worked well so far, and at least in Iraq and Afghanistan, military facilities have avoided a successful major VBIED attack, but if the trend towards putting units on smaller outposts continues, the VBIED threat will increase and the ability to rely on perimeter security to defend and protect against a VBIED will decrease. Hardening of facilities can only accomplish so much, and therefor other counter-VBIED techniques should be examined and developed as well, including detection and distant interdiction such as DHS is focused on.

1.2 The Scenario

This thesis is part of a larger research effort that addresses parts of this deficiency in Counter-VBIED efforts by exploring ways to combine a tactical UAV for detection with a ground based force for interdiction in order to better protect a specific facility from a VBIED attack. Specifically, this thesis examines a VBIED attack scenario and looks at employment factors of surveillance and interdiction assets as well as the strategic interactions between attacker and defender in a game theoretic model.

The scenario used in this project is built around an enemy attacker using a VBIED to target a small, remote FOB defended by a friendly force, similar to what might be found in the countryside of Afghanistan. The unit on this base can have any of a variety of different missions that require its presence in that area, but regardless of the primary mission, one task that all deployed military units have is force protection, including guarding the base against attacks. The defenders have a single tactical Unmanned Aerial Vehicle (UAV) that they control which can be used for surveillance. The defenders also have a ground force that can conduct patrols around the FOB, but due to limited numbers the defenders can only send out one patrol at a time. This Quick Reaction Force (QRF) will be used to interdict an enemy attack. In the studied example, this FOB is located near a three-way road junction, so that there are three avenues of approach leading to the base. Now imagine that the defenders receive credible intelligence warning of a VBIED attack planned for sometime the next morning, but the exact time and road that the attack will come from is unknown. The defenders obviously want to interdict the attack with the ground force as far from the base as possible to limit potential damage, but without knowing which road to send the force down this is a difficult decision. Figure 1.2 graphically depicts this situation. Given this scenario, how should the defenders act to best interdict the VBIED attack?

There are several plausible courses of action in this scenario, but for this project we assume the defenders keep the QRF at the base on stand-by and use the UAV to look for the VBIED. When the UAV detects the target, the QRF can then travel down the correct road to interdict the attack. In case the UAV misses the VBIED, the QRF is also conducting static surveillance from the FOB, and if the QRF detects an approaching vehicle it will then move on that road and stop the vehicle. In this case, the VBIED will get much closer to the base and if large enough will cause damage, so the preference is for the UAV to make the detection and allow the QRF to interdict the attack farther away. There are also several methods to employ the UAV, and for this scenario we model a barrier-type patrol, in which the UAV flies a circular route at various

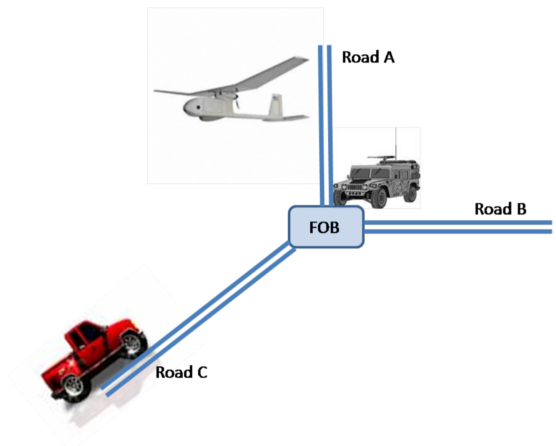


Figure 1.2: Basic Scenario Diargram. This picture shows the FOB in the center, with the road network of three avenues of approach leading to the FOB. The defenders have a ground force QRF on standby at the FOB to interdict the attacking VBIED once the UAV detects which road it is on.

fixed distances from the FOB. The details of this model are explained in later chapters.

As part of the larger research project, several field experiments were conducted during the Naval Postgraduate School (NPS)-United States Special Operations Command (USSOCOM) Field Experimentation Cooperative program at Camp Roberts Army National Guard Base, California. To better replicate a real-world situation, the general scenario was tailored to a specific location used in these field experiments. Use of this Camp Roberts scenario added real world complexity to the problem, such as curved roads, varied terrain from rolling hills to steep canyons, and different types of roads including improved packed gravel and dirt jeep trails, which allow the model to better represent a real-world situation. Appendix A shows a map of the location used at Camp Roberts.

1.3 Research Design

The purpose of this thesis is to examine the optimal methods of employing a UAV and ground force together to interdict a VBIED attack. The question this thesis addresses is how should the defenders act in order to best defend against a VBIED attack. This scenario is initially modeled as a one-sided decision in which only the factors related to the defender are considered. Then a game theoretic approach is taken in which the decisions of both attacker and defender are considered along with how they impact each other. The primary goal of this thesis is to determine an optimal UAV and QRF employment strategy for the defenders to successfully interdict a VBIED attack in the given scenario. There are a large number of possible issues involved in this problem that could be considered, and so the scope of this thesis is limited to the given scenario. Only a single UAV and ground force are considered. The UAV is a tactical one locally controlled and used only for surveillance (i.e., it is unarmed and not used for the interdiction task, but it is also dedicated to the defenders and will not be tasked away by a higher headquarters). This thesis focuses on employment of the UAV as a vehicle and not on the characteristics of the UAV's sensor; issues such as missed detections and false positives are not addressed. Other limitations on the scope of this model include no weather effects and the UAV functions normally (i.e., no mechanical or technical problems and the enemy does not interfere with UAV operations). These and other limitations and assumptions will be explained in detail in later sections.

1.4 Thesis Organization

Chapter 2 presents a review of UAVs, Barrier Patrol and how it is applied to this problem, and Game Theory as it is used here. Chapter 3 develops the model for UAV and QRF employment through spreadsheet analysis. Chapter 4 discusses the attacker and related factors. Chapter 5 examines the strategic interaction between attacker and defender through Game theory. Chapter 6 discusses the Field Experiments conducted as part of this research project. Chapter 7 concludes the thesis with some applications and future development of this research. There are three appendices: Appendix A details the area used in the Field Experiments, Appendix B shows the implementation of the linear program to solve the Game Theory problem, and Appendix C is the Field Experiment Procedures.

CHAPTER 2:
Background

2.1 Unmanned Aerial Vehicles

UAVs are becoming an ever increasing and more important part of military operations. Traditionally, intelligence platforms were a high-level asset and had very little direct link to tactical ground units. UAVs are changing this, however, and "provide frontline tactical formations ... with organic aerial capabilities that they can directly control" [11, p. I-1]. The traditional role of the UAV has also changed, from one of primarily intelligence, surveillance, and reconnaissance (ISR) to a strike platform as new technology allows more weapon systems to be employed on a greater number of UAVs [12]. Although this project does not examine the use of UAVs in a strike role, the increasingly ubiquitous nature of UAVs and the ability of tactical level ground commanders to control them is an important development that allows the scenario presented here to be realistically considered.

2.2 Barrier Patrol

Search Theory is a subset within the Operations Research effort that originated during World War II, and Barrier Patrol is a specialized technique within the general subject of Search Theory [13]. As the name implies, Search Theory deals with the process of detecting different things, with many different analytical factors involved [14]. The military had several applications that required efficient and effective search techniques, including locating missing people such as shot down air crews, finding enemy formations on land in order to better attack them, and detecting enemy forces that are approaching a friendly position. In particular, the Navy led the development of Search Theory in its application towards Anti-Submarine Warfare (ASW). Detecting and then defeating enemy U-boats was a vital effort and perhaps the most significant application of Search Theory. In the field of ASW, the specialized form of searching called Barrier Search was developed.

Barrier Search assumes that the enemy is trying to move from one area to another and that the friendly forces have created a line or barrier that they are searching along in order to detect the enemy as he crosses that line while moving from one area to another. A classic example to illustrate this concept comes from the naval campaigns of the Mediterranean Sea. The German U-boats wanted to conduct operations in the Mediterranean to disrupt Allied shipping there. To do so, the U-boats needed to move from the Atlantic Ocean, through the Straits of Gibraltar, and into the Mediterranean. The allies treated the straits as a barrier and patrolled back and forth (going north and south) across the straits, trying to detect the enemy traversing the straits. Koopman, in his report OEG 56 and a subsequent book, details much of the early work done in this field [13].

The basics of Barrier Search as described in this example are transferred to land for this scenario. Instead of U-boats moving from the Atlantic to the Mediterranean, VBIEDs are moving from a staging area to the FOB. Just as the Allies knew the path that the U-boats would take, the defenders in this scenario know that the VBIEDs will be travelling along a set of roads. However, the defenders do not have the ability to observe or block all three roads at once, just as the Allies could not observe or block the entire width of the Straits of Gibraltar. To deal with this, the Allies had ships and planes going back and forth searching the straits, which became their barrier line. In our scenario, the defenders have a UAV that searches across each road, and the UAV's flight path becomes the barrier line at which the defenders want to detect the VBIED. Rather than establish the barrier at a fixed chokepoint, though, the defenders are able to fly the UAV at any distance from the base and so can establish their barrier at any point along the roads. The factors leading to the decision on where this barrier should be established are discussed in the next chapter.

Nash presents an overview of recent Barrier Search methods related to ASW, including measures of effectiveness to evaluate specific searches [15]. Nash also develops a technique to calculate probabilities of detection in a Barrier Search based on the ratio of area (measured in search cells) covered by the sensor to the total area within the barrier. The model in this project is developed using a similar concept of ratio of time spent searching a specific node out of the total time of the search patrol.

2.3 Game Theory Application

Game Theory is the study of how decisions are made in situations where the decisions of one person affect the decisions of another. As one textbook on the subject says, "Game Theory is concerned with how rational individuals make decisions when they are mutually interdependent" [16, p. 1]. Game theory primarily developed out of the field of economics, but has since been applied to a wide range of areas. Current applications include biology, political science, international relations, and even areas where the decisions are not made by people, such as in computer science. The widespread use of Game Theory shows its usefulness and effectiveness at helping to understand and improve decision making in strategic situation (i.e., situations in which the decision of one side impacts the decision making of another. Just as there are a wide range of applications for Game Theory, there are also many variations of games that can be studied.

Two main branches of game theory are non-cooperative and cooperative [16]. Non-cooperative games imply individualism, and mean that the people involved (called players) cannot enter into and enforce agreements between themselves, although they may work together to further their individually perceived best interest. Cooperative games allow for players to join together and work towards a collective goal, which will result in the best outcome for the group but may not be the best result individually. The scenario in question here is clearly non-cooperative, and the attackers and defenders will not establish any sort of agreements between themselves.

Games can also be zero- or partial-sum games. In zero-sum games, in order for one side to gain an advantage or increased benefit, the other side must have a corresponding disadvantage or decreased benefit. For example, when setting the price of product for sale, as the price goes up the seller's profit will increase by exactly as much as the buyer's expenses. The amount of money that the buyer collects minus the money the seller spends always equals zero, and the sum of money (the benefit) that both sides have stays the same. In partial-sum games, the resulting amount of benefit that both sides have can vary based on which decisions are made. For example, the Prisoner's Dilemma is a famous partial-sum game. The scenario in this project results in a zero-sum game. In order for the attackers to succeed, the defenders have to fail, and an increase in the likelihood of a successful attack results in a corresponding decrease in the likelihood of a successful defense.

Games are also categorized by the timing of each player's move or decision. If one player moves first, and the next player knows something about the first player's move before making his own decision, the game is sequential. If both players make their decision at the same time or if at different times but without knowing anything about the other player's decision, the game is considered simultaneous. The game developed here is simultaneous. The defenders clearly do not know the attacker's decision on which road to use or even when or if to make the attack. Also, although the attacker might be able to learn how the defenders are employing the UAV, we assume that the attacker must commit to a course of action before knowing this decision.

Related to the timing of the game is how the game is represented [17]. Sequential games are generally shown as a tree to indicate the sequence of decisions, called extensive form. Simulta-

		Player II	
		C	D
Player I	A	3	1
	B	4	2

Table 2.1: Game Matrix Format: This shows a simultaneous, zero-sum game represented in matrix form. The rows represent a strategy available to Player I (strategies A and B) and each column is a strategy for Player II (strategies C and D). The numbers are the payoff values when that pair of strategies is used.

neous games are shown in a matrix format, as is done in this thesis. Table 2.1 shows an example matrix game. By convention, the friendly side will be the row player and refered to as Player I, and each row represents a different strategy that Player I can decide to use. The enemy will be the column player, Player II, and the columns represent the strategies available to him. The size of games can vary greatly. The simplest one is a two-person game where each side has two strategies to choose from, resulting in a 2×2 matrix as shown. However, a game can have any number of players, and each player can have a different number of multiple strategies. Our game will be a two-person game consisting of the friendly force defenders and the enemy attackers.

The solution to a game refers to the optimal strategies that each player should decide to use. This can be a single, pure-strategy solution, or a mixed-strategy solution in which the player uses multiple strategies. The value of the game (but not the solution) is the resulting benefit that each player receives when he employs his optimal solution strategy. In the example game in Table 2.1, if Player I chooses strategy B and Player II chooses strategy D, Player I receives a benefit value of 2. Since this is a zero sum game, Player II loses a value of 2. The solution to the game is to use strategies B and D, and the value of the game is 2.

One final important consideration in game theory is the idea of repeated versus one-time games. The theory is most applicable to situations that are repeated multiple times. Solving a game results in the optimal strategies that yield the greatest *expected* value. This is the average value that should be expected over the course of many iterations of the game. The strategy solutions might consist of mixed strategies. This indicates that more than one strategy should be used, each a certain optimal percentage of the time. In repeated games, following a mixed strategy is possible, but in a one-time game where the decision is made only once, only one strategy can be used. In this situation, the decision maker should randomly choose between the strategies according to the weighted optimal mixed strategy solution, and the optimal value of the game (the expected value) might not even be a possible result in this case. One-time games have a problem with risk that affect the decision making: since risk is not spread out over many iterations, the worst-case value of the chosen strategy might occur in a one-time game, rather than the expected value given by the optimal solution. The game in our scenario is considered a repeated game from the defender's point of view. They will make this decision many times, possibly every day, and so can employ a mixed strategy if called for. From the enemy perspective, this is perhaps a one-time decision, since putting together a VBIED attack is a large and difficult operation, although the enemy could possibly conduct repeated attacks.

To solve a game such as we will develop for this scenario, linear programming is used [17]. Player I has n pure strategies available and chooses mixed strategy $X = (x_1, x_2, ..., x_n)$ such that x_i is the percentage of time he uses strategy i. Player I must always choose X such that

$$\sum_{i=1}^{n} x_i = 1$$

This is the first constraint used in the linear program.

Player II has m strategies to choose from, indexed by the subscript j, and the game matrix is given by A (i.e., $a_{i,j} =$ the value in the matrix for row i and column j.) Player I's value of the game is given by:

$$E(X, j) = XA_j = x_1 a_{1,j} + x_2 a_{2,j} + ... + x_n a_{n,j} \; \forall \, j \in \text{set of } m \text{strategies}$$

$E(X, j)$ is the Expected Value of following strategy X when Player II uses pure strategy j. Also, by convention, Player I is usually maximizing, but in this case, the game matrix will represent a cost function and not the usual utility value, so Player I wants to minimize the expected value of the game, v. This gives the second constraint:

$$\sum_{i=1}^{n} (a_{i,j} x_i) \leq v \; \forall \, j$$

This is a set of constraints, with one for each column or strategy j that Player II can employ. If Player I has chosen his strategy optimally, his value of the game will always be at least as good as v, no matter which strategy Player II chooses. Solving this linear program with an optimization solver results in the optimal value of the game and the optimal solution strategy for Player I. Solving for the dual problem will give the optimal strategy for Player II, and by the Duality Theorem will always result in the same optimal value for the game [18].

CHAPTER 3:
Surveillance and Interdiction Model Development

3.1 UAV Search Method

This research focused on a barrier patrol technique, as described in the previous chapter. The UAV is sent in a somewhat circular path from one road to the next, rather than searching along the roads. Intuitively, when most people think about this problem, their initial answer is usually that the UAV should travel along the roads in some fashion. This maximizes the time searching and should therefore increase the chances of detecting the target. That is a reasonable conclusion, and future research should certainly look at that strategy. However, this project instead focuses on a barrier-patrol method in which the UAV crosses and searches each road at a single node. This was done partially for reasons of analysis (as discussed below), but also because having the UAV cover the area in between the roads can be useful as well. Depending on the terrain, vehicles are not restricted to roads. Although off-road travel will be slower, in many areas, driving off road is feasible, and if the defenders never search the off-road areas, the enemy can pick up on that and will then utilize those approaches to attack the base. Also, insurgents often video record their attacks for use as propaganda or in an Information Operations campaign. The recorder will be located in an isolated area off of the main roads. Finally, in some cases, VBIEDs are remotely detonated. In these cases, the person detonating the VBIED will also likely be in an isolated area away from the main road where he can observe and initiate the explosion without being seen. Therefore, having a UAV cover the space in between roads is useful and can increase the likelihood of the defenders detecting these people, while ignoring those area will leave a vulnerable avenue of approach open for exploitation.

There are also some analytical reasons for utilizing a barrier patrol method instead of a linear search along the roads. Barrier Patrol techniques are an established search method with an existing robust literature and analysis supporting them. It is a well-studied search method, and part of the goal of this research is to determine how well this method can be applied to new areas such as in this scenario. A Barrier Patrol method also allows for a discrete modeling technique, whereas searching along the roads requires a continuous model. For example, if the UAV is searching along a road traveling away from the base and the VBIED is traveling toward the base on the same road, if the model uses discrete time steps it is possible for the UAV and VBIED to jump past each other without the possibility of a detection. Although this particular problem does not play a major role in this thesis, it does impact related work on this project, and therefore it was a consideration in selecting a barrier patrol technique to focus on.

3.2 UAV Employment Factors

There are a vast number of factors that can be considered when working with UAVs, including the many different types of UAVs themselves. This project focuses on the small, tactical type of UAVs, for which the primary defining characteristic important here is being launched, controlled, and recovered from the area of operations. Even in this narrow subset of UAVs there are still many different factors that impact UAV performance. These include maximum speed, loiter speed, turning radius, control and communications range, endurance (maximum time of flight), impact of weather conditions, altitude, and others. The sensor on the UAV also has many important characteristics to consider: type such as optical, infrared or thermal and full motion video versus still pictures, day or night capable, resolution, and fixed or moveable.

Each type of UAV and sensor combination will have specific characteristics related to detection probabilities, both false alarms and missed detections. Although false alarms (when a detection is thought to be made but it turns out to be not a VBIED) are important considerations, this project does not specifically focus on those issues. Rather, the focus is primarily on missed detections, when a VBIED is actually there and the UAV does not detect it. Although a false alarm will result in deploying the QRF unnecessarily, it is clearly not as significant as a missed detection which puts the base at a greater risk.

While specific detection probabilities are important considerations, this project looks at the employment methods for a generic UAV without considering the specific characteristics of different, individual UAVs and sensors. If the model is used in a specific situation with a given UAV and sensor with known probabilities of detection, the model can be easily updated to reflect those specific numbers. For the development of this model, however, the UAV sensor is considered to be perfect, and the probability of a missed detection or a false positive is ignored. In other words, if the target enters the UAV sensor sweep, a correct detection is assumed, and so this project is more concerned with the employment methods of a general UAV rather than the detection characteristics of a specific sensor type, which can be investigated more extensively in future work.

For this analysis, the basic route of the UAV is set going from one road to the next at a fixed road distance from the FOB. The key variable for the UAV is the radius of its patrol from the

FOB. There are three measures of effectiveness to determine how well the UAV is employed: Patrol Efficiency, Search Effectiveness, and Patrol Success.

3.2.1 Patrol Efficiency

Patrol Efficiency is defined as the ratio of the amount of time the UAV spends searching to the total time of the UAV's patrol. To calculate Patrol Efficiency, the UAV's flight path must first be determined. As described, the flight path follows a periodic search pattern, going from a search node on one road to a node on the next road all the way around and back to the original node to complete one circuit. A full patrol is made up of repeated circuits following the same search pattern. Because of this, the bulk of the patrol consists of flying these circuits, and the initial transit from the base to the starting search node and the final transit back to the base are small parts of the overall patrol. To simplify the model, these two legs are ignored, and the UAV patrol is considered to be just the route between search nodes. The starting point can therefore be arbitrarily selected, and the patrol is considered symmetric, so the direction (clockwise vs. counterclockwise) is immaterial.

The search nodes for a given patrol are all an equal distance away from the base. Two approaches to this were considered: using the straightline distance and the road distance. When developing the model using the simple scenario with straight roads, these two distances were the same, and initially the search nodes were determined based on their direct, straightline distance to the FOB. However, when the model was implemented in the Camp Roberts scenario with curved roads, using straight-line distances to define the search pattern created some problems and did not work as well as using the road distance to each node. Figure 3.1 illustrates how each method can be used to define a different search pattern. Therefore, instead of using a radius to define the flight path, the nodes are determined using road distances, and each node in a particular search pattern is an equal road distance from the FOB. Once the location for the search node on each road is determined, the overall flight path is defined and the total length of a circuit can be calculated.

Once the flight route is developed, the flight time must be calculated. First, the travel time between search nodes was determined. This depends on the distance between the nodes and the nominal transit speed v of the UAV. For n search nodes,

$$T_{\text{transit}} = \sum_{i=1}^{(n-1)} d_{i,i+1} v_{\text{transit}} \text{ where } d_{i,i+1} = \text{distance from Node } i \text{to Node } i+1$$

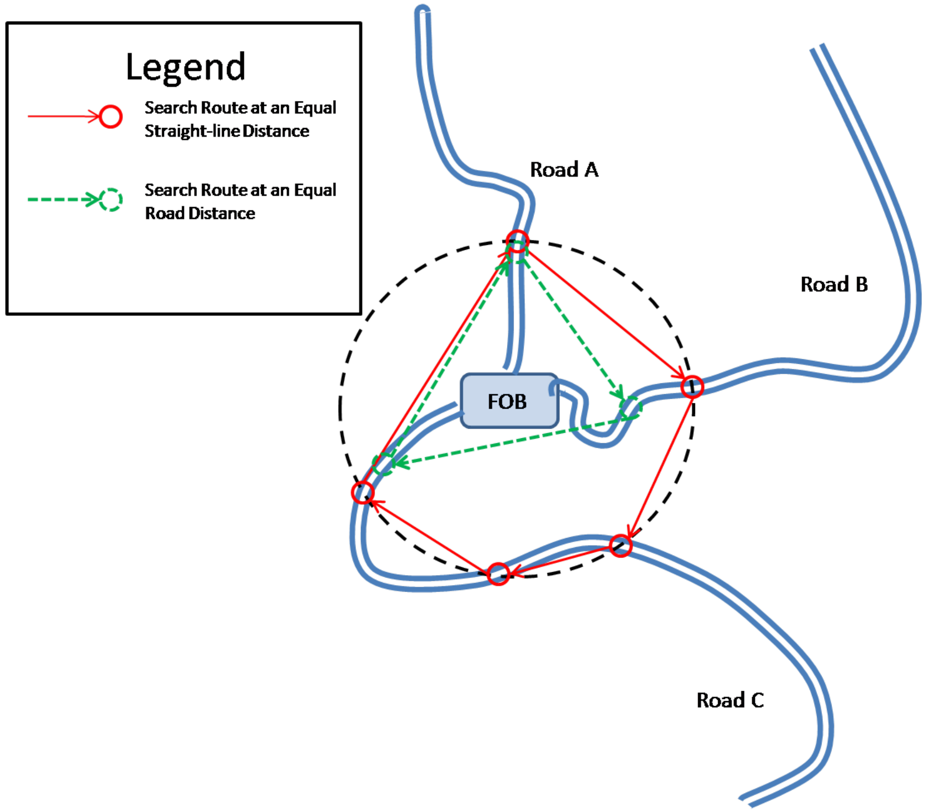


Figure 3.1: Straight-Line vs. Road Distance Search Pattern: This diagram shows how the flight path can differ when determining the search nodes based on the straight-line distance or the road distance from the FOB. As shown, in the straight-line search pattern there can be multiple search nodes on one road.

This is obviously a simplification and ignores several important factors, including wind and turning radius. As mentioned, the model treats the flight path as symmetric and does not consider direction, and so assumes there are no wind effects. The model also does not consider the turning radius of a UAV, which will be different depending on the specific type of UAV used. For these calculations, the UAV is assumed to pivot and move directly from one azimuth to another. The impact of this assumption depends upon the specific road network. In the simple case of straight roads, the azimuths of each leg of the route will always be the same regardless of the radius to the search nodes, so this simplification removes a constant value from the overall patrol length for each search pattern. As the road network gets more complicated with curved roads, the impact of this assumption varies: in general, the greater the change in azimuth between legs, the more impact this simplification has.

Once the travel time between nodes is determined, the search time is calculated. Depending on the UAV, it may fly slower when searching a node from its transit speed travelling between search nodes. This speed and the distance of each search node determine the search time.

$$T_{\text{search}} = \sum_{n} \left[\frac{d_n}{v_{\text{search}}} \right] \forall \text{ Search Nodes } n \text{ where } d_n = \text{distance across Node } n$$

d_n defines how big the search area at Node n is. For instance, a small rural road 8 m wide requires less time for the UAV to fly over and search than a four-lane divided highway that is 80 m wide. The search distance can also be used to have the UAV spend extra time searching. The UAV could fly one or more circles over a search node, increasing the loiter time at that node. To represent this in the model, the distance of the search node is increased.

Adding the total search time to the total travel time results in the total patrol time. Patrol Efficiency is the time spent searching out of the total patrol time.

$$\text{Patrol Efficiency} = \frac{T_{\text{search}}}{T_{\text{transit}} + T_{\text{search}}}$$

3.2.2 Search Effectiveness

A measure of Search Effectiveness is then created, which combines the Patrol Efficiency with the likely location of the VBIED. Search Effectiveness is the probability that the UAV detects the target (assuming perfect detection; more accurately this is the probability that the target enters the UAV sensor sweep). Effectiveness equals the sum of efficiencies for Node c, where c is on Road j, times the probability that the VBIED is on that road.

$$\text{Search Effectiveness} = \sum_{j=1}^{R} \left(\frac{T_{\text{search(Node } j)}}{T_{\text{transit}} + T_{\text{search}}} \right) \mathrm{P}_{(\text{VBIED on } j)}$$

Because this formulation sums over the roads and not the search nodes, it assumes the search pattern contains only one node per road. This is in keeping with the barrier patrol technique as described earlier. It also offers one reason why the search nodes are defined by road distance rather than straight-line distance, since as Figure 3.1 shows, the later method can result in multiple search nodes per road. Figure 3.2 graphically demonstrates the ideas of Patrol Efficiency and Search Effectiveness.

Consider a special case where all nodes and routes are equal. Since each search node is of equal distance, the efficiency related to each node is equal. If the enemy is equally likely to use any

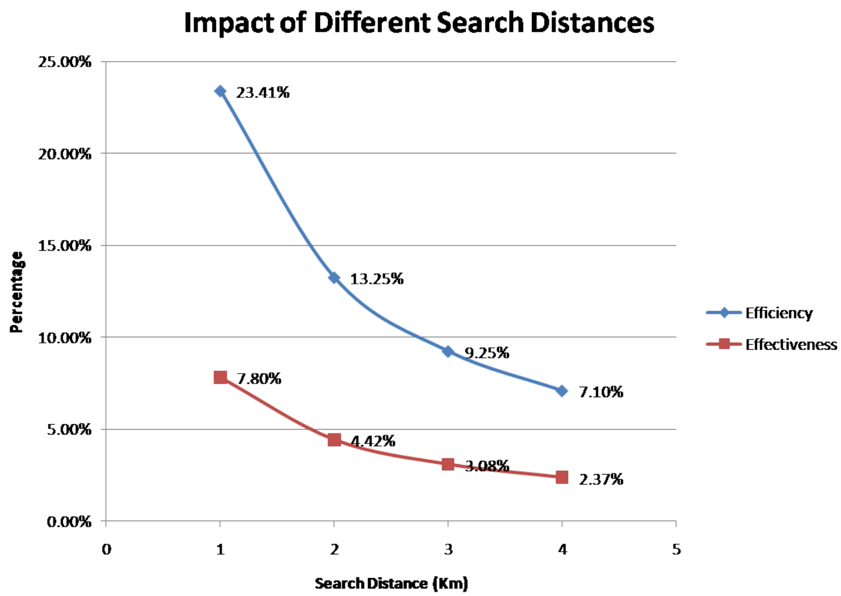


Figure 3.2: Impact of Search Distance: This graph shows the values of Patrol Efficiency and Search Effectiveness for various distances.

of the routes, the probability that the VBIED is on a given route is $1/(\#\text{ of routes})$, assuming that the enemy is definitely conducting an attack and the probabilities for each route sum to 1. Multiplying this probability times the efficiency gives the search effectiveness, which in this case is constant for each node. Therefore, in this special case of uniform target likelihoods and identical roads, overall Search Efficiency $= \frac{\text{Patrol Effectiveness}}{\#\text{ of routes}}$.

3.2.3 Patrol Success

The final measure of effectiveness to be considered in this model of UAV employment is the Patrol's Success. This is a measure of interdicting the VBIED and actually stopping the attack. It is a function of the Search Effectiveness and how far from the base the detection occurs. In order to be considered a success, the patrol must not only detect the VBIED, it must allow sufficient time and distance for a ground force to stop the target before it can cause damage to the base.

Blast Range

To begin with, a blast range for the VBIED is estimated. For this project, the blast range is arbitrarily set at 500 m. In practice, this range would be determined from intelligence estimates that predict the potential size of the VBIED and then using a look-up table to determine the blast range for VBIEDs of that size. The blast range represents the straight-line distance from

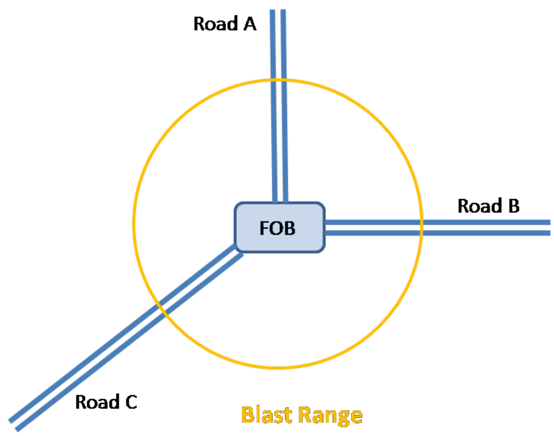


Figure 3.3: Blast Range Diagram: The circle in this figure represents the estimated blast range of the VBIED. If the VBIED reaches the circle, the explosion will cause damage to the FOB. This is the point at which the defenders must stop the VBIED.

the base at which the VBIED would cause damage to the base if the bomb explodes at that point or closer, without considering the mitigating effects of shielding by terrain or buildings between the explosion and the FOB, which can be studied by more sophisticated models to incorporate these effects in future work. This blast range is the point at which the defenders must stop the target. Figure 3.3 graphically displays this concept.

Threshold Distance

Based on the scenario, the defenders have a ground force that can be used to interdict the target. The QRF is located at the base until a decision is made which road to go down. Once the QRF is launched down the appropriate road, it must travel to at least the farthest point where that road enters the blast range before the VBIED reaches that point in order to be successful. In the simple case of straight roads, this is a straightforward time-distance analysis. In order for the QRF to have a chance at reaching this point, the detection must occur at a distance farther away. To determine this distance:

1. Calculate the time it takes the QRF to reach the blast range, using the estimated QRF's speed for that road.

2. Estimate the speed of the VBIED travelling on the same road.

3. Calculate how far the VBIED can travel in the time it takes the QRF to reach the blast range.

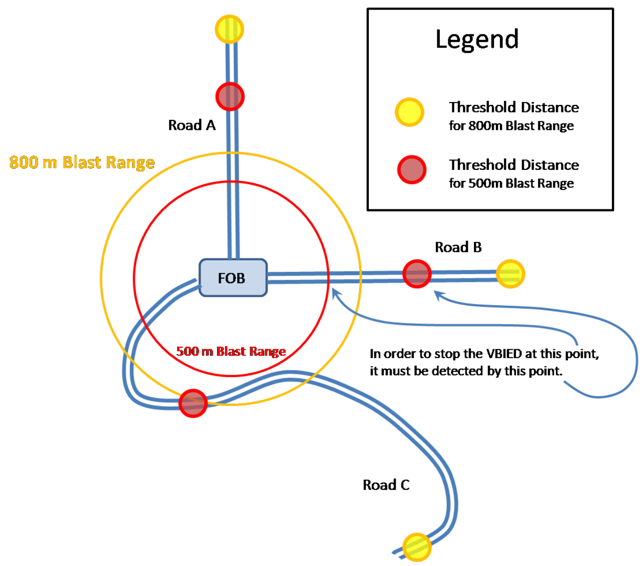


Figure 3.4: Threshold Distance: This figure shows the Threshold Distances for two blast ranges. In order to stop the VBIED at or before the Blast Range (the large circles), it must be detected at or before the Threshold Distance (the small circles). Note that with a curved road, a small change in Blast Range can cause a big change in Threshold Distance.

4. Add this distance to the blast range (adding a road distance measurement to a straight-line distance).

5. Using road distances, determine how far along the road this distance is.

This is the point at which the detection must occur for the QRF to have a chance at stopping the attack. This point is called the Threshold Distance (TD), and is given by the equation:

$$\text{TD} = \text{VBIED Speed}\left(\frac{\text{Blast Range}}{\text{QRF Speed}} + \text{QRF Launch Time}\right) + \text{Blast Range}$$

QRF Launch Time is the time between when the detection occurs and the time that the QRF actually departs the FOB. If the target crosses this threshold before being detected, and then acts optimally, the defenders cannot successfully stop the attack, and the VBIED will detonate within the blast range causing some damage to the FOB. The TD is also the minimum distance from the base that the UAV should search; putting a search node within the TD does not help stop the attack and would be pointless. Curved roads complicate the analysis, but the concept is still the same. Figure 3.4 graphically shows how Blast Range and TD relate for this more complex case.

The Threshold Distance represents the minimum threshold given ideal circumstances and reliable estimates. However, any number of factors could allow a successful VBIED attack even if a detection occurs outside the TD. If the size of the bomb is underestimated and it is really larger than anticipated, the actual blast range will be larger, and so even if the QRF stops the VBIED at what was planned for as the blast range, the base could still be damaged in the explosion. The estimates for travel speed could be wrong: the VBIED might go faster or the QRF could travel slower or road conditions might delay the QRF. In either case, if the detection happens right at the TD, the defenders risk not being able to stop the VBIED in time. This also assumes the time to launch the QRF once a detection is made is known. In practice this is highly variable: someone will have to analyze the UAV image or video and decide if it is a legitimate detection, and then decide to launch the QRF, and unless the QRF is sitting at the gate with the vehicle engines running (which may not be feasible), there will also be time between the decision to launch the QRF and when it actually starts moving. All of these factors contribute to the possibility that the VBIED attack might be successful even if a detection occurs before the Threshold Distance. These facts motivate the need to study the robustness and sensitivity of any strategy employed by the defenders.

QRF Reward Value

To mitigate these risks and allow the QRF the best opportunity to stop the VBIED at a safe distance, the defenders will want to maximize the distance at which the detection occurs. However, the farther away from the base that the UAV flies, the less effective the search becomes, as defined above. To maximize Search Effectiveness, the UAV should be flown as close to the base as possible, thus minimizing the travel time between search nodes, which increases the Patrol Efficiency and leads to increased Search Effectiveness. These two competing interests conflict with each other: one suggests flying the UAV as far away as possible (for earlier detection) and the other flying the UAV as close to the base as possible (for increased chance of detection).

Patrol Success, then, combines these two conflicting measures of effectiveness. To do this, a QRF Reward Function is used to measure the value of detecting the target at a distance greater than the Threshold Distance. For this project, a simple linear function is used. If the detection distance is below the TD, the QRF reward value is negative, indicating the QRF has no chance of successfully stopping the attack. At the TD, the value function crosses the x axis; at this distance the QRF reward value is zero, showing this is the minimum distance at which the defenders can be successful. The function increases linearly, indicating that as the detection distance increases, the value for the QRF also continues to increase. However, a more accurate function can also

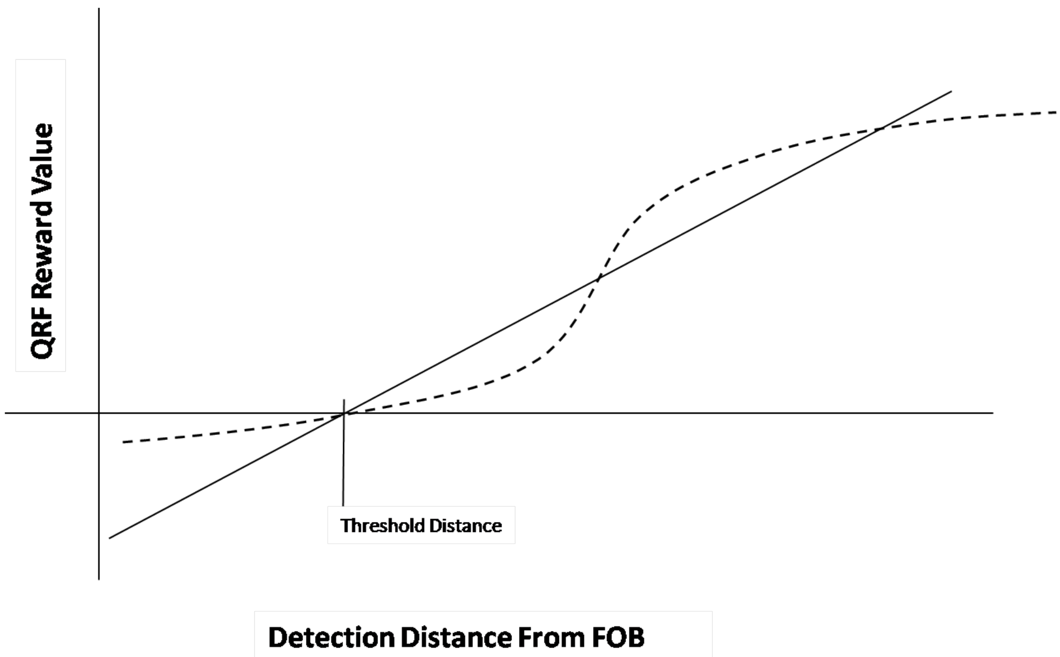


Figure 3.5: QRF Reward Value: This graph shows the function for the QRF Reward Value. This model uses a simple linear function, as shown with the solid line. The dashed line represents another function that is potentially more accurate. Both functions have a reward value of zero at the TD. Below this distance, the reward value is negative, indicating a penalty for failing to interdict the attack, since a detection at these distances does not allow the QRF time to stop the VBIED before it reaches the blast range.

be developed, and might have more of an ‘S’ shape as in a sigmoid curve. Figure 3.5 shows a general graph of these two functions. At distances near the threshold, the reward value probably should increase slowly: the difference in stopping the target at 600 instead of 500 meters is perhaps not that significant given the potential accumulation of errors in this range. Likewise, at large distances, the increase in value should also be small: the difference in stopping the VBIED at 5.1 km instead of 5 km is not that significant, since that distance is so far outside of the blast range even if the worst case estimates were true the attack would still likely be stopped successfully; also, at this range, there is very little if any benefit to stopping the attack farther away. However, a 100-meter difference at a medium range could be more significant than at a close or far range. More research is needed to justify this, however, and for simplicity, this project uses a simple linear increasing function:

$$\text{QRF Reward Value} = \text{Road Distance of Detection} - \text{TD}$$

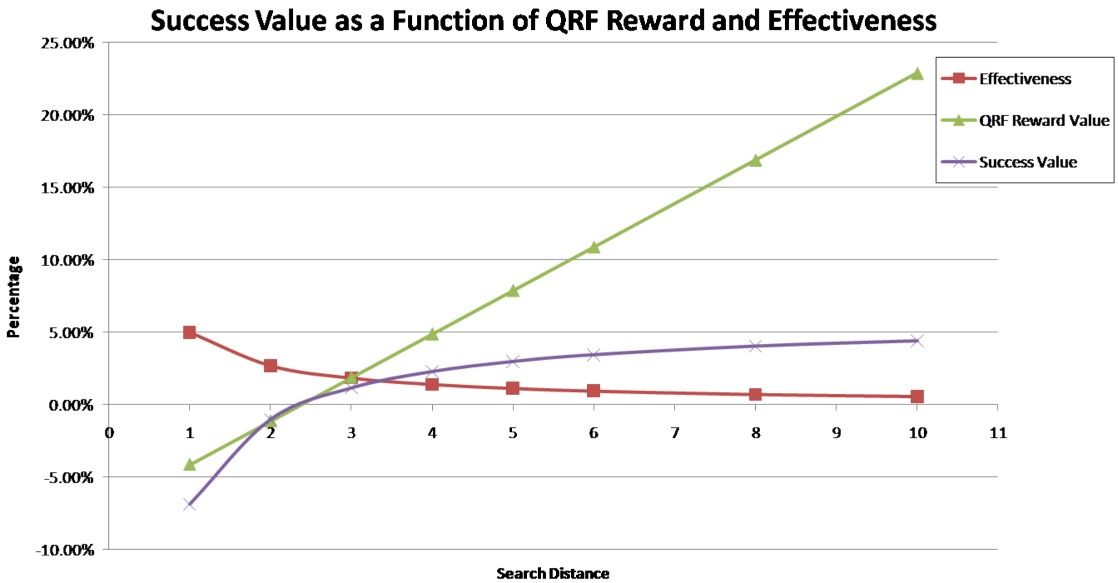


Figure 3.6: Success Values: This graph shows the relationship between Search Effectiveness, QRF Reward Value, and the Patrol Success Value for various distances.

Calculating Patrol Success

The final measure of Patrol Success is now determined by multiplying the Search Effectiveness value times the QRF reward value.

$$\text{Patrol Success} = (\text{Search Effectiveness}) \times (\text{QRF Reward Value})$$

By scaling the functions appropriately, the relationship between the Success Value, QRF Reward, and Search Effectiveness can be shown together, as seen in Figure 3.6. The success value is continuously increasing as search distance increases. Since the effectiveness function logarithmically decreases, the success value approaches a limit. Intuitively, one might expect the success function to begin decreasing at some point, indicating an optimal search distance. If the QRF Reward function is adjusted as described above to account for nonlinear dependencies on range, then this will potentially happen.

This completes the model for the UAV employment. The next step is to examine the factors that influence the QRF's employment. Some of these were already considered, such as when determining Threshold Distance, but there are several other important considerations that impact the decision on how to employ the QRF. These are discussed in the next section.

3.3 QRF Employment Factors

3.3.1 Characteristics

Once the VBIED is detected, the second part of the defense takes place: interdicting or stopping the attack by the QRF. This is a ground-based unit that the defenders control and will use to interdict the VBIED attack. Its specific characteristics will vary with the unit and location involved, but in general, assume that the QRF meets the appropriate minimum requirements of the given unit for a combat patrol to interdict a suspected VBIED. For many units, though not all, this means at least two or three vehicles with three or more people per vehicle. It will also have the appropriate weapons, communications, counter-IED equipment, and other mission specific equipment in accordance with that unit's Standing Operating Procedure (SOP). For the purposes of this scenario, the QRF is modeled based on a SOF team with limited manpower and resources such that it cannot split into two separate elements: the defenders only have enough forces to conduct one regular patrol at a time. Regardless of its specific characteristics, assume that the QRF can perform the VBIED interdiction mission as given in this scenario.

Similar to the UAV, there are numerous methods of employment for the QRF. As stated in the scenario description, for the purposes of this project, the QRF is held on stand-by at the FOB waiting for the detection of the VBIED and a decision to launch the QRF. Ideally, the UAV makes this detection away from the base, but as a last line of defense the QRF can also self-detect the VBIED once it is in visual range of the base. Although in the field experiments the QRF did self-detect, the following analysis assumes that the UAV must make the detection.

3.3.2 Employment Possibilities

The key independent variable related to the QRF employment to be examined here is when to launch it. There is a finite range of feasible alternatives, from launching as soon as a detection is made to waiting until the last possible moment that would still allow the QRF to stop the attack outside the blast range. There are several dependent variables used to evaluate the results of these alternatives, including various types of risk and costs.

At one end of the range of possibilities, the defenders could launch the QRF as soon as a possible VBIED is detected. This would ensure the target is interdicted as far from the base as possible, limiting the chances of the facility suffering any effects from that attack. In a simple, straightforward scenario in which a single VBIED is the only threat, this would lead to maximizing the base's security and is the best option. However, other factors complicate the situation. By launching the QRF as soon as possible and having it stop the VBIED as far from the base as possible, the defenders reduce the opportunity for the QRF to respond to a second threat coming on a different road. The identified target could possibly be a decoy, or as mentioned in the introduction, the use of multiple VBIEDs is not unheard of. Therefore, some trade-off exists. Does the QRF maximize its chances of successfully interdicting the already identified target at the increased risk of an as yet unidentified second attack? Additionally, there are some other costs associated with deploying the QRF to stop the target as far away as possible.

Travelling farther out to stop the VBIED also has a cost of increased risk to the QRF. Areas threatened with VBIED attacks are also likely to face roadside IEDs, and so every extra mile driven puts that unit at increased risk of attack. If the QRF drives five miles to stop the VBIED when it could have just as effectively stopped it at one mile away, then that is an extra eight miles round trip that the QRF is exposed to a possible IED or ambush attack. Also, the farther away from the base the QRF goes, the more difficult it will be for the defenders to send out a rescue team to help if the QRF is ambushed or to conduct a Medical Evacuation in the case of casualties. So by sending the QRF farther from the base, it is more likely to be attacked and the results of an attack are likely to be more damaging.

There is also an increased cost of the QRF's time spent travelling farther away. Depending on the environment and Operations Tempo (OPTEMPO), even a small time increase could be significant. For example, in 110-plus degree heat while wearing full battle gear, and extra 20 or 30 minutes on a combat patrol will negatively impact effectiveness. Also, if the members of the QRF are kept too busy due to a high OPTEMP, fatigue can become a problem, and even a short extension of a patrol may have a big impact.

Finally, there is also a small but increased cost for fuel and wear and tear on the vehicles by having them drive farther to interdict the VBIED. This is perhaps a negligible cost, and in general logistical considerations such as this should not drive operational decisions such as how to employ a QRF. However, in certain situations this cost might have greater importance. For instance, in a remote base where either the enemy or weather has temporarily cut off resupply, every gallon of fuel saved might be significant, and in this case the logistical costs of an alternative should certainly have a greater weight in the decision making process.

Although interdicting the VBIED as far from the base as possible may seem like the ideal situation, for all of these reasons launching the QRF as soon as a detection is made might not be the optimal decision. At the other end of the range of possibilities, the defenders could launch the QRF as late as possible in order to interdict the VBIED at the blast radius (the minimum distance from the base to avoid any blast effects against the facility). In other words, delay sending the QRF until it will reach the blast radius at just the right time to stop the target at that point. This has the desired effects of minimizing the costs identified above associated with using the QRF (resources, time, risk) as well as increasing the chances that the QRF can successfully respond to a second attack. However, this strategy puts the base at increased risk. As mentioned in the discussion of the threshold distance, all of the factors that determine when the QRF should be launched in this case are estimates, including speed of the VBIED, size and blast range of the bomb, and speed and response time of the QRF. Even if some of these factors are known, they may change once the decision is made. For instance, the UAV might be able to determine the VBIED's exact speed at the time of detection, but there is no way to predict its future speed with complete accuracy and reliability. If the defenders use that information to decide when to launch the QRF in order to interdict the target at exactly the blast radius, and the VBIED then speeds up, the bomb will get inside the blast range and will cause blast effects against the base. Similarly, the other factors used to make this decision are estimates and/or can change depending on conditions of each specific situation. If any of these assumptions or estimates are wrong or change, and the defenders delay so as to launch the QRF as late as possible, the VBIED could easily get within the blast range and damage the facility. Therefore, the strategy of waiting to launch the QRF as long as possible involves some amount of risk.

Ideally, some middle ground strategy between these two extremes can be found and used. As mentioned, the trade-offs are amount of risk to the base against efficient use of the limited QRF resource. For the purposes of this project, the QRF employment methods are divided into three alternatives: launch as early as possible, as late as possible, and at a mid-point in between the two extremes.

3.3.3 Decision Matrix

All of these factors are combined in a decision matrix to show how they all fit together, as shown in Figure 3.7. This is a 9x5 matrix: on the left are the nine friendly alternatives for the defenders and across the top are the evaluation criteria.

The alternatives are made up of the different UAV and QRF employment methods. There are three UAV strategies: patrol far from the base (UAV Far), patrol near the base, but still outside the Threshold Distance (UAV Near), and patrol at a middle distance between these two (UAV

			Risk			Expenses	
			From Known Target	From Unknown Target	Risk to QRF	Fatigue	Tangible Costs (Fuel, Wear on Vehicles, etc.)
Alternatives	UAV Far	QRF Early	Min	Max	Max	Max	Max
		QRF Mid	Low	High	High	High	High
		QRF Late	High	Min	Min	Low	Min
	UAV Mid	QRF Early	Low	High	High	High	High
		QRF Mid	Medium	Medium	Medium	Medium	Medium
		QRF Late	High	Low	Low	Low	Min
	UAV Near	QRF Early	Low	Medium	High	Medium	Medium
		QRF Mid	High	Low	Low	Low	Low
		QRF Late	Max	Low	Low	Min	Min

Figure 3.7: Decision Matrix. This figure shows the nine friendly alternatives for the defenders on the left and evaluates each according to five evaluation criteria across the top. The values within the matrix represent how well each alternative does evaluated against the criteria, and since they represent risk and expenses, lower is better.

Mid). For each of these UAV strategies, there are also three QRF strategies: deploy the QRF as soon as possible (QRF Early), as late as possible (QRF Late), and halfway in between these two times (QRF Mid). The possible combinations result in the nine different alternatives.

Across the top of this matrix are the evaluation criteria used to judge each of the alternatives. These are the factors described in the previous section, and they are divided into two categories: risk and expenses. The criteria include: risk to the FOB from the known target, risk to the FOB from an unknown target, risk to the QRF, QRF fatigue, and tangible costs. Figure 3.7 shows the qualitative assessment for each alternative using the evaluation criteria. Because these are negative factors (risks and expenses) that the defenders want to reduce, *lower values are better*. In each column, the alternative with the minimum and maximum values are identified, and the others are given a low, medium, or high ranking.

In the "Risk to FOB from Known Target" column, the best alternative is if the UAV identifies the target far and QRF is launched early; this stops the VBIED as far away as possible and provides the best chance for the base to escape the attack without any damage. The worst alternative is the UAV identifies near and the QRF is sent late. By sending the QRF late, the defenders are allowing the VBIED to reach the point that they consider to be the minimum safe distance, which depends on accurate assumptions and estimates and as mentioned earlier risks allowing the VBIED to get within the blast range. Since the UAV was patrolling near the FOB, there is little time between detection and when the QRF must launch, and the defenders will not have as much opportunity to update their estimates based on any information from the UAV (i.e., if the defenders had planned for a medium sized vehicle, but the UAV detects a large truck, the blast range should be increased.) In this alternative, there may not be time to accomplish that analysis and make the adjustments. If the UAV patrols farther out, the defenders will have more time to analyze the information from the UAV and update the model.

The values in the "Risk to FOB from Unknown Target" are nearly reversed. The UAV Far and QRF Early alternative is the worst (Max) for this criterion, while it was the best previously. In this alternative, the QRF will be farther away from the FOB than in any other alternative, and so it will be less able to react to a new threat and interdict a second VBIED on a different road. For this criterion, deploying the QRF Late is the best alternative (Min), although rather than pairing it with UAV Near, which is the worst alternative in the previous column, in this case it is paired with UAV Far. This alternative provides the most time between detection and deploying the QRF to allow for more planning and to allow the UAV or QRF itself to detect a second threat.

The values in the "Risk to QRF" column are relatively straightforward. This criterion encompasses the probability of a mishap to the QRF and the severity of the consequences. The probability of the QRF being ambushed or attacked by a roadside IED is strictly a function of how far it travels. The severity of the consequences is a function of both how far the QRF travels and how much time it has before deploying. The farther the QRF is from the FOB, the longer and more difficult it will be for the defenders to send aid to assist the QRF if needed, resulting in more exposure to enemy fire and longer times to evacuate casualties, both of which tend to result in more severe consequences. The values for this criterion are very similar to the previous one. Just as with that one, the UAV Far and QRF Early alternative is the worst because it has the QRF the farthest from the FOB. As the required QRF distance decreases, the risk also decreases. The three QRF Late alternatives all have the QRF traveling basically the same distance: out to the estimated blast range. In these cases, the increased reaction time between detection and deployment cause the values for UAV Far and UAV Mid to be better. This extra time between finding out which route to take and deploying allows the QRF to do last-minute planning and coordination along a specific route. This serves as a risk mitigation factor, so the best alternative is UAV Far and QRF Late. Although these two columns are similar in this general model, each represents a different criterion used to evaluate the alternatives. In a specific situation, conditions might be such that the values become different or the weighting of the criteria (discussed in the next section) changes, and so keeping these criteria separate is necessary.

Similarly, the last two criteria are also closely related but kept separate. The "Fatigue" column represents how much the QRF is employed: this is the 'wear and tear' on the personnel in the QRF. Again, the UAV Far and QRF Early alternative is the worst, because it requires the QRF to do and travel the most. As the QRF distance decreases, the fatigue value gets better. This also takes into account the time between detection (and when the QRF is put on alert) and deployment. The UAV Far and QRF Late alternative has the most time between alert and deployment when the QRF is all prepared and ready to go. Although not as stressful as being outside the base on patrol, standing-by like this is not as good in terms of fatigue as relaxing while waiting to get an alert. Therefore, the best alternative for this criterion is UAV Near, QRF Late.

Finally, the "Tangible Costs" criterion simply measures such expenses as fuel, maintenance, and repair parts. These values are strictly a function of how far the QRF travels. Since the three QRF Late alternatives have the QRF go the same distance to the blast range, these three are all the same, with a Min value. This is the only column in which there are multiple Min or Max values.

3.3.4 Weights

Each of the five evaluation criteria is given a weight which all together sum to one to show its relative importance to the others. These weights can be assessed through various means commonly used in Decision Theory analysis, such as direct assessment, equal weighting, rank reciprocal, or swing weighting. These weights will change based on the individuals involved and the specific conditions of a given scenario. Figure 3.7 shows an example weighting in the row highlighted in gray, subjectively assessed for the given scenario. In this case, the risk from the known target is determined to be the most important consideration, and it is given the highest weight of 0.5. The risk from an unknown target and the risk to the QRF are considered equally important, and both have weights of 0.2. For the expenses criterion, fatigue is weighted at 0.15, just slightly lower than the two previous risk criteria. As mentioned earlier, the Tangible Costs criterion is usually not an important consideration in this level of decision making, and so it is given a small weight of 0.05.

If circumstances change, these weights could change as well. For example, most deployed units now have armored vehicles. If the defenders in this scenario have two of the better armored vehicles, such as a Mine Resistant Ambush Protected (MRAP) vehicle, at the base for the QRF to use, the decision maker might feel that a weight of 0.2 for Risk to QRF is appropriate since the QRF is secure in their armored vehicles. However, if both vehicles go out of service for maintenance problems and the QRF is forced to use unarmored vehicles for the next patrol, the decision maker should consider the Risk to QRF to now be a more important consideration and increase its weight accordingly until the armored vehicles are back in service. Similarly, the Tangible Costs criterion is usually not a significant factor, but based on the discussion in the previous section it could become significant in certain situations, and if that happens it should be given a greater weight. The other criteria weights, too, can change based on changing circumstances.

3.3.5 Cost Function

The expected cost function for each alternative now needs to be calculated. Remember that this table is measuring risk and expenses, so lower values are better. The qualitative values from Figure 3.7 are converted to quantitative values as follows:

- Min = 0
- Low = 1 to 3
- Medium = 4 to 6
- High = 7 to 9
- Max = 10

The specific numbers within the low, medium, and high categories are subjectively assessed. The five values for each alternative are multiplied by the corresponding weight and then added together. The value of the cost function, C, is given by the equation:

$$C_i = \sum_{n=1}^{5} w_n v_{i,n} \forall\, i \in \text{Set of Friendly Alternatives,}$$
$$\text{where } v_{i,n} = \text{the value of alternative } i \text{ evaluated against criteria } n$$

Figure 3.8 shows the final matrix, with qualitative assessments replaced by numbers, weights, and the total value of the cost function shown in the far right column.

In this example, the UAV Far and QRF Late alternative is the best, at 4.3. UAV Near and QRF Early is second, at 4.6. UAV Mid and QRF Mid is the worst alternative at 6, although it provides

			Risk			Costs		
			From Known Target	From Unknown Target	Risk to QRF	Fatigue	Tangible Costs (Fuel, Wear on Vehicles, etc.)	Totals
Weights			0.4	0.2	0.2	0.15	0.05	1
Alternatives	UAV Far	QRF Early	0	10	10	10	10	**6**
		QRF Mid	2	9	8	8	8	**5.8**
		QRF Late	6	0	0	2	0	**2.7**
	UAV Mid	QRF Early	3	7	8	8	8	**5.8**
		QRF Mid	5	5	5	5	5	**5**
		QRF Late	7	1	1	1	0	**3.35**
	UAV Near	QRF Early	4	5	6	5	5	**4.8**
		QRF Mid	8	3	3	3	3	**5**
		QRF Late	10	1	1	0	0	**4.4**

Figure 3.8: This matrix has the qualitative assessments from the previous figure replaced by numbers, and the expected values using the appropriate weighting for the set of evaluation criteria are shown in the far right column.

the best result in terms of protecting the base from the known VBIED attack. Obviously, this is simply a decision tool, to help analysts explain their thought process to a decision maker and to help decision makers make a better, more informed decision. Decision makers and/or the analysts supporting them can clearly make adjustments to the specific values and weights based on experience and the advice of Subject Matter Experts, and making such changes may result in a different outcome. Therefore, this table should be treated as what it is: an aid to help make a decision, and not treat the resulting answer as the decision itself.

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CHAPTER 4:
The Enemy Attacker

So far, everything presented in the model has been focused on the defenders and their options; the enemy thus far has been presented as an unthinking element, reduced to a VBIED attack that the defenders know will happen but not when or where. In reality, the enemy is a thinking opponent who has his own alternatives and strategies available to maximize the chances of his success. To account for that, this project takes a game theoretic approach and examines the strategic interactions between attacker-defender in this scenario.

4.1 Enemy Characteristics

For this project, the enemy is considered to be an insurgent or terrorist group opposing U.S. military forces in a combat zone, such as is found in Afghanistan. We assume the enemy is fully capable of conducting a VBIED attack as described in this scenario (i.e., they have access to sufficient explosives and expertise to assemble a suitable IED as well as a commited driver willing to conduct a suicide attack.) Additionally, we assume the enemy is secure during the planning and preparation for the attack, to the point that the local defenders cannot disrupt the attack during this phase. Ideally, Counter-IED strategy focuses on disrupting the IED network and the attack before it is implemented, but in this case we force the defenders to deal with the VBIED attack as it happens.

Although the enemy is assumed to be a fully capable, rational actor committed to the attack, this is a worst case scenario and the defenders should not ignore the possibility that unexpected circumstances will create a less than optimal enemy attack. If the defenders are following a QRF Late strategy, and the QRF has an unexpected delay leaving the FOB, they might assume that there is no chance of stopping the attack if they believe the enemy will act optimally. In this case, the defenders might switch strategies completely, and rather than continue to send out the QRF they might try to move everyone to a bomb shelter. In reality, there are numerous reasons why the attack may not proceed as well as the enemy would hope: the vehicle may break down, the road could be blocked, or the driver could have a change of heart and delay the attack. Although planning for the worst case is fine and appropriate, the defenders must also realize that the worst-case scenario might not happen and therefore not base all decisions solely on that assumption.

4.2 Route Factors

4.2.1 Enemy Use Probability

Although the simple scenario presented earlier assumes the enemy is equally likely to use any route, there are factors that would cause the enemy to prefer one route over another, and the model developed in the previous chapter allows for this change in probability. These factors are grouped into four general categories: security factors, physical terrain, human terrain, and impacts on detection and interdiction. The defenders' intelligence analysts should have an understanding of these factors and be able to provide information needed to develop an estimate of the probability that the enemy would use a particular route.

Security Factors

Each road will have a different level of security associated with it related to the presence of local or foreign military security forces. Roads that primarily go through insurgent controlled territory where the U.S. military and local national security forces do not have a strong presence will be more favorable for the enemy. The enemy will also want a secure location out of which to stage the VBIED. If one of the three roads in this scenario passes through a village known to be an insurgent stronghold or safe haven, the defenders should be more likely to expect the attack to come from that road. Conversely, roads through areas that are firmly controlled by friendly forces or that pass by friendly or host nation forces' facilities are less favorable for the enemy. If a particular road passes next to a police station or through a permanent checkpoint, for example, the enemy might be more reluctant to use that route than another one that avoids such locations.

Physical Terrain

The roads themselves factor into the probability of which route the enemy prefers to use. For instance, if the defenders expect a large truck VBIED, then the roads considered must support that vehicle. If a route crosses a small bridge or goes through a town with narrow streets and tight turns, the enemy will be less likely to use that route for a large VBIED. There would be a greater chance of the attack being disrupted by the truck getting stuck in the town or by the bridge breaking, and so although the route might remain a possibility it would be less likely to be used. Speed of travel on the road is also a consideration. A road that consists of portions that are little more than rocky dirt tracks through the mountains means very slow travel, which creates more exposure for the VBIED and more time for the bomber to change his mind, so the enemy might be less likely to use that route. Various other similar factors can influence the likelihood that the enemy will use a particular route. For each specific situation, the road network must be analyzed to determine an estimation of these probabilities.

Human Terrain

The people along a route are also a consideration in determining how likely the enemy is to use a particular road. Different from the Security Factors which focuses on the military and police control of an area, this factor considers the sentiments of the local people and whether they favor the insurgents or the defenders. The enemy will prefer a road that travels through areas where the local people support the enemy's cause. If the vehicle develops mechanical problems or if the defenders' actions require a delay in the attack, the enemy will be more likely to find sanctuary and support along a road that is in such an area. In an area where the people are against the insurgents and support the friendly forces, the enemy might not find the needed support from the local people. Also, people unfriendly to the insurgents will be more likely to report to the defenders if they notice an outsider or suspect something is wrong. Consider the situation in Iraq during the high point of Sunni/Shia tensions. Imagine the results if a Sunni insurgent drove through a Shia town on his way to conduct a VBIED attack and the car broke down in that town: he most likely would not find anyone sympathetic to his plight willing to provide supprt, and the defenders might receive a good tip on the attack from one of the locals. Ideally, the enemy will avoid this situation and try to stay in areas that are friendly or at least neutral towards them.

Impacts on UAV

In addition to impacting the probability that the enemy will use a particular route, unique local conditions along each route also impact the ability of the UAV to make an accurate detection. As stated earlier, this project does not consider the impacts of different UAV sensors or their specific probabilities of missed detection. However, variations in the probability of missed detection in different areas due to local conditions are important factors considered in this project. There are many different reasons for these variations, several of which are explained here, and for each specific situation these factors will have to be analyzed to determine the appropriate probabilities.

To analyze these variations, start with the baseline probability of a missed detection, β, which will be unique to each sensor. Imagine that the VBIED is in the ideal setting with perfect conditions to make an accurate detection: the probability of a missed detection in this case is simply β based solely on the sensor. In such a situation, the target is most likely stationary, or at least slowly moving at a constant speed, on a straight and level road. The lighting conditions are perfect for the particular sensor being used, and there are no obstructions that could block the VBIED from the sensor's view. Of course in the real world perfect conditions do not exist and there will be numerous factors that degrade the sensor's ability to make an accurate detection.

For example, the road could travel through a forested area with large trees where the vegetation obstructs the UAV's sensor, or it could go through an urban area with tall buildings that will mask the road from the UAV's view unless the UAV is directly over the road. Both situations will limit the UAV's ability to detect the target, increasing the probability of a missed detection. Rolling terrain will also negatively impact the probability of detection compared to flat terrain; in general, the steeper and higher the hills, the harder it will be for the UAV to see the target.

Environmental factors might also be a significant impact. Depending on the size of the area being searched, environmental factors might impact the whole area equally, such as overcast skies or heat shimmer from high temperatures. However, if in a particular situation there are in fact environmental factors that impact only a specific area, they should be considered. For example, if one road travels through an area that always has thick morning fog and there is rarely fog on the other roads, then the area prone to fog should have a higher probability of missed detection. Similarly, a road might pass by a land fill that burns trash, resulting in smoke and haze along that section of road, which will reduce the UAV's ability to detect the target there.

Finally, background noise along each route is also a consideration when assessing probabilities of missed detection. This model assumes that the UAV is able to determine which vehicle is a VBIED, thus making an accurate detection. How this is accomplished is not addressed: perhaps the area is remote enough that the defenders know all of the local vehicles and can recognize a vehicle that does not belong in the area and will assume it to be the VBIED, or future technology is able to accurately detect the VBIED itself rather than just the vehicle (explosives sensors as called for in the DHS solicitation for research). In any case, the mechanics of how the determination is made are not important here—except that however it is done, increased background noise will make that detection more difficult. If the target is the only vehicle on the road and the sensor and analyst are able to focus exclusively on it, the probability of a good detection is higher than if the target is mixed in with many other vehicles and the sensor and analyst must examine all of them. Therefore, traveling through areas with other vehicles will tend to increase the probability of a missed detection.

Impacts on QRF

Just as local conditions along the roads impact the UAV's ability to detect the VBIED, they can also impact the QRF's ability to interdict the VBIED. In a similar manner, these factors need to be identified and analyzed, and a probability of missed interdiction can be developed for each area. For example, just as an increased number of vehicles can make detecting the target more difficult, it can also make stopping the target more difficult. Imagine that the QRF has to stop a single vehicle traveling along an otherwise empty highway; now compare that with trying to pick out and stop a specific vehicle on a busy highway where there might be dozens of vehicles passing by every few seconds. Interdicting the VBIED in the second situation is significantly more difficult, and unless the QRF has sufficient resources to enforce a checkpoint on the highway, the probability of a missed interdiction at that location will be higher than in the situation where the target is the only vehicle on the road. Similarly, other factors will also influence the likelihood of the QRF successfully stopping the VBIED or having a missed interdiction and letting the VBIED get past.

4.3 Probability Tables

Based on the above route factors, two tables are developed to reflect the information about the impacts of local conditions along the different routes that the enemy can attack on: a probability of missed detection table and a probability of missed interdiction table. These probabilities are subjectively assessed and are not based on analytical or experimental data. These tables are primarily used to represent the *relative* likelihood of a missed detection or interdiction at a given area versus another, rather than the *actual* value of that probability. In keeping with the employment methods of both the UAV and QRF, in which they are sent far from the FOB, kept near the FOB, or sent to a mid-point, the attack routes are also divided into far, mid, and near areas.

4.3.1 Missed Detection Table

This table deals with the UAV, so each row represents a UAV strategy: Far, Mid, and Near. For each road, the probability of a missed detection at those three distances is assessed. We assume a baseline probability of missed detection of 0.2 and increase that for local conditions. Table 4.1 shows an example based on the scenario set at Camp Roberts. See Appendix A for an annotated map of this area showing the FOB location and three roads under consideration.

Road 1 is fairly open with good visibility along its entire length, which is good for low missed detection rates, but at the near and far distances, there are some steep and curvy sections where

	Road 1	Road 2	Road 3
Far	0.6	0.6	0.8
Mid	0.3	0.7	0.5
Near	0.5	0.6	0.5

Table 4.1: Missed Detection Table. This table shows the probability of a missed detection by the UAV at different areas (far, mid, and near) along each road.

the road goes over and around hills, raising the missed detection rate. The entry node for Road 1 is at an intersection with a larger main road, so there is potentially more traffic in that area, and this background noise raises the missed detection rate slightly higher as well. For Road 1, the probabilities of missed detection are 0.6, 0.3, and 0.5 at the far, mid, and near distances.

Road 2 is named Canyon Road and, as might be expected, it travels through a small canyon, with steep and tall hills on both sides of the road. The terrain along this road limits the ability of the UAV to clearly see a vehicle on the road except when the UAV is nearly or directly over the road (i.e., when the UAV is approaching the road the hills mask the road at the bottom of the canyon until the UAV is close, whereas when the UAV approaches the other roads, it can see those roads from a greater distance.) Additionally, there is a small riverbed at the bottom of this canyon along the length of the road, and so the vegetation along Road 2 is significantly greater than along either of the other roads, especially the trees which are larger and more numerous. Both of these factors, the terrain and vegetation, result in higher probabilities of missed detection along Road 2, which gets values of 0.6, 0.7, and 0.6.

The entry node for Road 3 is near an airfield which also serves as the base area for everyone involved in the various field experiments, so this area is busy and the extra vehicles (i.e., background noise) make an accurate detection more difficult. Also, the airspace near the airfield is sometimes restricted limiting the UAV's ability to search that area. Therefore, the UAV Far area on Road 3 has the worst probability of detection at 0.8. The middle section of this road is straight, flat and open, which make for good detection rates when the UAV can fly in that area, but it is still within the airfield's airspace which can limit the UAV's flight; this section of road gets a value of 0.5. The near section is out of the restricted airspace, but hilly terrain in this area partially masks the road, so this section also gets a value of 0.5.

4.3.2 Missed Interdiction Table

This table deals with the QRF and each row represents a QRF strategy and how far from the FOB the QRF will travel. As with the previous table, for each road the probability of a missed

	Road 1	Road 2	Road 3
Early	0.5	0.3	0.8
Mid	0.6	0.1	0.5
Late	0.3	0.2	0.3

Table 4.2: Missed Interdiction Table. This table shows the probability of the QRF missing the target for each QRF alternative on each Road.

interdiction at each of those distances is assessed. Table 4.2 shows the results of the example analysis done for the Camp Roberts scenario.

The probabilities of missed interdictions along Road 1 are given as 0.5, 0.6, and 0.3 for QRF deploying Early, Mid, and Late, respectively. In addition to the intersection with a main road at the end of Road 1, there are two facilities along the middle section of this road which can generate traffic. If the QRF deploys Early or Mid, it may encounter extra vehicles that could interefer with stopping the VBIED. Also, the middle section of this road has several easily accessible side roads that dip behind the rolling terrain on which the VBIED could hide to escape notice of the QRF (particularly if the driver notices the dust cloud from the QRF vehicle or if a spotter informs the VBIED driver that the QRF is approaching). Therefore, the middle section gets the highest value for this road.

Road 2 is the easiest attack route on which the defenders can interdict the target. Although the riverbed and hilly terrain make detecting the VBIED difficult, they also make interdicting the target easy. Once the VBIED is on the road, it is very hard to get off the road until reaching the FOB location. There are only a few sites at which a vehicle can cross the riverbed, and the few jeep trails leading up the hill sides are steep and difficult to drive on. This is also a smaller road with little traffic to interfere with the QRF. Therefore, the probabilities that the QRF will fail to interdict the VBIED on this road are small, and they are assessed as 0.3, 0.1, and 0.2 when the QRF deploys Early, Mid, and Late.

If the QRF deploys Early on Road 3, it will encounter the heavy traffic around the airfield and headquarters area. Therefore, the probability of a missed interdiction in this area is high, given at 0.8. However, the rest of this road is relatively clear and the QRF should have little or no intereference. There are a few opportunities for the VBIED to slip off the road along the middle section, though not as much as on Road 1, and as this road gets closer to the FOB the easier it becomes to interdict the VBIED. The Mid section gets a value of 0.5, and if the QRF deploys Late the missed interdiction rate is assessed at 0.3.

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CHAPTER 5:
Attacker-Defender Strategic Interactions

Now that both the defender and attacker considerations have been examined and a model for each developed, this project considers the strategic interactions between the two sides. Using Game Theory, we determine the optimal strategies that each side should employ. This scenario results in a two-person, zero-sum game. A generalized formulation is presented first followed by a specific example based on the previous Camp Roberts scenario, and then a solution method using linear programming is developed. Several different examples are shown to highlight how the solution changes as the variables in the scenario change, and finally sensitivity analysis shows how to determine when to expect the solution to change.

5.1 Game Matrix Development

To examine the strategic interactions between the defenders and attacker in this scenario a two-person, zero-sum game is used. Table 5.1 shows the game matrix for this scenario with example payoffs. Player I, the row player, represents the defenders; Player II, the column player, is the attacker. The defenders have nine strategies available, as explained earlier: combinations of the three UAV strategies of far, mid and near, with the three QRF strategies of early, mid, and late. These nine strategies are set and will not change with different scenarios. The strategies for the attackers are simply the roads available on which to conduct the attack. In a generalized format, there are as many attacker strategies as there are roads, and in the specific Camp Roberts scenario there are three.

			Enemy		
			Route 1	**Route 2**	**Route 3**
Alternatives	**UAV Far**	**QRF Early**	0.35	0.14	1.12
		QRF Mid-point	0.325	0.13	1.04
		QRF Late	0.105	0.042	0.336
	UAV Mid	**QRF Early**	3.038	1.24	0.744
		QRF Mid-point	2.45	1	0.6
		QRF Late	1.3475	0.55	0.33
	UAV Near	**QRF Early**	0.49	1.568	0.294
		QRF Mid-point	0.45	1.44	0.27
		QRF Late	0.35	1.12	0.21

Figure 5.1: Payoff Matrix: This is the game matrix for the specific given scenario. It shows the nine defender strategies and the three attacker strategies, along with the corresponding payoff value for each pair of attacker/defender strategies.

The payoffs in the matrix represent the likelihood that the VBIED attack will be successful. Therefore, the defenders are minimizing and the attackers are maximizing. For this purpose, the game is zero-sum: if the defenders succeed then the attackers fail, and vice versa. In order for one side to do better or gain an advantage, the other side must do worse or have a corresponding disadvantage.

The payoff values are determined based on three components: the measure of risk and expense, the probability of a missed detection, and the probability of a missed interdiction. Figure 3.8 shows the cost function for each defender strategy, Table 4.1 shows the likelihood of the UAV missing the target on a given road for each UAV employment method, and Table 4.2 shows the likelihood of the QRF failing to interdict the target on a given road for each QRF employment method. These three values are multiplied together for each cell in the game matrix to complete the payoff values, as shown in Figure 5.2.

5.1.1 General Formulation

The game matrix is given by the following formulation:

Indices
s: Defender strategies
u: UAV employment method
q: QRF employment method
r: Attacker strategies (i.e., which road the VBIED is on)
n: the number of roads leading to the FOB

Sets
U: set of UAV employment methods, for $u \in U = \{$Far, Mid, Near$\}$
Q: set of QRF employment methods, for $q \in Q = \{$Early, Mid, Late$\}$
$S_{U,Q}$: set of defender strategies
R: set of attacker strategies, for $r \in R = \{1, ..., n\}$

Data
$C_{s_{u,q}}$ = cost function of strategy s
$D_{u,r}$ = Probability of Missed Detection on Road $r$using UAV employment method u
$I_{q,r}$ =Probability of Missed Interdiction on Road r using QRF employment method q
$P_{s_{u,q}r} = C_{s_{u,q}} D_{u,r} I_{q,r}$: Payoff value given defender strategy s and attacker strategy r

5.1.2 Scenario Specific Matrix

Using the method described above, the specific payoff matrix for the given scenario is developed. Figure 5.1 shows this example game matrix, based on the values used previously.

5.2 Game Solutions

5.2.1 General Solution

To solve this game and determine the optimal strategy or mixed strategy solution, linear programming is used. The Objective Function, Z, is the payoff value resulting from the strategies used, which the defenders wish to minimize. The decision variables are how much the defenders should use each of their nine strategies, given as a percentage. These variables are labeled $X_s \forall s \in S$. In a pure strategy solution, exactly one of these variables will have a solution value of one and the others will all be zero. In a mixed-strategy solution, all of the variables will have a solution greater than or equal to zero but less than one, and the sum of all nine variables must equal one.

To determine the Objective Function value, consider each of the attacker strategies in turn. If the enemy chooses route 1, then the resulting objective function will be the sum of the payoff values for route 1 for each defender strategy times the percentage of time that strategy is used,

$$\sum_{s \in S} P_{s,1} X_s$$

If the defenders have chosen an optimal strategy solution, this sum will be no greater than the overall optimal objective function (i.e., the value that is mutually optimal to both the defenders and attackers). If the enemy chooses a sub-optimal strategy, the defenders could do better than this optimal objective function, but they are guaranteed to do no worse. Therefore, this relationship results in the following constraint:

$$\sum_{s \in S} P_{s,1} X_s \leq Z$$

A similar constraint is developed for each of the other attacker strategies, given by the general form:

$$\sum_{s \in S} P_{s,r} X_s \leq Z \quad \forall\, r \in R$$

The final constraint, which was previously mentioned, is that the sum of the decision variables equals one:

$$\sum_{s \in S} X_s = 1$$

These constraints provide the means to solve the linear program and determine both the optimal strategy solution and the objective function value for the game. This linear program was implemented in the General Algebraic Modeling System (GAMS) as shown in Appendix B. The attackers' optimal strategy solution can be obtained in a similar fashion, or more directly from the dual problem.

5.2.2 Scenario Solution

As an example of a specific solution, the Camp Roberts scenario is solved using the data presented previously. Figure 5.2 compiles all of the relevant information and shows how it is related in one diagram. With this payoff matrix, the solution is for the defenders to use the strategy UAV Mid/QRF Mid, while the attackers' optimal solution is to attack from Road 3. The optimal objective function value is 0.8.

As developed, this particular scenario results in a pure strategy solution. Different data may result in different solutions, and in some cases a mixed strategy solution. Consider the Missed Detection Probability value for UAV Far on Route 3, which is the highest value in the table. Now assume that the reasons for that high value change: for example, perhaps that section of road went through a dense forest area resulting in a high chance of a missed detection, and so the defenders decide to cut down the trees along the road. Without judging the other consequences of such an action, it does have the result of making it easier for the UAV to detect a vehicle on the road in that area. Therefore, the Missed Detection Probability could go from 0.8 to 0.3, resulting in a new payoff matrix as shown in Figure 5.3. As expected since the defenders have improved their detection ability, the objective function value has also improved, from 0.8 to 0.55. The defenders now have a mixed strategy solution and should employ UAV Far/QRF Mid 65% of the time, and UAV Far/QRF Near 35% of the time. The attackers also have a mixed optimal strategy solution. They should still use Road 3, but only 68% of the time, along with Road 1 32% of the time.

Cost Function Table

		From Known Target	Potential Unknown Target	Risk to QRF	Fatigue	Tangible Costs (Fuel, Wear on Vehicles, etc.)	Total (Lower is Better)
Weights		0.4	0.2	0.2	0.15	0.05	1
Alternatives: UAV Far	QRF Early	0	10	10	10	10	6
	QRF Mid	2	9	8	8	8	5.8
	QRF Late	6	0	0	2	0	2.7
UAV Mid	QRF Early	3	7	8	8	8	5.8
	QRF Mid	5	5	5	5	5	5
	QRF Late	7	1	1	1	0	3.35
UAV Near	QRF Early	4	5	6	5	5	4.8
	QRF Mid	8	3	3	3	3	5
	QRF Late	10	1	1	0	0	4.4

Missed Detection Probability

	Road 1	Road 1	Road 3
UAV Far	0.6	0.6	0.8
UAV Mid	0.3	0.7	0.5
UAV Near	0.5	0.6	0.5

Missed Interdiction Probability

	Road 1	Road 2	Road 3
QRF Early	0.5	0.3	0.8
QRF Mid	0.6	0.1	0.5
QRF Late	0.3	0.2	0.3

X

Defender Alternatives		Attacker Alternatives: Road 1	Road 2	Road 3
UAV Far	QRF Early	1.800	1.080	3.840
	QRF Mid	2.088	0.348	2.320
	QRF Late	0.486	0.324	0.648
UAV Mid	QRF Early	0.870	1.218	2.320
	QRF Mid	0.900	0.350	1.250
	QRF Late	0.302	0.469	0.503
UAV Near	QRF Early	1.200	0.864	1.920
	QRF Mid	1.500	0.300	1.250
	QRF Late	0.660	0.528	0.660

Figure 5.2: Payoff Matrix Development: This figure shows how the cost function values, the Probability of Missed Detection and Probability of Missed Interdiction are multiplied together to create the payoff matrix for a specific scenario.

5.3 Sensitivity Analysis

Changing the values in the probability tables as described above generally requires changing the conditions of the scenario and cannot be arbitrarily done. However, the other component of the payoff values, the cost function, does have an element of arbitrariness: the weighting applied to the values of the evaluation criteria is arbitrarily determined by the analyst or decision maker based on what they consider to be more or less important. Determining the sensitivity of the solution to changes in these weights is a useful approach to analyzing the problem. As it is set up, the linear program does not lend itself to easy sensitivity analysis on the weights because these elements become part of the constraint matrix. Converting to the dual problem shifts

			Attacker Alternatives		
			Road 1	**Road 2**	**Road 3**
Defender Alternatives	**UAV Far**	**QRF Early**	1.800	1.080	1.440
		QRF Mid	2.088	0.348	0.870
		QRF Late	0.486	0.324	0.243
	UAV Mid	**QRF Early**	0.870	1.218	2.320
		QRF Mid	0.900	0.350	1.250
		QRF Late	0.302	0.469	0.503
	UAV Near	**QRF Early**	1.200	0.864	1.920
		QRF Mid	1.500	0.300	1.250
		QRF Late	0.660	0.528	0.660

Figure 5.3: Revised Payoff Matrix: This game matrix shows the revised payoff values after a change in conditions changes the Missed Detection Probability for UAV Far on Road 3 from 0.8 to 0.3.

the constraint matrix A in the primal problem to the costs of the objective function in the dual problem. The weights now are part of the costs C, to which sensitivity analysis can be applied. For each specific game, this will provide a range for the weights for which that solution remains valid.

CHAPTER 6:
Field Experiments

As part of this research project, several field experiments were conducted to collect additional data and to validate the results. These experiments were primarily done at Camp Roberts Army National Guard Base in California, through the NPS-SOCOM Cooperative Field Experimentation Cooperative. The first set of experiments was conducted in November, 2009, and was used mainly to confirm the suitability and realistic nature of the scenario as well as the viability of the technology available to support the experiment. At this time, the parameters of the scenario were determined, including the FOB location, road network to be considered, and the distances for the search and entry nodes. The UAV and its sensors were also tested. The primary UAV available was the NPS Rascal with a high-resolution full-motion video camera. The alternate platform available was the Raven UAV. Both UAVs were determined to be feasible in order to support the experiment, although the Raven was determined to be inadequate from an operational perspective. After confirming the details of the scenario in this initial testing period, the field experiment was further refined and developed and fully implemented in May 2010.

6.1 Experiment Procedures

Appendix C contains the procedures used for this experiment as briefed to the participants. The purpose is to test the model that was developed and described previously. To do this, a single QRF consisting of a driver and navigator in a tactical military vehicle was stationed at the three-way intersection where the notional FOB was positioned. Two other drivers in civilian vehicles played the role of VBIED attackers. On a pre-determined schedule, these vehicles departed their designated entry nodes on each of the three roads and drove towards the FOB. The UAV was flying its designated patrol route of either far, mid, or near to the FOB. The entire experiment was controlled from the experiment facility's Tactical Operations Center (TOC), where the UAV video feed was monitored. If the attacking VBIED was detected by the UAV, the TOC informed the QRF which then moved down the appropriate road to interdict the target. If the UAV missed the target and the QRF was able to detect it, the QRF would initiate movement on its own to stop the attack. If neither element detected the VBIED, which happened occasionally, then the VBIED would reach the intersection and that iteration would be considered a successful attack. At the conclusion of each attack, the VBIED returned to its starting point and the QRF returned to the FOB location and awaited detection of the next VBIED.

Ideally, the full model would have been tested, with multiple iterations conducted for each of the nine friendly alternatives. Due to time constraints and the limited availability of the UAV, only three separate runs were planned, each for a one hour time period, which was the approximate flight time for the UAV. Each UAV flight was to represent a different search radius (far, mid, or near), but only the QRF Early alternative was tested each time (i.e., the QRF was always launched as soon as a detection was made; this experiment did not try to test for delaying the QRF launch under the mid or late alternatives). Due to weather, technology, and scheduling problems, only two successful UAV flights were actually conducted, one at the far and one at the near search ranges.

To determine the accuracy of the model, the following data was to be collected:

- Time each VBIED began moving
- Time and location the VBIED was detected
- Time the QRF began moving Time and location that the VBIED was stopped
- Time the VBIED reached the intersection (if not detected and stopped)

6.2 Results

In this experiment, a total of twelve iterations were conducted. In only two iterations did the UAV make a detection (reasons for this low success rate are discussed below). Due to the lack of data and good runs, no significant analytical conclusions can be drawn from these results. However, the results are instructive to demonstrate how the experiment procedures are supposed to work as well as for developing a future framework for analyzing results from the follow-on capstone experiment.

The UAV first detected a VBIED on Road 1 at 1144 hours at the second search node (approximately 2 km from the FOB). The QRF was tasked to interdict the VBIED and left the FOB at 1145. At 1150 the QRF interdicted the target at approximately grid 004571. This shows a successful operation using strategies UAV Mid and QRF Early.

The second detection occured at 1159 on Road 2, where the UAV detected another VBIED. This detection was in the vicinity of grid 009559, approximately 500 meters from the FOB. This was not at a search node and was within the range of the first node. The QRF immediately departed and interdicted the VBIED at 1200 at approximately grid 004995, about 150 meters from the FOB. Although this iteration demonstrates the ideal interaction between the UAV and QRF, since the detection occured within the Threshold Distance it was not a successful operation, and the VBIED was able to get close to the base.

Of the remaining eight iterations, the QRF detected the VBIED on its own five times, but the interdictions in those cases were all within 500 meters. On three iterations, the VBIED was not detected at all and was able to drive all the way to the FOB location.

6.3 Observations

In addition to the analytical results, several other observations and lessons learned resulted from this experiment. In particular, the Raven proved to be an inadequate platform for this task. The speed and sensor capabilities of this UAV were not sufficient to conduct the search over such a large area. Its flight characteristics and handling capability in windy conditions also made flying a designated search route difficult. The network reliability and connectivity with the Raven system also made controlling the experiment from the TOC difficult. Other related experiments within this research project utilize the Raven to track a known target, and the Raven seems better suited for that task, although when flying into even a moderate headwind the Raven's slow speed was still a problem when tracking a vehicle. For the task of flying a repeated search pattern to detect an unknown target, the Raven was particularly ill-suited. Since the Raven is the primary UAV system used by frontline tactical units (including SOF teams), the surveillance and interdiction method developed in this model may not be appropriate for those units to employ if they have to rely on the Raven. This method is better reserved for units that have access to a larger UAV system.

Another significant observation related to the UAV comes from the fact that they were supporting the experiment but did not actually belong to the experiment controllers. Just as in the real world, these UAVs had other tasks to accomplish and competing priorities created problems accomplishing this experiment. Deployed units often face a similar situation with limited air assets. In order to fully implement this model of surveillance and interdiction, it is important for the defenders to own and completely control the UAV. Otherwise, they risk the UAV being tasked away or unavailable when needed. This requires the defenders to find some middle ground between using the inadequate but more ubiquitous and locally controlled Raven and a larger and better UAV, which is controlled by a higher headquarters.

Feedback from the participants provided some good lessons that can be applied in this situation. A specific plan is needed for the QRF to self-detect the VBIED if the UAV misses it. Visibility from inside an up-armored vehicle is so bad and restricted that the QRF missed the VBIED several times. Even from the gun turret, the terrain and vegetation limited how well the QRF could detect an approaching vehicle. If the FOB location does not allow the QRF to be positioned at a place with good observation (as in this scenario), an observation tower, either manned or electronic, should be used.

The speed of the VBIED was also determined to be a significant variable, as discovered previously by Byers [19]. One of the two VBIED drivers drove as expected at a moderate speed approximately at the posted speed limit. The other driver went considerably faster, which caught both the QRF and exercise controllers by surprise. Obviously, an enemy attacker is able to choose any speed to conduct the attack, and although driving excessively fast might draw attention to the vehicle, it can also catch the defenders off guard. However, as a counterpoint, one of the experiment participants pointed out that driving a vehicle full of improvised explosives that fast on a rough dirt road has other risks such as a premature detonation.

Other than problems associated with the UAV, this experiment was successful and demonstrated the utility of the approach of this model to surveillance and interdiction operations.

CHAPTER 7: Conclusion

7.1 Conclusions

This project demonstrates a good technique for combining surveillance and interdiction operations to better defend against VBIEDs. UAVs are a rapidly expanding technology, both in terms of quantities and capabilities, and research such as this is needed to better inform decisions on how to employ them. Tactical UAVs are such a rapidly emerging field that today's commanders may not have used or been trained on them in previous assignments, rendering intuitive decision making based on experience difficult. Analytical research such as this, which develops a decision tool to aid decision makers, is particularly useful in this situation.

Additionally, VBIEDs are a particularly difficult threat that has not been adequately researched. A great deal of effort has gone into the Counter-IED fight, but that has been almost exclusively focused on roadside IEDs targeting convoys, especially in the military and through JIEDDO. Very little research has focused on defeating VBIED attacks against fixed facilities. The DHS has made some progress in this field to protect domestic targets, but the military has largely taken a passive approach towards defending against VBIEDs, using perimeter security and hardened defenses as protection. When dealing with small bases or very large truck bombs, these measures are insufficient and a proactive approach to interdict the VBIED before it reaches the FOB is needed.

This project has addressed both of these shortcomings: how to better employ an emerging new technology (tactical UAVs) and how to better interdict a VBIED attack before it reaches the intended target. The development of the decision matrix provides a theoretical model that can help analysts organize and think about the information needed to accurately determine the optimal employment methods for both a UAV and QRF. The development of the Game Theory model also highlights the important factors that should be considered in this scenario, and shows the impacts of the strategic interactions between attacker and defender. These models are flexible enough to be adjusted to specific circumstances yet hopefully detailed enough fully explain their development and use. Together, these models will aid analysts and decision makers who have to combine surveillance and interdiction operations to defend their base.

Although this project focused on a specific military scenario to illustrate the concepts, it is applicable to other scenarios as well. The ideas developed in this project have already been employed to protect moving convoys in military exercises. Other, non-military, applications in which an important fixed facility needs to be protected against attack are also feasible. These might include embassies, oil facilities, transportation hubs, and any other key location where surveillance and interdiction operations can be combined to defend against an attack. Future work might also extend this project to situations that do not necessarily involve protecting a facility but still utilize surveillance and interdiction operations, such as the Border Patrol monitoring and stopping illegal border crossings.

7.2 Future Work

This thesis was part of a larger research project. Related work includes the Situational Awareness for Surveillance and Interdiction Operations (SASIO) tool, developed at the Naval Postgraduate School. This tool has been briefed at the Navy Fleet level and was employed in Joint Expeditionary Forces Experiment 10-3 at Norfolk, Virginia. A concurrent master's thesis looks at employing multiple UAVs in surveyor and tracker roles in a variety of missions. In this case, a larger, theater level UAV conducts a search, and then the ground force launches an organic tactical UAV to track the target until the ground force can interdict it. In August 2010, a capstone Field Experiment is planned at Camp Roberts which will more rigorously test all of these models and combine them into a realistic capstone exercise.

Specific future work that could be done to expand this project includes a greater sensitivity analysis on the game matrix. Analytical development of the tables and matrices for specific UAV and sensor combinations could also be done, since this project only considered a generic UAV without specific sensor characteristics.

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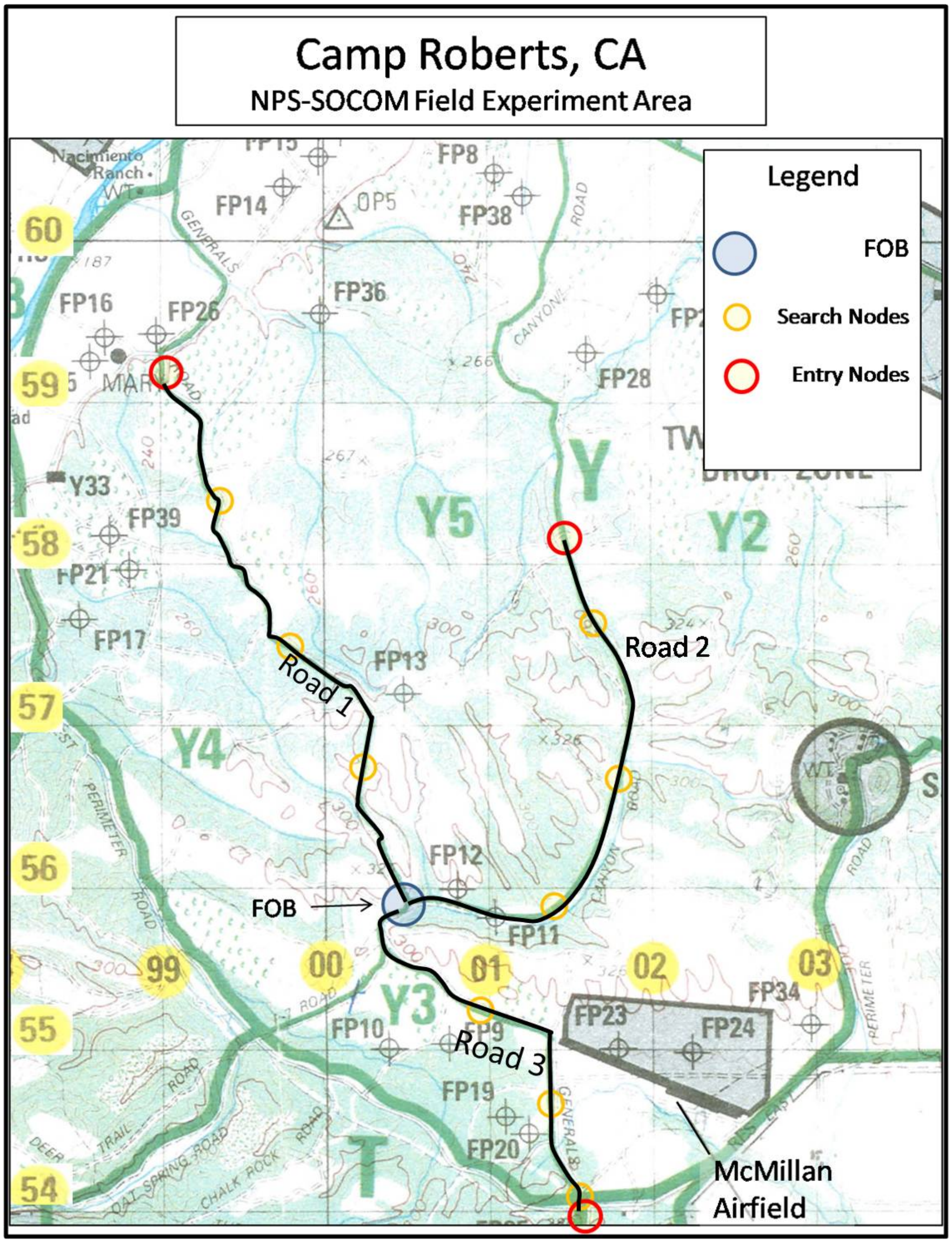
APPENDIX A: Camp Roberts Map

This is the map of the Camp Roberts training area where the Field Experiments were conducted.



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APPENDIX B:
Linear Programming to Solve the Game

The following code[1] is the GAMS program written to solve the game. It returns the objective function Z, which is the optimal payoff value in the game, as well as the optimal solution strategies. It requires three input files: R.txt for the number of routes, S.txt for the number of friendly alternatives, and Game_Payoffs.csv which is a comma separated data table for the game payoff values.

```
$TITLE Zero_Sum_Game
$offlisting
options limcol=0, limrow=0, solprint=off;
SET S friendly strategies /
$Include S.txt /;
SET R routes enemy strategies /
$Include R.txt /;

$ondelim
TABLE p(s,r) payoffs
$Include Game_Payoffs.csv;
$offdelim

POSITIVE VARIABLES X(s);
VARIABLE Z Total Value;

EQUATION Cover_Enemy; Cover_Enemy(r).. Z =G= SUM(s, p(s,r)*X(s));

EQUATION Probability_Sum; Probability_Sum.. SUM(s, X(s)) =E= 1;

MODEL Zero_Sum_Game /ALL/;

SOLVE Zero_Sum_Game USING LP MINIMIZING Z;
```

[1]GAMS code developed with the assistance of Professor Javier Salmeron, NPS Operations Research Department.

```
DISPLAY Z.l, X.l;
```

Input Files:

R.txt

```
* Enemy routes
r1     route 1
r2
r3
```

S.txt

```
* My friendly strategies
s1      UAV Far QRF Early
s2      UAV Far QRF Mid
s3      UAV Far QRF Late
s4      UAV Mid QRF Early
s5      UAV Mid QRF Mid
s6      UAV Mid QRF Late
s7      UAV Near QRF Early
s8      UAV Near QRF Mid
s9      UAV Near QRF Late
```

Game_Payoffs.csv is the game matrix saved as a comma delimited CSV file.

```
,r1,r2,r3
s1,1.500,0.240,0.960
s2,0.300,0.600,1.920
s3,0.825,0.330,1.584
s4,0.915,0.610,0.488
s5,0.165,1.375,0.880
s6,0.608,1.013,0.972
```

```
s7,1.300,0.520,0.624
s8,0.290,1.450,1.392
s9,1.350,1.350,1.944
```

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APPENDIX C:
Field Experiment Procedures

This is the write-up for the Field Experiment procedures and script that was used for the 9 May, 2010, experiments at Camp Roberts.

Background

This experiment is intended to test a Surveillance and Interdiction model utilizing a tactical UAV and ground based QRF to interdict a VBIED attack. A notional Forward Operating Base (FOB) located near a three-way intersection at grid 004558 is the target of the attack. In the scenario, the defenders receive an intelligence warning of an impending VBIED attack, but the time and direction of the attack are unknown. The defenders want to interdict and stop the attack as far from the base as possible, and they have a ground based QRF available to do that task. However, the QRF cannot leave until it knows which road the attack is coming from, otherwise if they guess wrong the VBIED could travel all the way to the base. The defenders also have tactical UAV available for surveillance, which they will use to attempt to identify which road the VBIED is traveling on. After this detection is made, the QRF is then able to depart the base and interdict the attack. As a last line of defense, the QRF can self-detect the VBIED when it is in sight of the FOB and then move to stop it, although in this case the VBIED will likely get within blast range of the FOB.

Requirements

1 UAV (NPS Rascal or Raven) with video imaging and all supporting equipment and software to control the flight and view the images from the Experiment Tactical Operations Center (TOC).
1 QRF consisting of a vehicle (tactical HMMWV) equipped with a tracking device similar to a Blue Force tracker. If available, QRF should also have a laptop computer that can view the UAV image feed real-time.
2-3 vehicles to simulate VBIEDs. These vehicles should be high clearance SUVs or trucks capable of driving the roads and trails throughout the Camp Roberts training area. They will be marked with an orange marker panel secured to the hood or roof. Each VBIED driver should have a GPS unit or tracking device to give a grid coordinate and determine the vehicle's location.
Communications: All elements need radio communication with the exercise controller at the TOC.

Procedures

UAV

The UAV will fly a designated patrol route. Each route will be flown repeatedly for about one hour (based on the UAV's flight endurance). Three separate flights will be conducted, one for each patrol route. The search nodes for each route are given below, in Military Grid Reference System coordinates.

Patrol Route 1:
Node 1.1: 00255680
Node 1.2: 01455593
Node 1.3: 00975535

Patrol Route 2:
Node 2.1: 99825750
Node 2.2: 01775662
Node 2.3: 01455460

Patrol Route 3:
Node 3.1: 99405825
Node 3.2: 01455825
Node 3.3: 01525405

VBIED

The VBIEDs will stage at designated entry nodes on each road. At the designated time (or on order from the TOC if the timeline changes), the VBIED will begin moving towards the FOB to simulate an attack. VBIEDs should drive at approximately 20-25 MPH. When stopped by the QRF, the VBIED driver should record the time and location. If not stopped, record the time that the VBIED reaches the FOB. After each attack, the VBIED moves to the next entry point and waits to begin the next attack.

Entry Nodes:
Road 1: 99035935
Road 2: 01435890
Road 3: 01505400

QRF

The QRF will stage from the notational FOB location at the three-way road intersection located at grid 00475590. When the UAV detects the VBIED the QRF then moves along the correct road to interdict the VBIED. If the QRF is able to see the UAV video it can self launch, and the TOC will confirm; otherwise the TOC will initiate the QRF movement. If the UAV does not detect the VBIED, the QRF will begin moving when it detects the VBIED itself.

Interdiction Procedures

QRF will record the time it departs the FOB and then drive towards the VBIED. Approximately 100m from the target vehicle, the QRF should stop and block the road. The VBIED will stop next to the QRF and confirm that it is the correct vehicle (and not miscellaneous traffic moving through the exercise area). Both drivers will record the time and location of the stop and the QRF will report by radio to the TOC. The QRF will then return to the FOB and the VBIED will move to its next entry node.

Timeline

The exercise consists of three sessions or flights, tentatively scheduled for 1000-1200 and 1300-1500. At the completion of the exercise, turn in the log sheets and equipment at the TOC.

NLT COB 8 May: Identify the QRF and VBIED vehicles and drivers

9 May Session 1 (1000-1100)

Line	T-time	Real Time	Event	Notes
1	T-60	0900	Prep exercise players and equipment	Radios distributed and tested, UAV preflight, exercise brief
2	T-15	0945	QRF and VBIEDs move to position	
3	T-0	1000	UAV launch and begin patrol 1	
4	T+10		VBIED 1 begins movement	
5	On Order		QRF moves to intercept VBIED 1 (when spotted)	
6	T+20		VBIED 2 begins movement; VBIED 1 moves to entry node	
7	On Order		QRF moves to intercept VBIED 2 (when spotted)	
8	T+30		VBIED 3 begins movement; VBIED 2 moves to entry node	
9	On Order		QRF moves to intercept VBIED 3 (when spotted)	
10	T+40		VBIED 1 begins movement; VBIED 3 moves to entry node	
12	On Order		QRF moves to intercept VBIED 1 (when spotted)	
13	T+50		VBIED 2 begins movement; VBIED 1 moves to entry node	
14	On Order		QRF moves to intercept VBIED 2 (when spotted)	
15	T+60		All elements reset and wait for next session or return to TOC at exercise completion	

Session 2 (approximately): 1100-1200 Session 3 (approximately): 1300-1400

Timelines are the same as Session 1.

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