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The Persian Gulf War introduced a new, highly effective threat in the form of the mobile short range ballistic missile (SRBM). The non-guided SCUD missile proved to be most effective in the political arena as Iraq continually targeted Israel in an attempt to force them into the conflict through retaliation. Although this Iraqi objective ultimately failed, a price was paid by the Coalition forces. A significant percentage of Allied air sorties were diverted to search for fixed and mobile SCUD launch sites. The mobile launchers proved to be highly elusive as post-war analysis has shown little or no success in countering them. Post-war research and development continues to focus on the improvement of post-missile-launch tactics used during Desert Storm to counter the mobile launchers. This thesis intoduces an integrated approach to the problem which stresses the inclusion of mobile launcher prosecution prior to weapon release. The general principles of anti-submarine warfare (ASW) are suggested as a structure to build an effective mobile SRBM counter effort doctrine. The benefit of pre-hostility intelligence and pre-missile-launch prosecution, the backbone of successful ASW, is revealed through the analysis of a circulation model which reflects the standard operations of a third world mobile missile launcher during hostilities. A decision model is constructed and analyzed to give insight into the development of pre-hostility intelligence policies.

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Countering the Third World Mobile Short Range Ballistic Missile Threat: An Integrated Approach

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ABSTRACT

The Persian Gulf War introduced a new, highly effective threat in the form of the mobile short range ballistic missile (SRBM). The non-guided SCUD missile proved to be most effective in the political arena as Iraq continually targeted Israel in an attempt to force them into the conflict through retaliation. Although this Iraqi objective ultimately failed, a price was paid by the Coalition forces. A significant percentage of Allied air sorties were diverted to search for fixed and mobile SCUD launch sites. The mobile launchers proved to be highly elusive as post-war analysis has shown little or no success in countering them. Post-war research and development continues to focus on the improvement of post-missile-launch tactics used during Desert Storm to counter the mobile launchers. This thesis introduces an integrated approach to the problem which stresses the inclusion of mobile launcher prosecution prior to weapon release. The general principles of anti-submarine warfare (ASW) are suggested as a structure to build an effective mobile SRBM counter effort doctrine. The benefit of pre-hostility intelligence and pre-missile-launch prosecution, the backbone of successful ASW, is revealed through the analysis of a circulation model which reflects the standard operations of a third world mobile missile launcher during hostilities. A decision model is constructed and analyzed to give insight into the development of pre-hostility intelligence policies.

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I. INTRODUCTION

A. THE THREAT

As evidenced by the Persian Gulf War, the short range ballistic missile (SRBM) is a highly effective political weapon even when its direct military effectiveness is, as in the case of the non-guided SCUD missile used by Iraq, relatively low. Indirectly, the public fears and possible political repercussions created by SCUD missile launches forced the Allies to divert a significant percentage of air sorties, previously scheduled for other missions, to hunt for both fixed launch sites and mobile launchers [Ref. 1]. It is proposed that the degree to which the Iraqi government measured the success of their SRBM force was based largely on the capability of continuous SCUD missile launches throughout the war, independent of whether the intended target was destroyed or not. In this respect, the mission was highly successful.

The scramble to destroy the elusive mobile SRBM launchers became headline news as the war proceeded and a number of SCUD missiles, apparently not launched from fixed sites, penetrated the air defenses of the Coalition, with a few reaching their targets inside Israel and Saudi Arabia. The speculation that Iraq might use chemical warheads on its missiles increased the urgency of the mission. One can assume that other potential third world adversaries noted the success of Iraq's mobile missile force and might view them as an effective weapon system in which to invest. The threat appears here to stay and will only become more accurate and lethal with time.

B. SCOPE OF THESIS

The mobile SRBM counter effort is examined in this thesis. Emphasis is placed on prosecuting the mobile launchers themselves. The current counter effort focus is briefly described and possible shortcomings are pointed out. A restructuring of the mobile launcher counter effort is called for using the general principles of anti-submarine warfare as a basic doctrine upon which to build. The benefits of, and policy development for, prosecuting the mobile launchers prior to missile launch are stressed.

The following chapters provide a partial answer to questions concerning the mobile SRBM counter effort. They raise questions concerning the actual hardware, tactics, and intelligence requirements by modeling the counter effort as a decision analysis problem. Included in the model is the ability to make trade-offs among methods of countering the third world mobile SRBM threat.

C. THESIS GOALS AND OUTLINE

This thesis has three specific yet related goals. The first is to restructure the current SRBM counter effort focus to include pre-missile-launch search tactics and pre-hostility intelligence effort against the mobile missile launchers. Second, to provide the decision maker or analyst with a tool to gain valuable insight into the development of pre-hostility intelligence policies. Third, and ultimately, to avoid repeating the less than optimal results obtained during the Persian Gulf War in countering the mobile SRBM threat in future third world conflicts.

Chapter I has introduced the problem and stated the scope and goals of the thesis. Chapter II argues the case for requiring pre-missile-launch and pre-hostility tactics against mobile launchers to optimally counter the SRBM threat. In Chapter III, a decision model is constructed to reflect the events and decisions that must be made, with respect to mobile missile launchers, leading up to the outbreak of hostilities with a third world country. Chapter IV analyzes the decision model and presents a methodology to determine optimal policies to counter the mobile launchers. Chapter V contains concluding remarks and a recommendation for further work.

II. THE MOBILE SRBM COUNTER EFFORT

A. THE PROBLEM

The mission of defeating or significantly suppressing the mobile SRBM threat is not an easy one. Post Desert Storm analyses have discounted the optimistic war time battle damage assessment of a significant percentage of mobile launchers destroyed. Some reports have indicated a lower bound of zero on the estimated number destroyed during the conflict [Ref. 2]. The effectiveness of the PATRIOT system in defeating incoming missiles is also under debate. All reports agree that the inclusive counter effort failed to produce results which normally indicate mission success.

B. AN INTEGRATED APPROACH

To the analyst familiar with the general principles of anti-submarine warfare (ASW), the poor results of the counter effort to suppress mobile SCUD launcher activity during the Persian Gulf War come as no surprise. An effective counter effort against a highly elusive target such as a mobile missile launcher or a submarine, should not begin *after* weapon release, as is the current focus, but well before the threat is in the position to do so. This section introduces the concept of including pre-missile-launch search tactics as well as pre-hostility intelligence effort in the mobile launcher counter effort and suggests an existing structure to use to create an effective counter effort doctrine.

1. Current Focus

Current research and development to counter the mobile SRBM threat is focused primarily on post-missile-launch hardware and tactics to counter both the missiles and the mobile launchers. Air defense systems such as PATRIOT are being designed to kill incoming missiles with a high degree of confidence. Weapon systems are being developed to allow for greater success in the prosecution of launchers after missile launch cuing data is received, referred to in this thesis as the *flaming datum* tactic. All these approaches assume that the mobile SRBM problem begins *after* missile launch. The remainder of this thesis focuses on the benefits and policy development of prosecuting the mobile launchers themselves *prior* to both missile launch and hostilities.

Most effort to counter the mobile launchers is being placed into upgrading or mimicking programs which enjoyed very limited success during the Persian Gulf War. A step back from this is required to view the problem in its entirety and to determine a possibly more effective counter effort. The programs currently under development are essential to successfully defeating the threat, but are arguably not the complete solution.

2. Anti-Submarine Warfare and SCUD Hunting

The capability to detect, track, classify, and if needed, destroy an enemy submarine has increased dramatically over the last half century. A Second World War aircrewman, while visually (and later with the help of radar) searching the thousands of square miles of the Bay of Biscay for German U-boats, would have dismissed the idea of one day passively tracking a submarine while submerged as impossible. Today, this is commonplace. The point is, to successfully counter a new, highly effective and elusive threat, it is often necessary to look beyond the engineering bounds of what is available, or can be modified, today. The ASW community has been effectively searching for increasingly invisible targets for many years; the lessons have already been learned and, in many cases, can be used to counter mobile missile launchers.

The general principles that provide the structure for the current ASW doctrine have been developed through theory and tested by experience as the submarine gained in capability and stealth sophistication. Although the specifics such as tactics and hardware will be different to implement them, many of these principles that have brought success to ASW directly apply to countering mobile launchers. Listed below is just a sampling of ASW principles that require consideration, each with a brief statement relating them to the mobile SRBM problem.

- **Strong community identification.** Essential for mission success. Like ASW, the mobile SRBM counter effort requires a dedicated community that is committed to defeating the threat. The predicted diversity of such an effort (possibly from special force units on the ground to satellites in space) will place a need for a strong community identification with a defined focal point for all aspects of the counter effort.

- **Intense scrutiny of enemy signatures.** Every possible signature, ranging from the obvious (infrared, electromagnetic, etc.) to the not so obvious (seismic, aural, tire patterns, etc.) needs careful examination for potential exploitation. Signatures play a large role in both detection and classification of targets.

- **Understanding of enemy tactics.** The ability to predict or estimate the actions of the enemy mobile launcher force is invaluable in developing tactics for specific situations.

- **Environment considerations.** The environment of the counter effort will change from enemy to enemy, country to country. Future conflicts may not all be fought in a desert environment, as was the Persian Gulf War.

- **Heavy emphasis on intelligence.** Mobile launcher search without intelligence is much like a needle search in one of *many* haystacks. Intelligence (HUMINT, ELINT, etc.) can narrow the search to a single haystack, effectively giving the search effort a starting point.

- **Localization capabilities on many platforms.** The more platforms with the capability to localize a target the better. This increases the probability of a capable unit being in the vicinity of a reported datum and giving the potential target little or no time to evade.

- **Integrated weapon and sensor platforms.** This extends the last principle to target destruction. It is optimal for the same platform that localizes the threat to be capable of classification and destruction. This avoids potential time delays and communication failures associated with calling in an attack.

- **Large area search capabilities on a continuous basis.** The capability to conduct continuous search of large areas is required to gain initial detection on possible targets. The system conducting the search must then be capable of providing a real time datum to a platform capable of target localization, classification, and destruction.

- **Base watch and choke point tactics.** Intelligence effort focused on the locating and subsequent watching of launcher storage bases is vital to determine weapon mobilization and estimating enemy order of battle. A choke point can be thought of as an easily searched area where a target should pass through, usually due to geographic constraints, to get from point A to point B. For mobile launchers, this definition is simply extended to include paths of least resistance; highways and bridges, for example.

- **Tracking of all known threats at all times.** Once a mobile launcher is detected and classified, there must be the capability to continue tracking until either hostilities erupt and it can be destroyed or it is no longer considered a threat.

- **Well exercised, coordinated prosecution.** An optimal counter effort must combine the capabilities of all services as well as those of our Allies. Joint and NATO exercises are required to ensure all participants involved with the effort are in concert with each other.

- **Quick and successful response to reported datum.** This encompasses many of the above principles. Once intelligence is received on a possible target, a capable platform must arrive expeditiously at datum and perform effective localization.

The mobile SRBM counter effort is still in its infancy. It should not be limited by engineering constraints. The effort, like ASW, is multi-faceted and the solving of the problem should start from the ground level, requiring knowledge from a broad array of science as well as engineering. The general principles of ASW should be used as a basic structure, or guideline, to ensure the effort is focused in the direction to optimally counter the threat today and into the future.

Many of the principles listed in this section involve or imply the prosecution of mobile launchers prior to receiving cuing data from a missile launch. The next section points out the benefits to be gained through the inclusion of both pre-launch search tactics and pre-hostility intelligence in the mobile launcher counter effort doctrine through the analysis of a circulation model.

C. A CIRCULATION MODEL

A simple model can help show the benefits of prosecuting the mobile launchers prior to missile launch. Figure 1 shows a circulation model which approximates the general flow of an enemy mobile missile launcher during mobilization and hostilities. During peacetime, the mobile launchers are kept at storage bases. As with all weapon systems, it is assumed the launchers deploy during peacetime for the general upkeep of the systems and proficiency training for the crews, but eventually return to storage. As the possibility of war increases, the launchers are covertly deployed, either individually or in groups, to forward replenishment bases to await firing instructions. As hostilities erupt, the individual mobile launchers begin a cycle which carries them from the forward

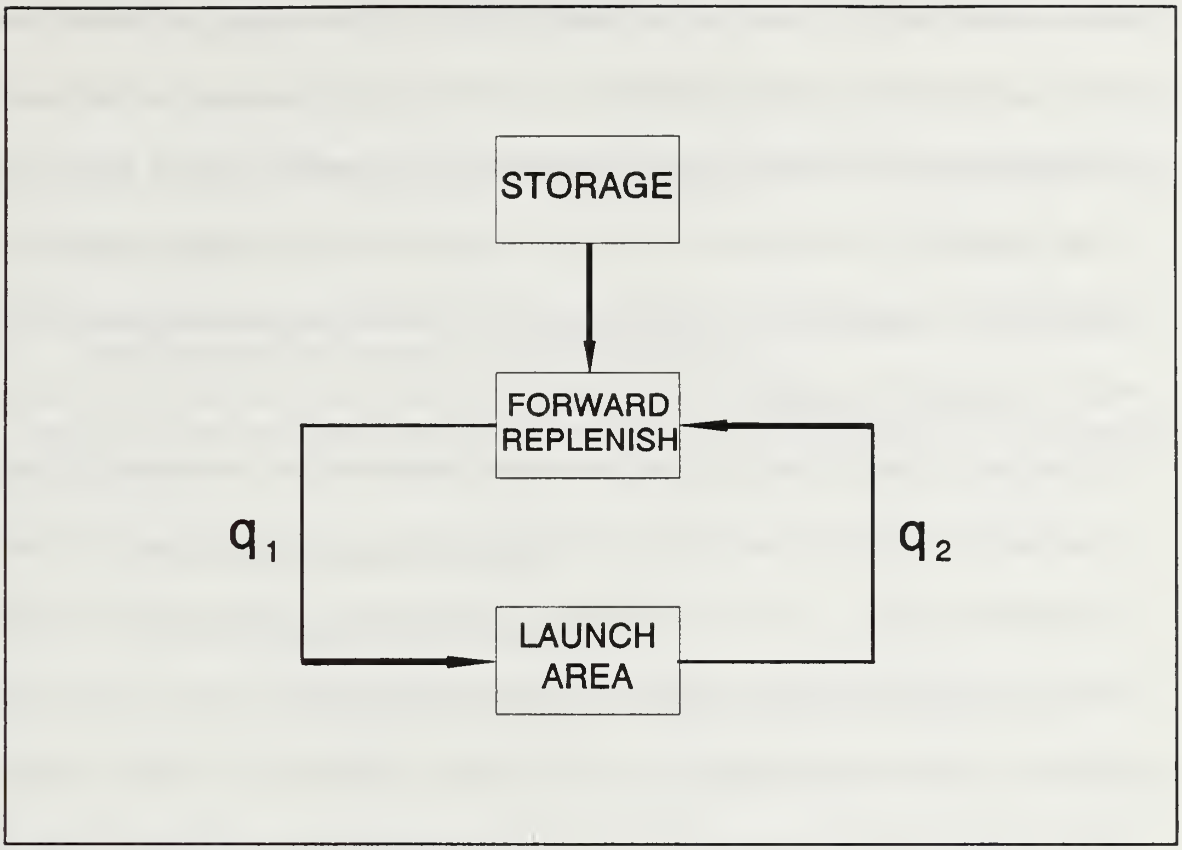

Figure 1. Mobile SRBM Launcher Circulation Model

replenishment base to a designated launch area, and then back to the replenishment base for re-armament and further instructions.

A probability of survival (avoiding destruction) for the launchers can be assigned to each leg of the cycle, represented by q_1 and q_2 in Figure 1. This cycle will continue until the launcher is destroyed or hostilities cease (assumes no upper bound on the supply of missiles). Although a model such as this is simple in both construction and nature, broad insight can be gained through its analysis.

The model in Figure 1 resembles a simple circulation model developed and analyzed by the Center for Naval Analyses (CNA) in 1969 [Ref. 3]. The CNA model was developed to study an idealized, steady state antishipping campaign carried out by independently operating submarines. The CNA analysis centered on the scenario where the probability of survival of a submarine on its transit to a patrol area is equal to the probability of survival for the transit home ($q_1=q_2$). Since a submarine is vulnerable to essentially the same ASW search and detection tactics on both transit legs, this is a reasonable assumption. In the case of a mobile missile launcher, however, very different tactics must be used on the outbound and return transits. On the return transit, the primary detection data comes from the flaming datum of the missile launch to locate the launchers position. On the outbound leg, pre-hostility intelligence data to predict launcher locations and pre-missile-launch search tactics must be relied upon for initial detection. Without such information, the survival probability on the outbound leg, q_1, would be very close, if not equal, to 1.0. After initial detection by whatever means, the localization, classification, and destruction probabilities of both legs are assumed equal (same prosecution tactics applied).

This thesis extends the analysis in Ref 3 to a more realistic model for the mobile launcher problem, where the probabilities, q_1 and q_2, are not equal. Specifically, the focus is determining what effect a reduction in q_1 from the current value of approximately 1.0 will have on the expected number of missile launches as a function of the launcher survival probability after launch (q_2). Due to the excellent cuing data provided for initial detection by a missile launch, it is assumed $q_1 \geq q_2$.

Let a successful cycle by a mobile launcher be defined as surviving the transit to the launch area and the launch of a missile. All launchers are assumed to begin the cycle at a forward replenishment base. This implies that the first cycle is defined as the transit from the forward base to the launch area. All subsequent cycles are defined as surviving the transit from the launch area to the forward base, and then back to the launch area. Of specific interest are the following:

- The probability distribution of the number of successful cycles completed by a launcher before being killed, and its expected value,
- The probability distribution of the total number of missile launches by all mobile launchers in a conflict, and its expected value.

1. Circulation Model Analysis

The following notation is needed:

n = estimated total number of enemy mobile launchers.

C_i = number of successful cycles per mobile launcher i (random variable).

M_i = number of missile launches per launcher i per successful cycle (fixed).[1]

q_1 = Pr{mobile launcher survives transit to launch area and launches missile}.

q_2 = Pr{launcher survives transit from launch area to forward base}.

---

[1] For this thesis, it is assumed M_i is fixed at 1 for all launchers. A mobile launcher, unlike a submarine, has limited field reload capability, especially in a hostile environment. The model can easily be adapted for $M_i > 1$, if needed.

The probability distribution of C_i is geometric in nature,

$$P(C_i = n) = \begin{cases} 1 - q_1, & n = 0 \\ q_1 (q_2 q_1)^{n-1} (1 - q_1 q_2), & n = 1,2,3\ldots \end{cases}$$

and is derived in Appendix A. The expected value (or average value) of C_i is then

$$E[C_i] = \frac{q_1}{1 - q_1 q_2}.$$

Let $q_2 = \propto q_1$, with $\propto$ being a constant less than one to reflect the decrease in launcher survival probability after missile launch cuing data is received. The expected value of C_i is now expressed as

$$E[C_i] = \frac{q_1}{1 - \alpha q_1^2}.$$

As mentioned, the assumption is made that M_i, the number of missile launches per launcher i per successful cycle, is equal to 1. It follows that the expected number of missile launches by launcher i before destruction will simply equal the expected number of cycles the launcher survives or

$$E[\text{LAUNCHES}_i] = E[C_i].$$

Figure 2 is a plot of the expected number of missile launches by launcher i as a function of $\propto$ with q_1 held constant at various feasible values. The interpretation of the plot follows shortly.

Define the random variable R as the total resultant missile launches by all n mobile launchers during a conflict. Assuming a large number of mobile launchers

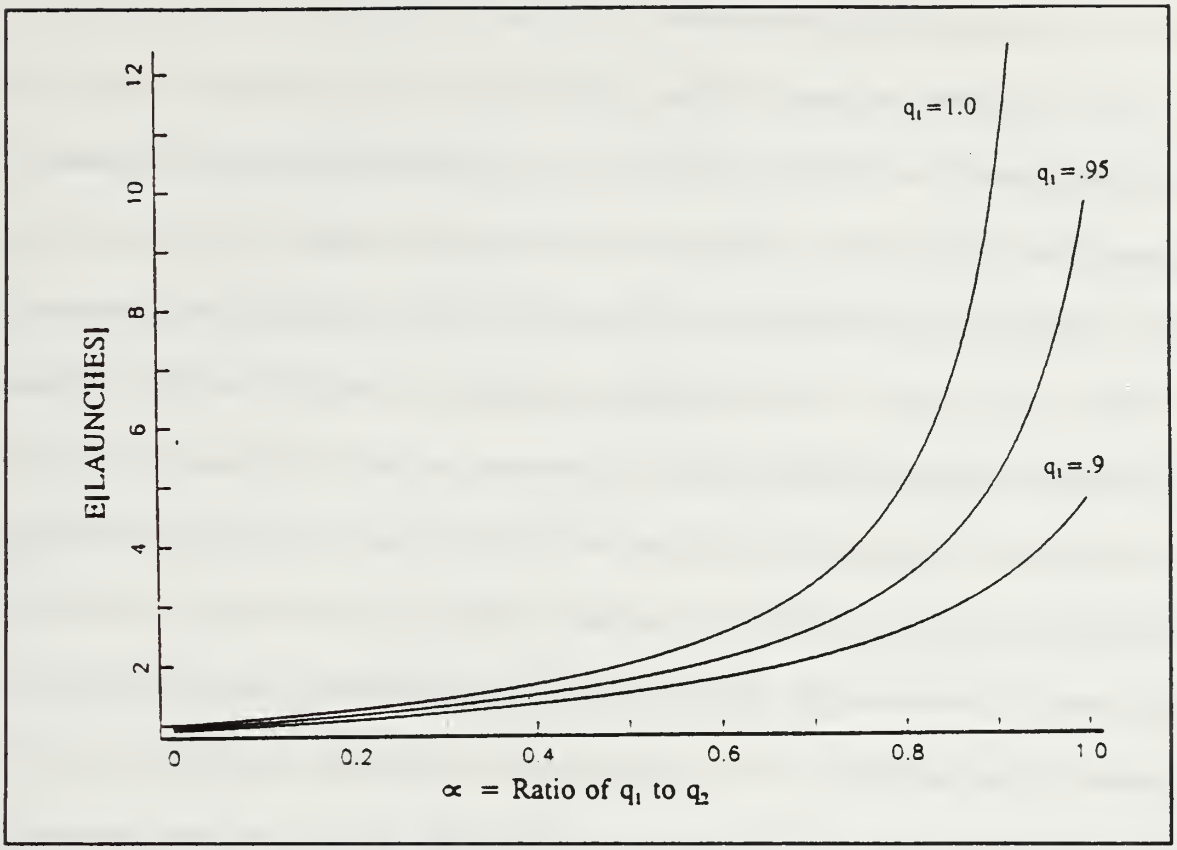

Figure 2. Expected Missile Launches as a Function of ∝

operating independently, the probability distribution of R can be approximated by the normal distribution (see Appendix A). The expected total resultant missile launches by all mobile launchers in a conflict can be expressed as

$$E[R] = n\,E[\mathrm{LAUNCHES}_i]. \tag{1}$$

This model assumes worst case, an extended war with no upper limit on the supply of enemy missiles. Hence, the model results can be looked upon as an upper bound on expected missile launches during a conflict.

2. Circulation Model Results

Possibly the most striking result obtained through the analysis of the circulation model is displayed in Figure 2. As mentioned earlier, the current focus of the mobile launcher counter effort is on the flaming datum tactic. Little attention has been given to the importance of pre-missile-launch data gathering and prosecution. Without such actions, it is reasonable to assume an outbound launcher survival probability (q_1) approximately equal to 1. Referring to the $q_1=1.0$ curve in Figure 2, it is seen as $\propto$ increases above .65 or so (referred to as the *critical* $\propto$ value), the number of expected launches by launcher i before destruction begin to increase exponentially with no upper bound! A simple interpretation of this is if the flaming datum tactic is unable to obtain a probability of mobile launcher kill of at least .35 (calculated as $1-.65q_1$), the expected number of missile launches may be unacceptably high and the mobile launcher counter effort should be expanded. The plot includes curves for q_1 equal to 1.0, .95, and .90. These curves effectively show the benefits of pre-launch effort. As q_1 decreases due to pre-launch tactics and pre-hostility intelligence, the critical $\propto$ value increases, and the maximum expected missile launches decrease considerably.

An additional counter effort option is highlighted in Equation 1. The expected total resultant missile launches, E[R], is a function of both $E[LAUNCHES_i]$, the expected launches from a single launcher i, as well as n, the estimated total number of enemy launchers to be used in the conflict. The following is obvious yet seemingly overlooked. The fewer launchers that are allowed to *enter* the cycle (reducing n), due to successful interdiction upon the outbreak of hostilities, the fewer total missile launches result. Once a launcher enters the cycle it is committed to covert operations, and the probability of detection by friendly forces, much less its destruction, shrinks considerably. Of course pre-hostility intelligence and subsequent interdiction, which the above implies, are sensitive and possibly risky options that need to be approached and planned carefully. Chapters III and IV further address this important problem.

In a conflict such as the Persian Gulf War, a short range ballistic missile launched by a third world country need not reach its intended target for mission success. The mere launch of the weapon can be a political victory for the enemy, spreading terror through targeted friendly populations and governments. However, air defense systems of the future are predicted to have no greater than 90 to 95% efficiency in defeating incoming missiles, leaving up to 10% to reach their destination [Ref. 4]. Also, short range ballistic missiles, like all weapon systems, will only continue to increase in accuracy and lethality. Therefore, perhaps it is also of interest to examine the effect of pre-missile launch effort on the expected number of missiles which penetrate the air defense system. This is the focus of the following subsection.

3. Further Analysis

Recall that the expected total resultant missile launches during an extended conflict is defined as

$$E[R] = n\ E[LAUNCHES_i] = n\frac{q_1}{1-q_1 q_2}.$$

After launch, each missile is subject to an air defense network (PATRIOT, for example). The air defense system attempts to destroy the missile prior to reaching its targeted area. Let $q_3 =$ Pr{incoming missile survives air defense network}. Define the random variable S_i as the number of missiles launched from launcher i that are not destroyed by the friendly air defense network. The probability distribution for S_i given C_i, is binomial with parameters C_i and q_3 (see Appendix A for details). Thus,

$$E[S_i] = q_3 E[C_i] = q_3\left(\frac{q_1}{1-q_1 q_2}\right).$$

Define the random variable T as the total number of enemy missiles which successfully penetrate the air defense network and reach their targeted area from all n enemy launchers. The distribution of T is derived in Appendix A and the expected value is expressed as

$$E[T] = nE[S_i] = n\ q_3\left(\frac{q_1}{1-q_1 q_2}\right). \qquad (2)$$

Equation 2 effectively shows the feasible options available to reduce the expected number of missiles that penetrate and reach their targeted area. They are: (i) reducing n through pre-hostility intelligence/interdiction effort, (ii) reducing q_3 through upgrading air defense systems such as PATRIOT, (iii) reducing q_1 through pre-launch tactics, and (iv) reducing q_2 through increasing the success rate of the flaming datum tactic. To analyze the results of modifying the above parameters, a data table is useful.

Table 1 contains the expected number of missiles that survive the air defense network, E[T], using various feasible values for parameters, obtained for an example analysis. For this example, the estimated number of launchers, n, is fixed at 100. Three values of q_3, the missile survival probability, are listed across the first row of the table. For each q_3, three values of q_2, the return transit survival probability, are examined and listed in the second row. Six values of q_1, the outbound launcher survival probability, from 1.0 to .5, are listed down the second column of the table. Due to the previous assumption that $q_1 \geq q_2$, some E[T] values are omitted.

As mentioned numerous times, the current focus of the mobile launcher counter effort essentially neglects pre-launch effort, forcing q_1 to approach 1.0. Examining the row of Table 1 which corresponds to $q_1 = 1.0$ gives E[T] values for various combinations of q_2 and q_3. The value of pre-launch tactics and pre-hostility intelligence effort, especially in cases of both q_2 and q_3 being large, can be seen by examining the rows corresponding to reduced values of q_1. Even a small reduction of q_1 to .9, in cases where q_2 also equals .9 (under any value of q_3), results in a greater than 50% reduction in E[T]!

Table 1 can also be used to roughly determine the probabilities required to obtain a determined *acceptable* level of missile hits. As an example, the shaded cells in Table 1 show different combinations of parameters that yield an expected number of missile hits of around 30. The analyst and decision maker can then determine which combination of probabilities is the most feasible and cost effective to achieve in order to obtain the desired E[T].

TABLE 1. EXAMPLE OUTPUT

	q_3	.1			.3			.5		
	q_2	.5	.7	.9	.5	.7	.9	.5	.7	.9
q_1		E[T]			E[T]			E[T]		
	1.0	20	33	100	60	100	300	100	167	500
	.9	16	24	47	49	73	142	82	121	236
	.8	13	20	-	49	61	-	66	102	-
	.7	11	19	-	32	59	-	53	98	-
	.6	9	-	-	26	-	-	43	-	-
	.5	7	-	-	20	-	-	33	-	-

D. SUMMARY

In this chapter, the validity of the current focus of the mobile SRBM counter effort was questioned. A new approach to the problem was suggested using the existing general principles of ASW, recognized as the leader in countering elusive targets, as the basic structure. The value of pre-missile-launch and pre-hostility effort was stressed through a simple circulation model and its analysis.

Many of the principles that have led to success in ASW include pre-hostility intelligence effort. As mentioned in this chapter, this is often a sensitive option and, if used, must be carefully planned and based on informed decisions only. The focus of Chapters III and IV is on the development of a quantifiable procedure to gain insight into the determination of pre-hostility intelligence policies as well as the level of effort required to achieve an acceptable number of expected missile launches.

III. THE DECISION MODEL

A. INTRODUCTION

As stated in Chapter I, one goal of this thesis is to provide the decision maker with a tool which will give valuable insight into the development of pre-hostility intelligence *policies* directed against the third world mobile missile launcher threat. Chapter II argued that the inclusion of pre-hostility effort will lead to more effective results in reducing expected missile launches than efforts focused on post-missile-launch tactics only.

The model presented in this chapter and analyzed in the next will help determine the appropriate level of intelligence effort to be used against the mobile SRBM threat by quantifying the pre-hostility options available to the decision maker and identifying the policies that minimize the expected number of missile launches during a conflict. The costs and benefits of a pre-hostility intelligence effort are explored through decision model analysis. An option to interdict the threat following intelligence gathering during peacetime is included in the model for analysis.

B. DECISION MODELING

It is important to understand at this point that a decision model can only lead to optimal policies if the results of the decisions made, and random events that occur, can be measured or predicted. This is extremely relevant to this thesis in that calculated results of pre-hostility intelligence efforts to counter the third world mobile SRBM threat may not be readily available today. As tactics and hardware are developed for a pre-hostility intelligence effort, so too must their *predicted effectiveness* against the threat. It is when these numbers become available that a model such as the one presented in Chapter II can accurately predict results of a pre-hostility effort and the decision model introduced in this chapter will become the most valuable. The model is developed and analyzed using generic results and broad assumptions to obtain regions, rather than point solutions, which are defined by model parameters, where one policy or set of decisions is preferred to another.

Influence diagrams and decision tree analysis are the tools used to help formulate and analyze the problem. It is worthwhile to review the basic structure and methodology of these as well as the symbology specific to decision modeling.

1. Symbology

The symbology used throughout this thesis is consistent with that found in most decision making literature. Each decision has a set of alternatives denoted by D. In a multi-stage decision problem such as the one developed in this thesis, D_i represents the set of decision alternatives at stage i. D is used to represent a generic decision prior to it being made.

Decision trees and influence diagrams utilize the same basic elements to represent visually a problem, although the two are quite different in nature. A square node represents a decision, a circle represents a random event, and a diamond represents a result. Figure 3 shows the possible nodes.

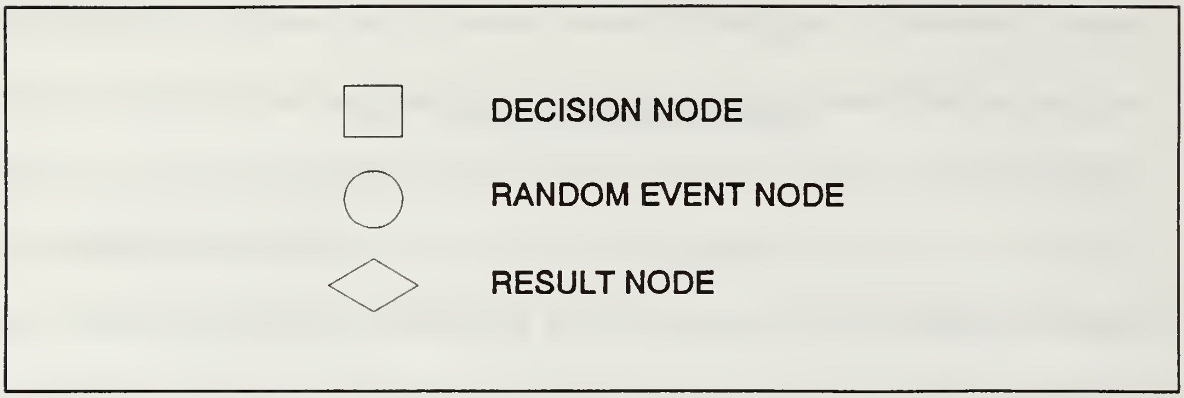

Figure 3. Decision Modeling Symbology

2. Influence Diagrams

Directed arcs are used between nodes in influence diagrams to indicate possible dependence between them. The generic situation, X→Y, would denote that event Y may be dependent or could be influenced by the outcome of event X. All combinations of nodes may be joined by directed arcs in influence diagrams. Another important feature of these diagrams is that the nodes are placed in order to show the natural sequence of events. Influence diagrams for the problem at hand will be introduced in the next section. [Ref. 5]

3. Decision Trees

Decision trees give a visual representation of all possible outcomes of decisions and random events that can occur in a given problem. Once again, the nodes are placed in their natural sequence. Extending from each decision or random event node, there will exist a number of branches equaling the number of possible decisions or outcomes at that node. The decision tree for this thesis is constructed in the following section and shown in Figure 6. [Ref. 5]

The decision tree is used in conjunction with the influence diagrams. Although the decision tree reveals the basic structure of the problem, it gives no insight into any probabilistic dependence that may exist between events. Influence diagrams are used to display this required information.

C. MODEL CONSTRUCTION

As alluded to in Chapter I, no specific tactics or hardware used for the prosecution of mobile short range ballistic missile launchers are used in the decision model. A model to gain insight into optimal policy development was sought that could be applied using either information gathering techniques which may be available today, but more realistically, those developed in the future. Also, by keeping the model as generic as possible, it can be applied to countering other weapon systems that, as viewed by a potential enemy, possess similar military or political qualities. For this reason, a very broad term of *intelligence effort* is used to encompass all friendly pre-hostility search, detection, and tracking capability that is available at the time the model is implemented. By aggregating effort this way, a decision model can be constructed which focuses on the question of whether or not a general pre-hostility intelligence effort should be undertaken, and if so, under what circumstances or set of conditions.

A decision model must have a quantifiable result measure if it is to be useful in making trade-offs among various possible decisions. Expected cost for the proposed intelligence effort immediately comes to mind as continually tighter military budgets are predicted. A measure perhaps more relevant, as evidenced by the Persian Gulf War and alluded to in Chapter II through the circulation model, is the total expected number of missile launches from mobile launchers against friendly forces or populations during a conflict, defined in the analysis as E[R]. As stated in Chapter I, this result measure is based on the assumption that a third world country achieves, to a significant degree, mission success by merely *launching* a missile and is independent of target destruction.[2] For modeling purposes, it is assumed that expected number of missile launches is indeed the proper measure and the goal is to determine policies which will minimize this number. Expected cost of the intelligence effort is carried through as a second attribute for analysis if needed as well as a constant reminder to the decision maker that all decisions have a price.

Hostilities with a third world country are assumed to follow a three stage escalating process. All stages are defined in terms of the enemy's utilization of the weapon system in question. Stage 1, peacetime, is defined as standard operating procedures (SOP) for the general upkeep and proficiency training of the weapon system. Stage 2, mobilization, is defined as an obvious departure from the SOP during times when the probability of a conflict is approaching one. Stage 3, hostilities, occur when weapons are used. Again,

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[2] The expected number of missiles penetrating the air defense network, E[T], also introduced in Chapter II, was not used for the result measure as q_3, the probability of intercepting and destroying an incoming *missile*, is independent of the policies developed to counter the *mobile launchers*.

the decision model addresses a pre-hostility question so it follows that decisions will need to be made at two distinct stages, peacetime and, given that it occurs, mobilization of the mobile launchers.

Two distinct modes of intelligence gathering are considered in this thesis, covert and overt. As will be clearly shown by the influence diagrams found in the next subsection, each mode needs to be examined separately as the probability distributions of the random events in the covert mode are not influenced by the decisions made at each stage as they are in the overt mode. This assumes an intelligent enemy that will perceive the intelligence effort in the overt mode and fail to do so in the covert mode. All further analysis of the decision model is divided between covert and overt intelligence effort.

1. Sets and Influence Diagrams

The problem is comprised of two stages with decisions to be made during peacetime and upon enemy mobilization of the mobile launchers. Let D_1 be the peacetime decision set, or the set of alternatives available to the decision maker during peacetime; it consists of two elements: (1) invest in intelligence effort, denoted by **E** and (2) apply no effort, denoted by **N**. Let D_2 be the mobilization decision set; it consists of three elements: (1) intelligence effort, **E**, (2) no effort, **N**, and (3) interdict prior to hostilities, denoted by **I**. It is a model assumption that interdiction at D_2, the mobilization decision stage, is an option only if there has been intelligence performed during peacetime ($D_1 =$ **E**).

Whichever decision is made during peacetime, whether the enemy mobilizes or not is uncertain. The same holds true for the mobilization decision and the outbreak of hostilities. Let M be a Bernoulli random variable that is 1 if the enemy mobilizes and 0 if it does not. Inherent in this definition is the concept of a time period, say for example, a year. If mobilization does occur during the year, $M=1$. Otherwise it is zero and the decision problem can be repeated in the next period. Let H also be a Bernoulli random variable that is 1 if hostilities break out and 0 if they do not. The random outcome sets are now defined as $M = \{0,1\}$ and $H = \{0,1\}$.

The result measure set, *R*, contains the different levels of expected missile launches $\{0, r_1, r_2, r_3, r_4\}$ from mobile launchers given the possible combinations of the two decisions and the outcomes of the random events. Clearly, no missile launches would occur $(R=0)$ when no mobilization or hostilities occur. Let r_1 be the estimated number of missile launches during a conflict given that no intelligence effort is applied during peacetime or mobilization. Let r_2 be the estimated number if no intelligence effort is applied *until* mobilization of the launchers, r_3 be the number if intelligence is conducted during both peacetime and mobilization, and r_4 be the estimate if intelligence during peacetime is followed by interdiction upon mobilization. The influence diagrams for the two intelligence effort cases and their descriptions follow.

a. Covert Intelligence

The covert intelligence influence diagram is shown in Figure 4. Two decision nodes and two random event nodes interact to lead to a result node. The sequence of the nodes is important. The peacetime decision (D_1) is made, the enemy either mobilizes or does not (M), the mobilization decision (D_2) is made, hostilities may or may not break out (H), and a number of missiles (R) are launched during the conflict.

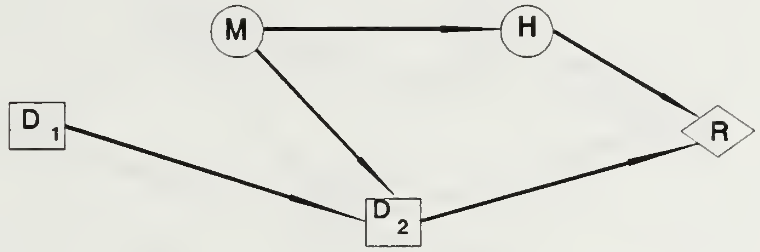

Figure 4. Covert Intelligence Influence Diagram

Note the arcs, which imply possible dependence, between the nodes. Of specific importance in the covert case is that, since the intelligence effort is assumed to be unknown to the enemy, the decisions that are made at each stage have no influence on the probability of either threat mobilization or hostility break out and thus no arcs from decision nodes to random event nodes exist.

b. Overt Intelligence

The overt intelligence influence diagram is shown in Figure 5. The diagram is the same as the covert case except for the addition of three directed arcs. This is of key importance. A potential enemy now has the knowledge, whether by

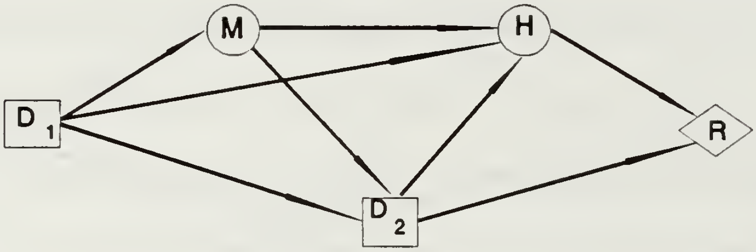

Figure 5. Overt Intelligence Influence Diagram

recognition of actual intelligence gathering assets or simply word of mouth, that intelligence is being gathered on his weapon system. Depending on the scenario, this knowledge may influence both the probability of enemy mobilization and his willingness to go to war. To represent this, arcs now extend from both decision nodes to the random event node or nodes that follow them in the normal sequence of events. The concept of overt intelligence is further examined in Chapter IV.

2. The Decision Tree

The decision tree which represents the problem with general parameters and results is shown in Figure 6. The sequence of the nodes follows that shown in the

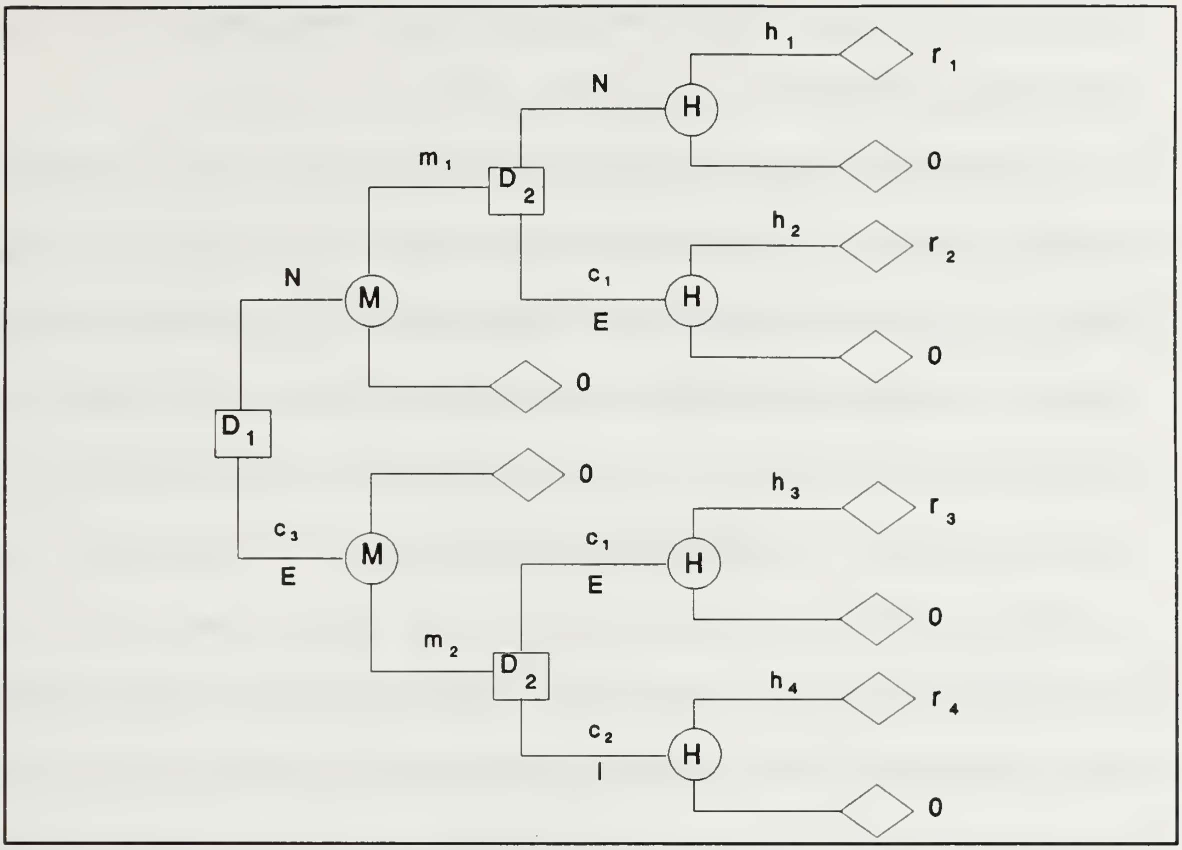

Figure 6. The Decision Tree

influence diagrams. Extending from each of the decision nodes are branches which represent all possible decision options at that stage. Applied to four of these decision branches is a *utility* cost, c, of making that decision. Let c_1 be the mobilization period cost of the intelligence effort, c_2 be the cost of a decision to interdict at D_2, and c_3 be the peacetime cost of intelligence. Although not used by the model to determine optimal policies, these utility costs are relevant to the decision maker in that they should include derivatives of making a specific decision, such as potential political ramifications and friendly casualties, as well as actual monetary cost. Those branches not labeled are assumed to have no cost. Each of the decision branches terminate at a random event node as described earlier.

The random event nodes are labeled **M** for mobilization or **H** for hostilities. Extending from each random event node are two branches which represent the uncertain outcome, 1 or 0, of the random event. The parameters m and h have been used to represent the estimated probabilities of each possible outcome of 1 occurring. The probabilities of the 0 outcomes, 1-m and 1-h by definition, have been omitted from the decision tree diagram for reasons explained in the next subsection. Subscripts are used to differentiate between estimated parameters under different policies with m_1 = Pr{mobilization occurs given the peacetime decision is no effort} = $\Pr\{M=1/D_1=\mathbf{N}\}$ and $m_2 = \Pr\{M=1/D_1=\mathbf{E}\}$. The following four estimated probabilities of hostility break out are also required: h_1 = Pr{hostilities occur given the peacetime decision is no effort, mobilization occurs, and the mobilization decision is no effort} = $\Pr\{H=1/D_1=\mathbf{N}, M=1, D_2=\mathbf{N}\}$, $h_2 = \Pr\{H=1/D_1=\mathbf{N}, M=1, D_2=\mathbf{E}\}$, $h_3 = \Pr\{H=1/D_1=\mathbf{E}, M=1, D_2=\mathbf{E}\}$, and $h_4 = \Pr\{H=1/D_1=\mathbf{E}, M=1, D_2=\mathbf{I}\}$. These probabilities are clearly labeled on the decision tree.

The branches extending from the random event nodes terminate in either a result node or the second stage decision node. All possible outcomes of the model are represented by the different branches of the decision tree.

The decision tree structure shown in Figure 6 is the same for both the covert and overt cases. However, the values of the estimated parameters used will be different. These differences reflect the added dependencies alluded in the overt case.

3. Possible Cases

The analysis of the decision model begins at the terminal or result nodes of the decision tree. By working backwards, expected numbers of missile launches can be calculated at each random event node and minimizations found at each decision node. Each random event in the model is viewed as a simple Bernoulli trial with outcome 1 or 0. The general expected value (or average value) expression is then

$$E[\text{value}] = a\text{p} + b(1\text{-p}),$$

where *a* and *b* are the result values of each outcome and p is the probability of the outcome with result value *a* occurring. Note that $b=0$ in the decision model, by definition (no hostilities or mobilization will lead to 0 missile launches) thereby eliminating the second term from the equation and relieving the requirement for the probabilities of the 0 outcomes (1-m and 1-h).

As stated earlier, the goal is to find those decisions that minimize the expected number of missile launches. Therefore, at the upper mobilization decision node (D_2) of the decision tree, choose

$$\text{Min}\ \{h_1r_1,\ h_2r_2\} \tag{3}$$

and at the lower D_2 node, choose

$$\text{Min } \{h_3r_3,\ h_4r_4\}. \tag{4}$$

Continuing to work backwards taking expected values, the optimal decision at peacetime decision stage (D_1) is the one that again minimizes the expected number of missile launches. This can be expressed as

$$\text{Min } \{m_1 * \text{ Min } \{h_1r_1,\ h_2r_2\},\ m_2 * \text{ Min } \{h_3r_3,\ h_4r_4\}\}, \tag{5}$$

where * indicates multiplication.

From (3) and (4), it immediately follows that four possible combinations, referred to in this thesis as cases 1 through 4, of comparing expected number of missile launches can occur at the mobilization decision stage (D_2). Each case results in a different set of choices to be compared at the peacetime decision node (D_1). The logic for case 1 is shown and the results of cases 2, 3, and 4 are summarized in Table 1.

Let case 1 in the comparison of expected missile launches at the mobilization stage (D_2) be defined by the inequalities

$$h_1r_1 < h_2r_2 \text{ and}$$

$$h_3r_3 < h_4r_4.$$

The minimum expected value in each of the above inequalities is preferred. Therefore, referring to the decision tree, the preferred decision for case 1 at the mobilization decision node is no effort (D_2= N) and the optimal decision at the lower is intelligence (D_2= E). It follows from (5) that the optimal policy at D_1 is defined by

$$\text{Min } \{m_1h_1r_1,\ m_1h_2r_2\}.$$

Each of the policies in the above set results in corresponding expected costs, calculated in the same expected value manner, of

$$(0,\ c_3 + m_2c_1).$$

Similarly, cases 2 through 4 can be readily defined and calculated. Table 2 summarizes the results.

D. SUMMARY

The decision model has been constructed for the general case and the attributes which determine as well as define the optimal policies have been identified. Two modes of intelligence effort to counter mobile launchers, covert and overt, have been introduced for analysis. At the mobilization decision stage (D_2), four cases, defined by inequalities comparing expected missile launches, exist and are summarized in Table 2. Chapter IV introduces assumptions for both covert and overt intelligence modes that reduce the number of feasible cases defined in Table 2 and ultimately lead to the identification of optimal policies to counter the mobile missile launcher threat.

TABLE 2. CASE DEFINITION SUMMARY

CASE	CONDITIONS	E[LAUNCHES]	E[COST]
1	$h_1r_1 < h_2r_2$ $h_3r_3 < h_4r_4$	$\text{Min}\ \{m_1h_1r_1, m_2h_3r_3\}$	0 $c_3 + m_2c_1$
2	$h_1r_1 > h_2r_2$ $h_3r_3 < h_4r_4$	$\text{Min}\ \{m_1h_2r_2, m_2h_3r_3\}$	m_1c_1 $c_3 + m_2c_1$
3	$h_1r_1 < h_2r_2$ $h_3r_3 > h_4r_4$	$\text{Min}\ \{m_1h_1r_1, m_2h_4r_4\}$	0 $c_3 + m_2c_2$
4	$h_1r_1 > h_2r_2$ $h_3r_3 > h_4r_4$	$\text{Min}\ \{m_1h_2r_2, m_2h_4r_4\}$	m_1c_1 $c_3 + m_2c_2$

IV. OPTIMAL POLICIES

A. ANALYSIS OF INTELLIGENCE MODES

As stated in Chapter III, all further analysis of the decision model is divided between two distinct modes of intelligence effort, covert and overt. The influence diagrams in Chapter III clearly reveal the necessity of this by displaying the difference in probabilistic dependence of random events for covert and overt intelligence. In the following sections, assumptions are introduced and the optimal policies for each intelligence mode is determined in terms of model parameters and is graphically displayed to determine the amount of effort required to achieve a specific level of expected missile launches.

Although the estimated numbers themselves may change, the relationships between the result measure parameters, (r_1, r_2, r_3, r_4), are assumed to be the same for covert and overt intelligence. Chapter II argued that if pre-hostility intelligence is feasible, it will be effective in reducing the number of missile launches. Keeping this in mind and recalling that the parameter, r, is defined as the estimated total number of missile launches given different sets of decisions made during peacetime and mobilization, it is assumed that the most missile launches will occur when no intelligence effort is applied prior to hostilities, represented by r_1. The least missile launches are assumed to occur when intelligence effort during peacetime is followed by interdiction prior to the outbreak of hostilities, or r_4. The remaining two result measures, r_2 and r_3, follow the *assumed* rule that less intelligence effort focused on the mobile launchers during peacetime and mobilization will lead to higher numbers of missile launches should hostilities break out. The relationships between the result measures used in the analysis of the model are mathematically expressed as

$$r_1 > r_2 > r_3 > r_4. \tag{6}$$

The relationships of the utility costs, c, associated with making specific decisions are also assumed to be the same for covert and overt intelligence. Interdiction at the mobilization decision stage (D_2) is assumed to be the most costly. The utility cost of intelligence effort after enemy mobilization is assumed to have a greater cost than intelligence effort during peacetime. The relationships are expressed as

$$c_2 > c_1 > c_3.$$

Cost is not used in the decision model to determine the counter effort policies. However, scenarios could exist where the optimal policy is somewhat unclear and cost can then be used to further break out the preferred option. The decision maker must bear in mind the consequences of any decisions made and the expected utility costs serve this purpose.

1. Covert Intelligence

Covert intelligence, by definition, requires that the effort take place without enemy counter detection. Referring to the covert influence diagram shown in Figure 4, the decisions made at each stage of the problem are assumed to have no influence on either uncertain outcome of enemy mobilization or hostility break out. This is clear in that the enemy, without knowledge of the intelligence effort, will continue to proceed with operations as if no effort whatsoever is being applied. This directly leads to the assumption that the probabilities of the similar uncertain events (hostilities or mobilization) under a covert intelligence effort will be equal, expressed as

$$h_1 = h_2 = h_3 \text{ and}$$

$$m_1 = m_2.$$

The final assumption is that friendly interdiction of the mobile launchers forces the probability of hostilities, along that branch of the decision tree, to certainty, or

$$h_4 = 1.$$

Directly, the above assumptions, combined with the result measure assumption shown in (6), imply that

$$h_1r_1 > h_2r_2 > h_3r_3.$$

Therefore, referring to the case definitions summarized in Table 2, cases 2 and 4 only require further analysis as the conditions for cases 1 and 3 are not met. For ease of notation, further covert intelligence analysis will use h to represent h_1, h_2, and h_3 and m to represent m_1 and m_2. Using the logic developed at the end of Chapter III, the analysis of covert intelligence, cases 2 and 4, follows.

Referring again to the case definitions found in Table 2, case 2 holds only if the conditions

$$hr_3 < r_4 \text{ and}$$

$$hr_1 > hr_2$$

are met. Ignoring the peacetime decision made to arrive there, the above inequalities imply that the preferred decision at either mobilization decision node (D_2) is intelligence in that it leads to the lower number of expected missile launches in both circumstances.

The expected number of missile launches that need to be compared at the peacetime decision node (D_1) to determine the optimal *policy* for case 2 are also drawn from Table 2. It follows from the result measure assumptions in (6) that the inequality,

$$mhr_3 < mhr_2,$$

will always hold. Literally tracing the route through the decision tree which terminates in r_3 (the estimated number of missile launches from the minimum expected value expression above), gives the optimal policy, or set of decisions, for covert intelligence, case 2. They are: intelligence at the peacetime decision stage ($D_1^* = E$) and if launcher mobilization, continue with intelligence ($D_2^* = \mathbf{E}$). Finally, referring back to Table 2, expected missile launches and corresponding costs for this policy are

$$\text{E[Launches]} = mhr_3 \text{ and}$$

$$\text{E[Cost]} = c_3 + mc_1.$$

Using the same logic from above and referring again to Table 2, it follows that case 4 exists if the inequalities

$$r_4 < hr_3 \text{ and}$$

$$hr_2 < hr_1.$$

hold. Examining the decision tree with these relationships imply the optimal decision at mobilization (D_2) is interdiction given the peacetime decision is to apply intelligence effort and to *begin* an intelligence effort if no effort is applied during peacetime. Due to the assumptions in (6), the inequality comparing expected missile launches at the peacetime decision stage,

$$mr_4 < mhr_2,$$

will always hold. Again from the decision tree, this condition implies the optimal policy for case 4 is to perform intelligence during peacetime ($D_1^* = \mathbf{E}$) and if the threat is mobilized, interdict ($D_2^* = I$). This policy leads to expected missile launches and costs for covert intelligence, case 4 of

$$E[\text{Launches}] = mr_4 \text{ and}$$

$$E[\text{Cost}] = c_3 + mc_2.$$

The optimal policies for cases 2 and 4 under a covert intelligence effort can be combined and displayed graphically as a function of h, the estimated probability of hostilities. This is shown in Figure 7. It is interesting to note that in order to determine the covert optimal policy, only the *ratio* of the result measures, r_4 and r_3, is required, not each individual estimated number of missile launches. This relieves the analyst of the task of estimating r_1 and r_2. Note also from Figure 7 that the decision maker is not required to make a point estimate of h to determine the optimal policy; a region or interval will suffice. As alluded to earlier, if the estimate of h does lie near the border of the two regions, making the optimal policy unclear, the decision maker can use expected cost to help distinguish the optimal policy.

The expected missile launches under covert optimal policies can also be plotted as a function of h. This is shown in Figure 8. Note that expected missile launches increase linearly with h from 0 with a slope of mr_3 and then become constant with a maximum value of mr_4 for $h \geq r_4/r_3$. Recall that under covert intelligence the parameter m, or the probability of enemy mobilization, cannot be influenced by friendly decisions. The plot clearly shows that to effectively reduce the expected launches during

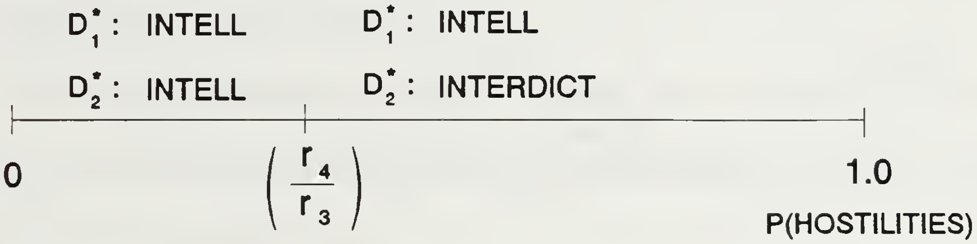

Figure 7. Covert Optimal Policies

a conflict to a desired level, the parameters r_3 and r_4 need to be reduced. This is accomplished through increasing the effectiveness or amount of both pre-hostility intelligence and interdiction.

The analysis can be continued by combining the covert intelligence results with those obtained in the circulation model analysis presented in Chapter II. The details of this further analysis are contained in Appendix B. The interesting result is the ratio, r_4/r_3, can be expressed in terms of interdiction effectiveness only. Specifically,

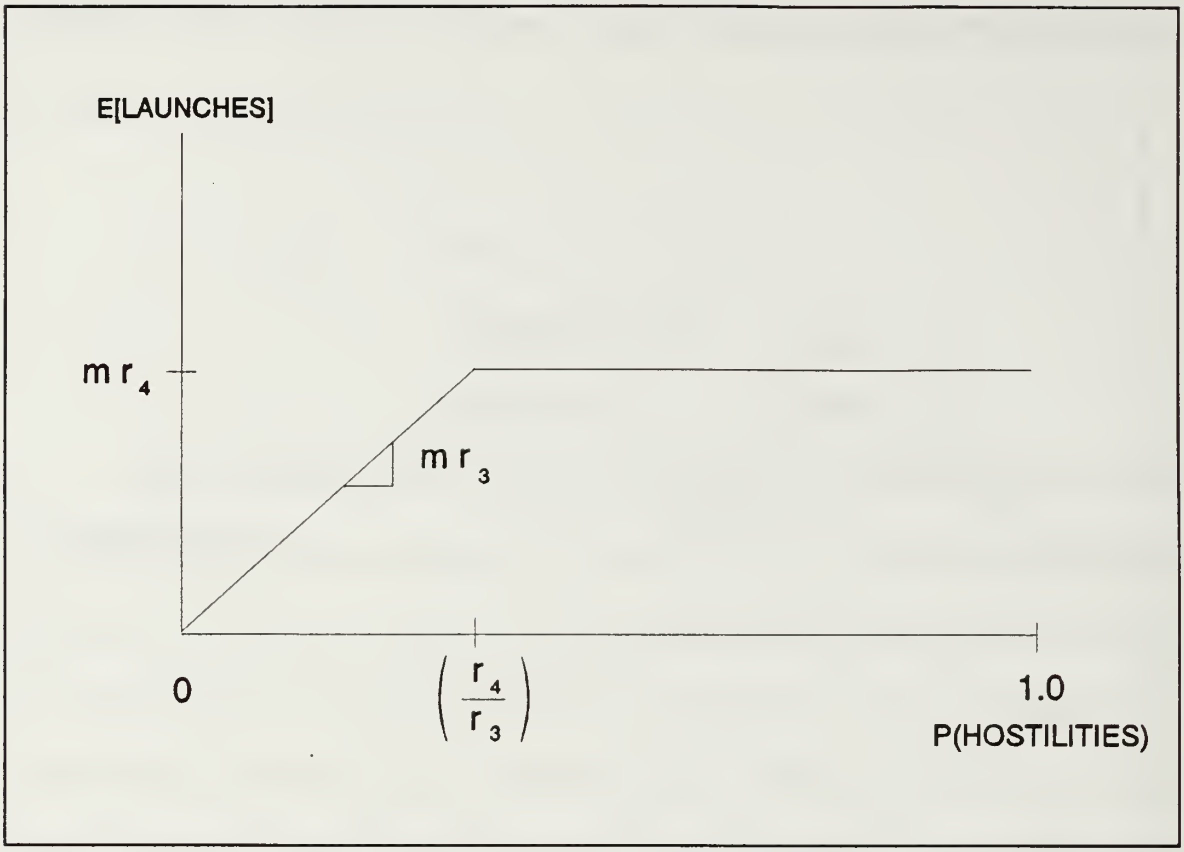

Figure 8. Expected Missile Launches: Covert Optimal Policies

$$\frac{r_4}{r_3} = \frac{n^{(4)}}{n},$$

where n represents the estimated total of enemy launchers and $n^{(4)}$ represents the estimated number of launchers remaining after an interdiction effort. This implies the optimal policy decision is based on the estimated fraction of launchers remaining after interdiction, independent of circulation model launcher survival probabilities, q_1 and q_2.

As an example, say the analyst or decision maker estimates that 40% of the mobile launchers could be eliminated by interdiction, which corresponds to a fraction of launchers remaining of .6. If the probability of hostilities, h, is estimated to be anywhere in the region greater than .6, the optimal policy is to gather intelligence during peacetime and interdict upon mobilization. If the probability of hostilities is estimated as less than .6, to continue to gather intelligence upon mobilization is optimal. If h is considered to be very close to .6, the utility cost of each option is used by the decision maker to determine the optimal policy.

The covert intelligence expected launches plot (see Figure 8) can be constructed for this example by noting that the equations needed to calculate expected launches, derived in Appendix B, are

$$m h r_3 = m h \left[\frac{n q_1}{1 - q_1 q_2} \right] \quad \text{and}$$

$$m r_4 = m \left[\frac{n^{(4)} q_1}{1 - q_1 q_2} \right] .$$

Again, the benefits of pre-hostility intelligence gathering and pre-missile-launch search tactics can be shown by simple sensitivity analysis. This is done by plotting various decreasing values of q_1, the outbound launcher survival probability. For this example, let q_2, the return transit launcher survival probability, be fixed at .7, the probability of enemy mobilization, m, at .6, and the estimated number of launchers, n, at 100. Using values for q_1 of 1.0 (current counter effort focus), .9, and .8 in the equations for expected launches, the plot in Figure 9 is created.

The plot clearly shows that as q_1 is decreased, the expected number of missile launches decreases substantially. This is an important issue, recalling that during a

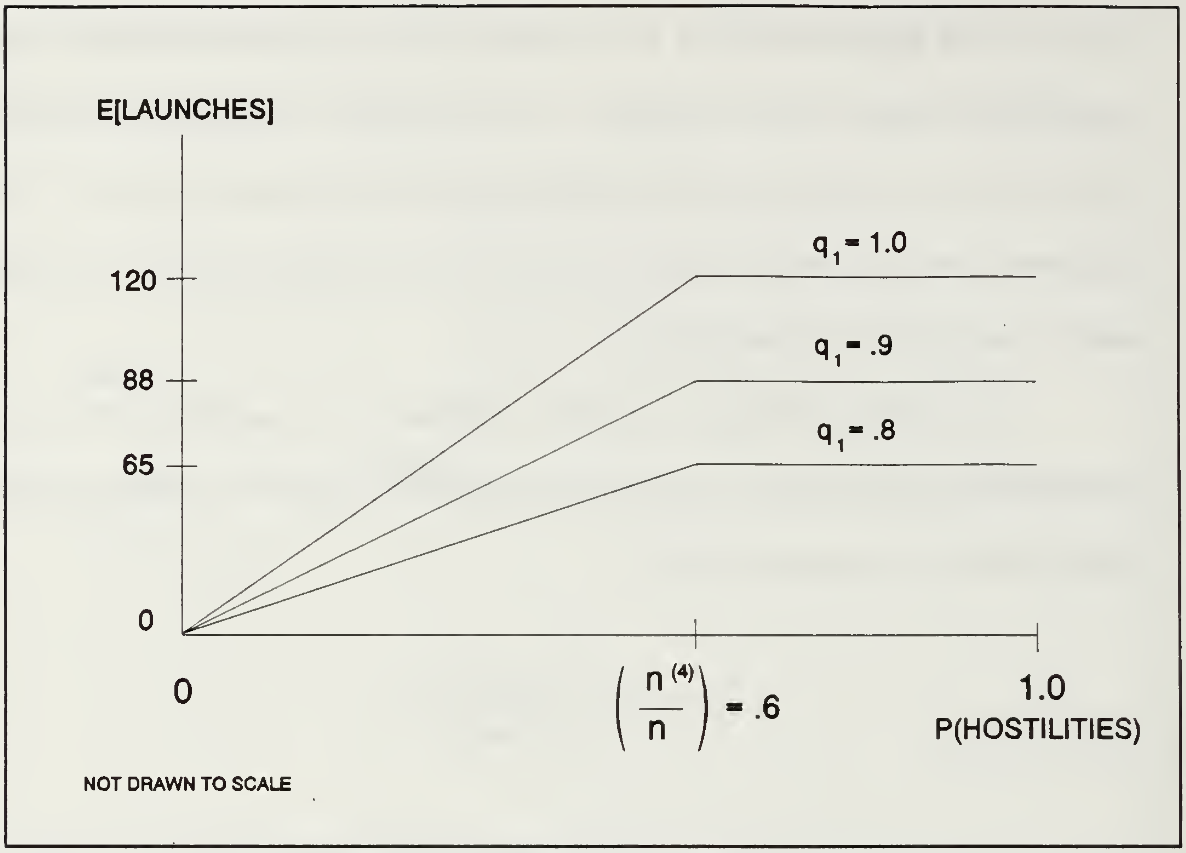

Figure 9. Example Covert Expected Missile Launches

covert intelligence effort, expected missile launches can only be reduced by decreasing either r_3, which was effectively achieved in this example by decreasing q_1, or r_4. The covert intelligence analysis also revealed that reducing r_4 involves both pre-hostility intelligence as well as interdiction, which, depending on the political sensitivity of the scenario, may or may not be an option.

2. Overt Intelligence

The result measure relationships shown in (6) still hold true for overt intelligence as well as friendly interdiction forcing hostilities ($h_4 = 1$). However, an overt intelligence effort differs from covert in that the potential enemy now is assumed to have knowledge of the effort. This knowledge may or may not influence the outcomes of the uncertain events. The assumption is made that the enemy may be deterred by the knowledge that the movement and operations of his weapon system, which he feels possesses great political or military effectiveness, is the focus of a heavy intelligence effort. It is also assumed that the more overt intelligence applied, the greater the deterrence effect. The model parameter relationships which are affected by this assumption and differ from covert intelligence are expressed by the inequalities

$$h_1 > h_2 > h_3 \text{ and}$$
$$m_1 > m_2. \tag{7}$$

The assumptions in (7), together with those in (6), directly imply that

$$h_1 r_1 > h_2 r_2 > h_3 r_3$$

and, as in the covert analysis, cases 1 and 3 defined by Table 2 are eliminated. Cases 2 and 4 require further analysis. As with covert intelligence, each case is analyzed separately.

Again referring to Table 2, and recalling that h_4 is unity, case 2 holds if the inequalities

$$h_3 r_3 < r_4 \text{ and}$$

$$h_1r_1 > h_2r_2$$

hold. Due to leading to fewer expected launches in both inequalities above, intelligence is the preferred option at both mobilization decision nodes (D_2). The assumptions shown in (6) and (7) lead to determining the optimal policy by noting that the inequality, drawn from Table 2, which again compares expected missile launches at the peacetime decision node (D_1), of

$$m_2h_3r_3 < m_1h_2r_2,$$

must always be true. By following the route through the decision tree which contains the parameters of the minimum expected missile launches from above, it follows that the optimal policy for case 2 under overt intelligence is to perform intelligence during peacetime ($D_1^* = \mathbf{E}$) and continue with intelligence if mobilization occurs ($D_2^* = \mathbf{E}$). The expected missile launches and costs for overt intelligence, case 2 are then

$$E[\text{Launches}] = m_2h_3r_3 \text{ and}$$

$$E[\text{Cost}] = c_3 + m_2c_1.$$

Figure 10 plots the above expected number of missile launches as a function of m_2, the probability that the enemy will mobilize given an overt intelligence effort during peacetime. The parameter m_2 was chosen to plot against in that mobilization is the first

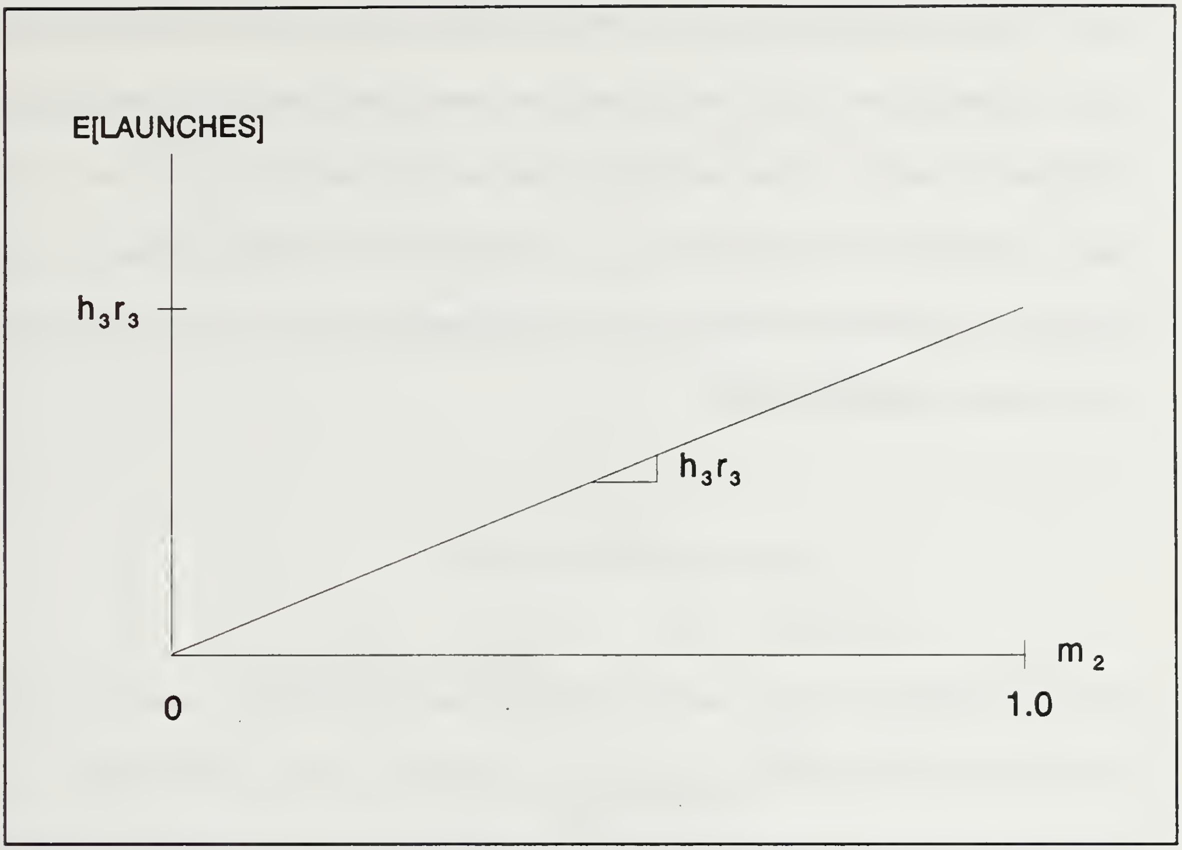

Figure 10. Expected Missile Launches: Overt Effort Case 2

event that can possibly be influenced by an overt intelligence effort and therefore, perhaps, the most tangible to the decision maker. The plot clearly shows that if under the conditions of case 2, any overt intelligence effort that is effective in reducing the probability of enemy mobilization (m_2) or his willingness to go to war (h_3) will result in a corresponding decrease in expected number of missile launches.

Again, referring to Table 2, case 4 is defined by the inequalities

$$h_3r_3 > r_4 \text{ and}$$

$$h_1r_1 > h_2r_2.$$

Using the same methodology as before, these conditions imply that the preferred decision at the mobilization node (D_2) is interdiction given intelligence effort during peacetime and intelligence if no effort during peacetime. However, the optimal *policy* for case 4 is not clear. Recalling that the optimal policy is defined by the set of decisions made, or route through the decision tree, which minimizes the expected number of missile launches, the set of expected missile launches,

$$\{m_1h_2r_2,\ m_2r_4\},$$

drawn from Table 2, must be compared at D_1, the peacetime decision node. Due to the h_2 term in the first expected value of the set, which can vary between 0 and 1, the relationship between them is not obvious. By setting the two expected values equal and solving for m_2, the relationship can be expressed as the linear function

$$m_2 = \left(\frac{h_2r_2}{r_4}\right)m_1. \tag{8}$$

This function is plotted in Figure 11 to obtain a graphical representation of the optimal policies under overt intelligence, case 4. Three distinct regions, which can vary in size as the slope of the line defined by (8) increases or decreases, are obtained and denoted as I, II, and III on the plot.

Recalling the overt intelligence assumption that m_1 is always greater than m_2, region I is infeasible. Region III shows the area where the inequality,

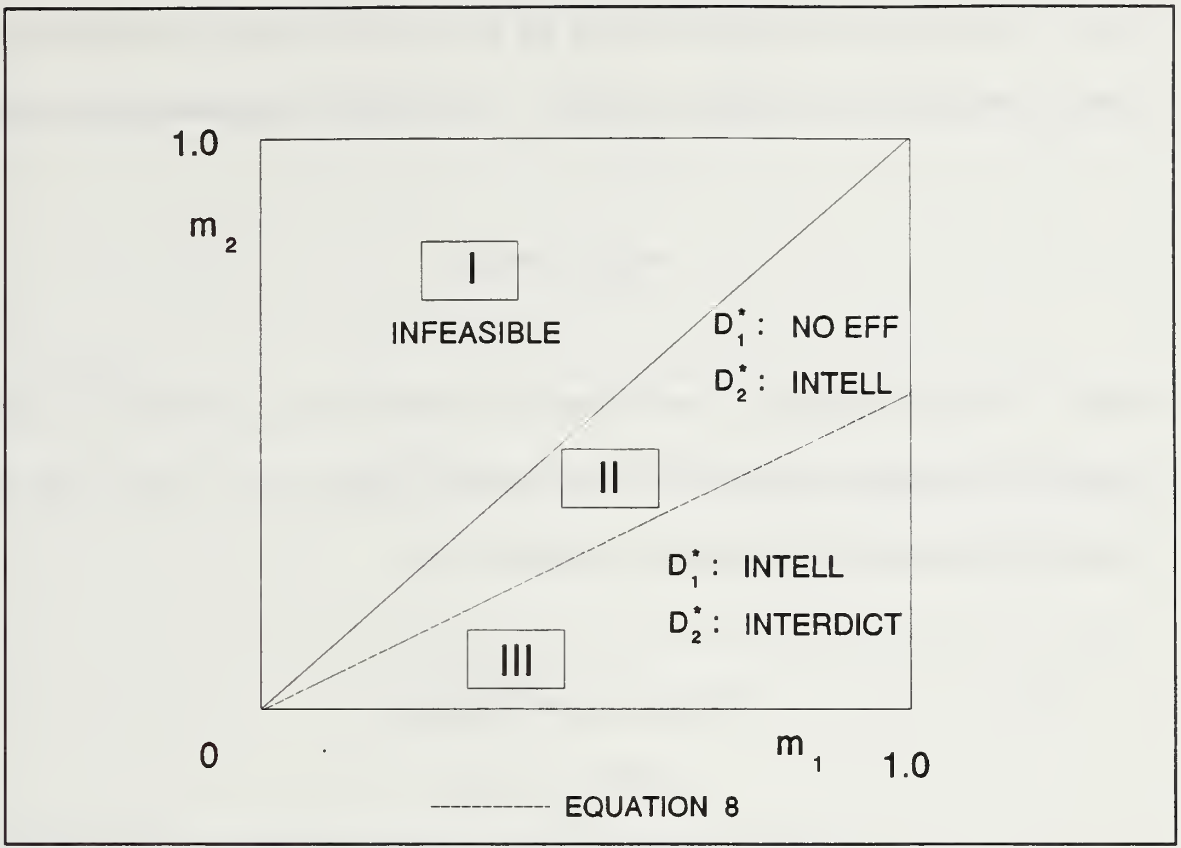

Figure 11. Optimal Decision Plot: Overt Effort Case 4

$$m_2h_4r_4 < m_1h_2r_2,$$

holds. The optimal policy under these conditions is to perform intelligence during peacetime ($D_1^* = \mathbf{E}$) and interdict if the threat mobilizes ($D_2^* = \mathbf{I}$). The expected missile launches and costs under this policy are

$$E[\text{Launches}] = m_2r_4 \text{ and}$$

$$E[\text{Cost}] = c_3 + m_2c_2.$$

Region II is the most interesting, showing the area where the preferred decision is to apply no intelligence effort during peacetime. This situation exists when the inequality

$$m_1h_2r_2 < m_2h_4r_4$$

holds. The optimal policy is now defined as no effort during peacetime ($D_1^* = N$) followed by intelligence should the enemy mobilize ($D_2^* = E$). It follows that the expected missile launches and costs for this policy are

$$E[\text{Launches}] = m_1h_2r_2 \text{ and}$$

$$E[\text{Cost}] = m_1c_1.$$

Figure 12 combines the results of the analysis of feasible regions II and III under overt effort, case 4. As with case 2, the plot shows expected missile launches as a function of m_2, the probability of mobilization given overt intelligence during peacetime. It is interesting to note from the plot that the deterrence effect of overt intelligence on the probability of mobilization does not cause a decrease in the expected number of missile launches until m_2 is driven below the critical value, defined by estimated model parameters, of

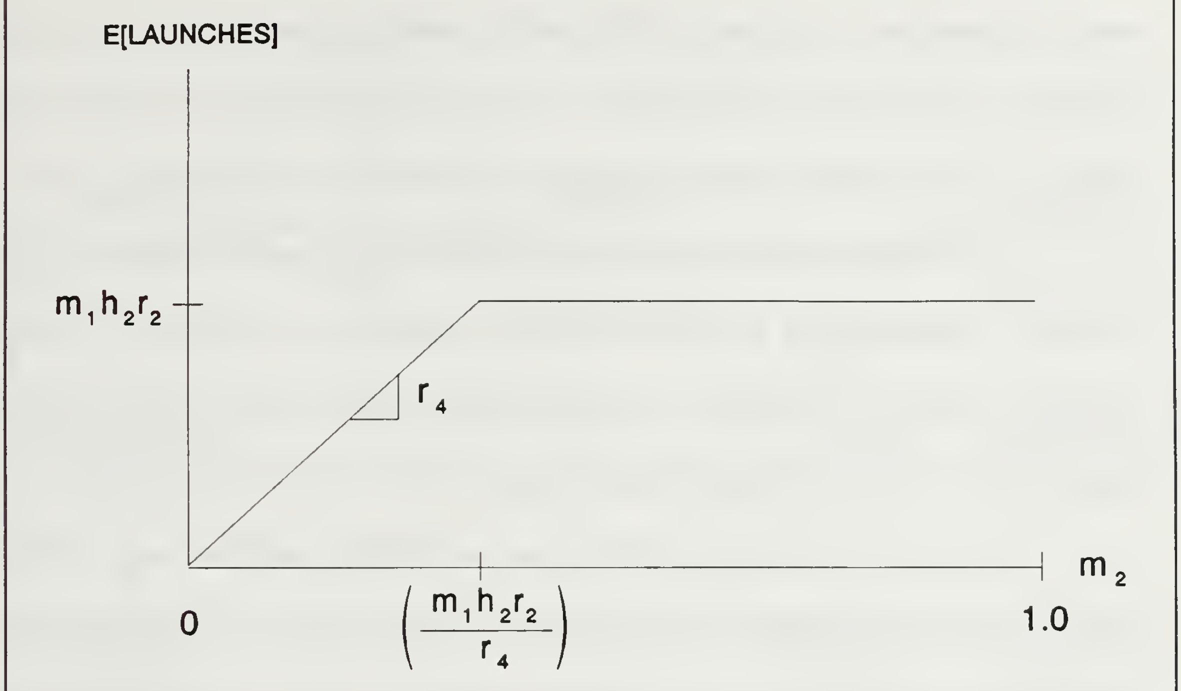

Figure 12. Expected Missile Launches: Overt Effort Case 4

$$\frac{m_1h_2r_2}{r_4}.$$

This is in contrast to case 2; recalling that, while under the conditions of case 2, *any* reduction in m_2 leads to a decrease in the expected number of launches. If the decision maker estimates that m_2 is, indeed, in the region above the critical value and the option of different *amounts* of overt intelligence does exist, there is yet another decision to be made. If the decision maker feels that more overt intelligence can drive m_2 below the critical value then it is perhaps wise, if the utility cost is acceptable, to do so. Conversely, if it is estimated that more overt intelligence will not decrease m_2 below the critical value, or the utility cost is too high, it is the best decision, based on expected missile launches only, to remain with the current amount of intelligence. Note that by reducing r_4 (by increasing the effectiveness of an interdiction effort) it moves the critical value to the right and the region where the above phenomena exists grows smaller.

Overt intelligence provides for more options to reduce the expected number of missile launches during a conflict than covert intelligence. However, it must be remembered that this advantage is possible only if the option *exists*. Rules of engagement or a delicate political situation may force a covert effort to be the only choice. This concept also holds true for the mobilization decision stage option of interdiction. It may be that friendly forces are instructed to wait for the enemy to initiate hostilities. In this case, the decision model can still be utilized by simply ignoring the branch of the decision tree which represents interdiction and performing the analysis described in this chapter.

B. MODEL SUMMARY

1. Decision Model User's Guide

The flow chart shown in Figure 13 delineates the suggested steps to be taken by the analyst to utilize the decision model presented in this thesis. The initial decision in the flow chart of which intelligence mode is to be analyzed (covert or overt) is a separate issue which must be addressed by the decision maker, independent of the decision model or scope of this thesis.

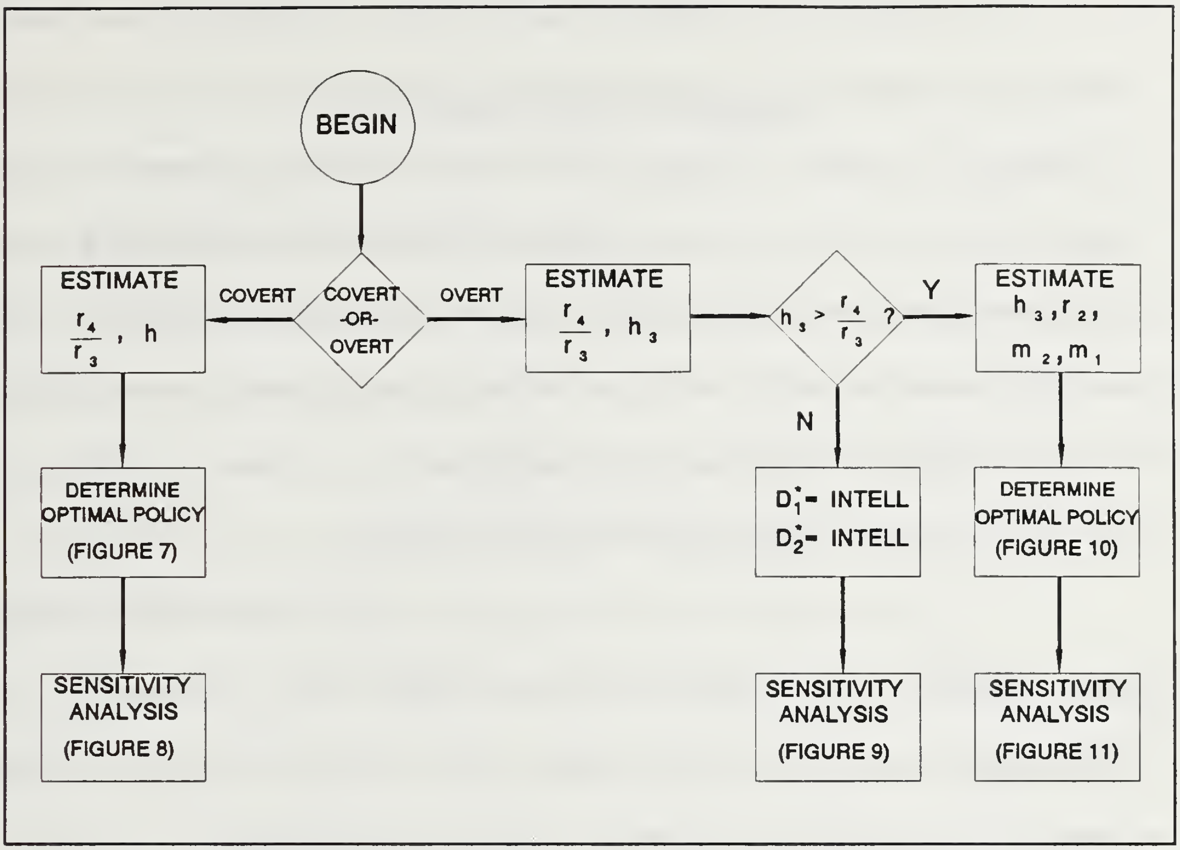

Figure 13. Decision Model Flow Chart

2. Conclusions

The model construction as well as the assumptions made have been designed to approximate reality. The result measure of expected missile launches was selected to reflect the current political and social attitude towards mobile short range ballistic missiles. Given that they are acceptable to the decision maker, the model gives valuable insight into the amount of pre-hostility intelligence effort required to obtain desired levels of expected missile launches as well as the construction of optimal policies to counter a third world weapon system such as the mobile short range ballistic missile.

For both covert and overt intelligence efforts, no point estimates or specific solutions are included in the insight gained through analysis of the model, rather, *regions* of preference are stressed. Should a combination of estimated parameters cause the optimal policy to be unclear, a second attribute of expected cost has been carried through to help determine the preferred decisions. The plots of expected missile launches enable the decision maker and analyst to perform relatively simple sensitivity analysis by clearly showing the model parameters that can be manipulated for each mode of intelligence and how each affects the expected number of missile launches.

The result measure relationships expressed in (6) assured that the developed optimal policies never included *no intelligence effort* during both peacetime *and* mobilization. However, it is perhaps counter intuitive that there does exist conditions under overt intelligence where no effort is optimal during peacetime.

A decision model of this nature is not meant to dictate policy. As an example, should the model reveal that interdiction is the preferred policy, it must be remembered that this is with respect to the mobile SRBM threat only. This would be used merely as one input into higher level strategy planning. By quantifying the different options available, the input will be based on an *informed* decision made by the decision maker and avoid one based solely on past experience or feelings.

V. CONCLUDING REMARKS

A. THE INTEGRATED APPROACH

The third world mobile short range ballistic missile problem possesses many of the same traits as classical anti-submarine warfare. Many of the developed principles used in ASW can be used to help effectively counter the mobile SRBM threat. It is recommended that these principles are considered as a possible structure for the mobile SRBM counter effort doctrine.

The analysis of the circulation model presented in Chapter II clearly shows the benefits of pre-missile-launch search tactics and pre-hostility intelligence effort in reducing the number of expected missile launches and missiles which penetrate the air defense during a conflict. Perhaps more striking is the penalty incurred, in terms of exponentially increasing expected missile launches, for focusing on post-missile-launch tactics which do not result in a sufficient probability of kill to offset the absence of pre-launch prosecution effort. This will only increase in importance as third world countries obtain biological and nuclear warfare capability and the maximum number of acceptable missile launches during a conflict diminishes towards zero.

As hardware and tactics are developed to counter the mobile SRBM prior to the outbreak of hostilities, the decision model constructed and analyzed in Chapters III and IV will become increasingly relevant. The decision maker now has a tool to aid in the development of optimal pre-hostility intelligence policies to counter the threat based on insight gained through firm analysis.

The Persian Gulf War highlighted the mobile SRBM as an effective and elusive threat. Emphasis must be placed on pre-hostility intelligence effort and pre-missile-launch prosecution tactics as they are integral parts of a complete effort to successfully counter such a threat in future conflicts.

B. RECOMMENDATION FOR FURTHER STUDY

Recall that the decision model presented in this thesis aggregated all friendly pre-hostility detection, classification, and tracking capability as *intelligence effort*. As specific methods to gather intelligence are developed and quantified (space, air, and human assets, for example), the aggregated intelligence effort could then be split and the decision model used to compare the effectiveness of each specific method used alone, as well as in various combinations of others, to determine the optimal force structure to counter the threat.

APPENDIX A. CIRCULATION MODEL PROBABILITY DERIVATION

The probability used in Chapter II for the mobile launcher circulation model is derived in this appendix. The purely mathematical steps have been omitted for clarity of argument.

The probability distribution for the random variable C_i, defined in Chapter II as the number of successful cycles by mobile launcher i before being destroyed is geometric in nature and derived as follows. The initial successful cycle is defined as the launcher surviving the transit from the forward replenishment base to the launch area and the subsequent launch of a missile. The probability that $C_i=0$ (the probability that the launcher is destroyed before a single success) is simply one minus the probability that it survives the first transit from the forward base to the launch area. Thus,

$$P(C_i=0) = 1-q_1.$$

All subsequent successful cycles are defined as surviving the return transit to the forward base and the outbound transit back to the launch area. The probability that $C_i=1$ is defined as the probability that the launcher survives the initial transit to the launch area, q_1, and is destroyed prior to reaching the launch area for the second time on either the return leg to the forward base or the transit back to the launch area. This is expressed as

$$P(C_i=1) = q_1(1-q_1q_2).$$

Continuing with the same logic,

$$P(C_i=2) = q_1(q_1q_2)(1-q_1q_2)$$

$$P(C_i=3) = q_1(q_1q_2)^2(1-q_1q_2)$$

$$\vdots$$

$$P(C_i=n) = q_1(q_1q_2)^{n-1}(1-q_1q_2)$$

$$\vdots$$

These combine to give the probability distribution of C_i as

$$P(C_i=n) = \begin{cases} 1-q_1, & n=0 \\ q_1(q_1q_2)^{n-1}(1-q_1q_2), & n=1,2,3\ldots \end{cases}$$

The expected value of C_i is then calculated as

$$E[C_i] = \sum_{n=0}^{\infty} n\ P(C_i=n) = q_1(1-q_1q_2)\sum_{n=1}^{\infty} n\ (q_1q_2)^{n-1}$$

$$= \frac{q_1}{1-q_1q_2}.$$

The variance of C_i is defined as

$$VAR[C_i] = E[C_i^2] - E[C_i]^2$$

and is calculated as follows:

$$E[C_i^2] = \sum_{n=0}^{\infty} n^2 P(C_i{=}n) = q_1(1-q_1q_2)\sum_{n=1}^{\infty} n^2 (q_1q_2)^{n-1}$$

$$= \frac{q_1(1+q_1q_2)}{(1-q_1q_2)^2}$$

and

$$E[C_i]^2 = \left(\frac{q_1}{1-q_1q_2}\right)^2.$$

Therefore,

$$VAR[C_i] = \frac{q_1(1+q_1q_2)-q_1^2}{(1-q_1q_2)^2} = \frac{q_1^2q_2-q_1^2+q_1}{(1-q_1q_2)^2}.$$

As stated in Chapter II, it is assumed that a successful cycle by a single launcher implies a single missile launch. Therefore, it follows that the expected number of missile launches by launcher i before destruction will be equal to the expected number of cycles by launcher i before destruction. This is expressed as

$$E[LAUNCHES_i] = E[C_i].$$

The same holds true for the variance, or

$$VAR[LAUNCHES_i] = VAR[C_i].$$

The total resultant missile launches by *all* mobile launchers, R, can now be expressed as

$$R = \sum_{i=1}^{n} \text{LAUNCHES}_i$$

where n is the estimated total number of enemy mobile launchers. Assuming the launchers operate independently of each other and there are a large number of them in a conflict, the distribution of R can be approximated by the normal distribution, or

$$R \sim N(n\,E[\text{LAUNCHES}_i],\ n\,VAR[\text{LAUNCHES}_i]).$$

The random variable S_i is defined as the number of missiles launched from launcher i that are not destroyed by the friendly air defense network. For each successful cycle, one missile is launched. Each missile will either be destroyed or not. The probability that S_i is equal to some constant k, given a number of successful cycles, is binomial. The probability distribution is expressed as

$$P(S_i = k \mid C_i = c) = \binom{c}{k} q_3^{\,k} (1 - q_3).^{c-k}$$

The conditional expected value is then

$$E[S_i \mid C_i] = C_i q_3$$

and the conditional variance is

$$VAR[S_i \mid C_i] = C_i q_3 (1 - q_3).$$

Unconditioning on C_i gives

$$E[S_i] = q_3 E[C_i] = q_3\left(\frac{q_1}{1-q_1 q_2}\right)$$

and

$$VAR[S_i] = E[VAR[S_i \mid C_i]] + VAR[E[S_i \mid C_i]]$$

$$= \frac{q_3 q_1 (1 - q_2 q_1 + 2 q_3 q_2 q_1 - q_3 q_1)}{(1 - q_1 q_2)^2}.$$

The random variable T is defined as the total number of enemy missiles that are not destroyed by the enemy air defense network. This implies that

$$T = \sum_{i=1}^{n} S_i$$

where n is again the total number of enemy launchers. For a large number of independent, identically distributed missiles that are not destroyed by the air defense, T can be approximated by the normal distribution with

$$E[T] = nE[S_i] = nq_3\left(\frac{q_1}{1-q_1 q_2}\right)$$

and

$$VAR[T] = n\,VAR[S_i].$$

APPENDIX B. COVERT ANALYSIS CONTINUED

Recall from Chapter II that the expected total number of missile launches, E[R], is equal to n, the estimated number of enemy launchers that enter the circulation model, multiplied by E[LAUNCHES$_i$], the expected number of launches by launcher i before being destroyed. Combining the notation from Chapter II and Chapters III and IV, the result measures from the decision model, (r_1, r_2, r_3, r_4) can be generally expressed as

$$r_j = \frac{n^{(j)} q_1^{(j)}}{1 - q_1^{(j)} q_2^{(j)}}, \quad j = 1,2,3,4 \tag{9}$$

where the superscript (j) on the parameters represents the four possible outcomes of the decision tree. For example, $n^{(1)}$ represents the estimated number of launchers remaining given the peacetime decision is no effort ($D_1^* = N$), mobilization occurs ($M = 1$), the mobilization decision is no effort ($D_2^* = N$), and hostilities occur ($H = 1$). It follows that

$$n^{(1)} = n^{(2)} = n^{(3)} = n,$$

as nothing has been done prior to hostilities to reduce the number of launchers in those instances, and

$$n^{(4)} < n,$$

as $n^{(4)}$ represents the branch of the decision tree which contains the option to interdict.

The outbound launcher survival probabilities, with respect to pre-hostility intelligence, follow the thesis argument that more intelligence leads to a reduced chance of survival. This is expressed as

$$1.0 = q_1^{(1)} > q_1^{(2)} > q_1^{(3)}.$$

It is assumed the outbound launcher survival probability upon hostilities is approximately the same whether peacetime intelligence is followed by more intelligence or interdiction upon threat mobilization. This assumption is expressed as

$$q_1^{(3)} = q_1^{(4)} = q_1.$$

Post-missile-launch counter effort tactics are assumed to be independent of pre-hostility intelligence effort. Therefore, it follows that all return transit launcher survival probabilities are equal. Thus,

$$q_2^{(j)} = q_2,\ j = 1,2,3,4.$$

To determine the optimal covert policy, Figure 7 in Chapter IV shows that the ratio, r_4/r_3, must be estimated. Using Equation 9, the ratio can be expressed as

$$\frac{r_4}{r_3} = \frac{\dfrac{n^{(4)} q_1^{(4)}}{1 - q_1^{(4)} q_2^{(4)}}}{\dfrac{n^{(3)} q_1^{(3)}}{1 - q_1^{(3)} q_2^{(3)}}}.$$

From the relationships listed above and recalling that $n^{(3)} = n$, the equation reduces to

$$\frac{r_4}{r_3} = \frac{n^{(4)}}{n},$$

which is the estimated fraction of launchers remaining after interdiction!

The expected number of missile launches can also be expressed in terms of the circulation model results. Recalling that $q_1^{(3)} = q_1^{(4)}$ and $q_2^{(3)} = q_2^{(4)}$, the expected launches for covert intelligence, case 2 are

$$E[\text{LAUNCHES}] = mhr_3 = mh\left(\frac{nq_1}{1-q_1q_2}\right)$$

and for case 4 are

$$E[\text{LAUNCHES}] = mr_4 = m\left(\frac{n^{(4)}q_1}{1-q_1q_2}\right).$$

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