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COUNTERING SHORT RANGE BALLISTIC MISSILES

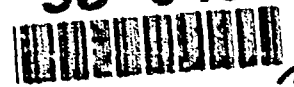
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January 1993

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Prepared for:
Office of the Chief of Naval Operations (OP-091)
Washington, D.C. 20350

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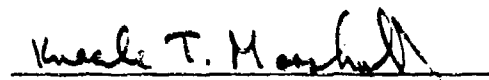
This Report was sponsored and funded by The Office of the Chief of Naval Operations (OP-914) and by the Naval Postgraduate School.



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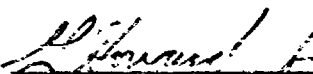
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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NPSOP-93-009			7a. NAME OF MONITORING ORGANIZATION Office of Navy Requirements for Research and Development, Test and Evaluation (OP-914)		
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School		6b. OFFICE SYMBOL (If applicable) OR	7b. ADDRESS (City, State, and ZIP Code) Washington, DC 20350		
6c. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943		8a. NAME OF FUNDING/SPONSORING ORGANIZATION OPNAV			
8b. ADDRESS (City, State, and ZIP Code) Washington, DC 20350		8b. OFFICE SYMBOL (If applicable) OP-914		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
10. SOURCE OF FUNDING NUMBERS		PROGRAM ELEMENT NO.		PROJECT NO.	
				TASK NO.	
				WORK UNIT ACCESSION NO.	
11. TITLE (Include Security Classification) Countering Short Range Ballistic Missiles					
12. PERSONAL AUTHOR(S) George W. Conner, Mark A. Ehlers, and Kneale T. Marshall					
13a. TYPE OF REPORT Technical		13b. TIME COVERED FROM 4/92 TO 12/92		14. DATE OF REPORT (Year, month day) 1993 January	
15. PAGE COUNT					
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Ballistic Missiles, Short Range, Search, Decision Analysis, Influence Diagrams		
19. ABSTRACT (Continue on reverse if necessary and identify by block number)					
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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT			21. ABSTRACT SECURITY CLASSIFICATION		
<input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			UNCLASSIFIED		
22a. NAME OF RESPONSIBLE INDIVIDUAL K. T. Marshall			22b. TELEPHONE (Include Area Code) (408) 656-2474		22c. OFFICE SYMBOL OR/Mt

COUNTERING SHORT RANGE
BALLISTIC MISSILES

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ABSTRACT

Concepts commonly found in ASW search are used to model the flow and detection of mobile launchers for short range ballistic missiles. Emphasis is on detection and destruction of the launcher before launch. 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-hostilities intelligence policies.

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1. Introduction

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 (Ref. [1]). 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. The degree to which the Iraqi government measured the success of their SRBM force is thought to be based largely on the capability of continuous SCUD missile launches throughout the war, independent of whether the intended target was destroyed or not. By this measure the mission was highly successful.

The scramble to destroy the mobile SRBM launchers became headline news as the war proceeded and a number of SCUD missiles penetrated the air defenses of the Coalition; a few reached their targets inside Israel and Saudi Arabia. The speculation that Iraq might use chemical warheads on its missiles increased the urgency of the launcher destroy 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 to be increasing and will probably become more accurate and lethal with time.

This report proposes a basic model that captures the important aspects of the mobile SRBM counter effort. 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 current mobile launcher counter effort is proposed using the general principles that have been effective in anti-submarine warfare. The benefits of, and policy development for, prosecuting the mobile launchers *prior to missile launch* are stressed.

The following sections provide a partial answer to solving the mobile SRBM counter effort. They raise questions concerning the actual hardware, tac-

tics, 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.

Section 2 argues the case for requiring pre-missile-launch and pre-hostility tactics against mobile launchers to counter the SRBM threat. Section 3 describes a circulation model based on launcher transits between forward replenishment points and launch areas. From this model we derive expressions for a number of performance measurements, including the expected number of missiles launched and the expected number that will reach their target area, in terms of critical model parameters. Included are numerical and graphical examples. Section 4 describes a decision model constructed to reflect the major events and decisions that must be made with respect to mobile missile launchers leading up to the outbreak of hostilities with a likely adversary. Optimal policies are derived in terms of model parameters, and examples are given. Section 5 combines the circulation model of Section 3 with the decision model of Section 4, and presents a methodology to determine optimal policies to counter the mobile launchers. Section 6 contains concluding remarks and a recommendation for further work.

2. The Mobile SRBM Counter Effort

The mission of defeating or significantly suppressing the mobile SRBM threat is difficult. Post Desert Storm analyses have revised downward the optimistic war time battle damage assessment (BDA) of a significant percentage of mobile launchers destroyed (Ref. [2]). Some reports have indicated numbers close to zero for the estimated number destroyed during the conflict. 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 that normally indicate mission success.

2.1 An Integrated Approach

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 (Ref. [3]). Air defense systems such as PATRIOT are being designed to kill incoming missiles. 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. These approaches assume that the mobile SRBM problem begins *after* missile launch. This report focuses on the benefits and policy development of prosecuting the mobile launchers themselves prior to both missile launch and hostilities.

The analyst familiar with the general principles of anti-submarine warfare (ASW) find the poor results of the counter effort to suppress mobile SCUD launcher activity during the Persian Gulf War to be 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 with the SRBM, but well before the threat is in the position to do so. This section introduces the concept of using search tactics prior to missile launch as well as pre-hostility intelligence effort in countering the mobile launcher, and suggests using an existing structure to create an effective counter effort doctrine.

2.2 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 air crewman, 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 as impossible the idea of one day passively tracking a submarine while it is submerged. Today, this is commonplace. 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 adapted 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 specific tactics and hardware will be different, many of these principles that have brought success to ASW apply directly to countering mobile missile 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.

a) Strong community identification. Like ASW, the mobile SRBM counter effort requires a dedicated integrated 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.

b) 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 crucial role in both detection and classification of targets.

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

d) 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.

e) 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.

f) 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.

g) 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.

h) 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.

i) 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.

j) 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.

k) 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.

l) 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 be thought of in broad terms, not simply as a science and/or engineering problem. The effort, like ASW, is multi-faceted and will need a broad array of disciplines including tactical modeling, risk analysis and decision modeling in addition to science and 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.

Many of the principles listed in this section involve or imply the prosecution of mobile launchers prior to receiving cueing 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.

3. A Launcher Circulation Model

The following simple model shows the potential 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 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 replenishment base to a designated launch area, and 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

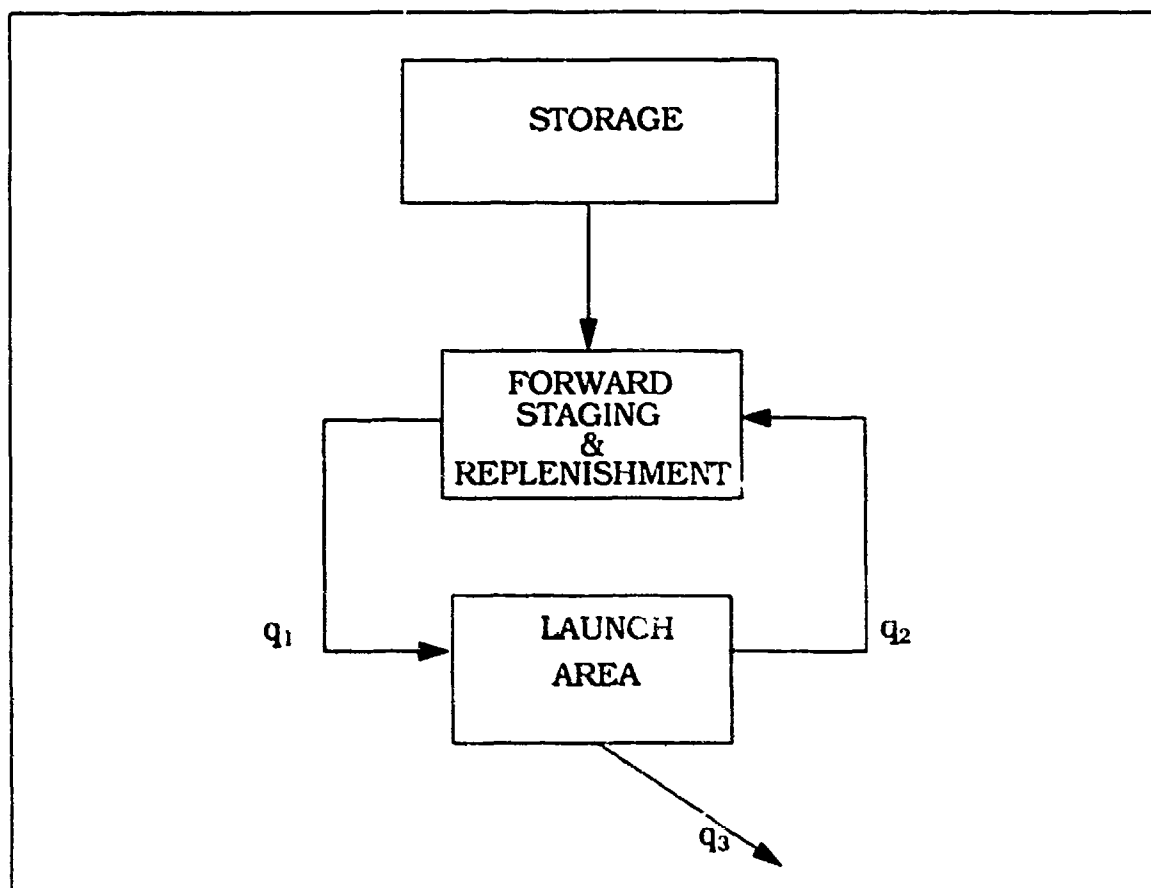


Figure 1: Mobile SRBM Launcher Circulation Model

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. [4]). The CNA model was developed to study an idealized, steady state anti-shipping 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 detec-

tion 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 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).

We extend the analysis in Ref. [4] to a more realistic model for the mobile launcher problem, where the probabilities q_1 and q_2 are not equal. Specifically, we focus on determining the effect on the expected number of missile launches of reducing q_1 from its current value of approximately 1.0. 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 this base to the launch area. All subsequent cycles are defined as surviving the transit from the launch area to the forward base, and back to the launch area. Of specific interest are the following:

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

3.1 Circulation Model Analysis

The following notation is used:

n = estimated total number of enemy mobile launchers.

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

$q_1 = \text{Pr}\{\text{mobile launcher survives transit from the forward base to launch area and launches missile}\}.$

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

The probability distribution of C_i is geometric in nature. It fires no missiles if it is destroyed on its first transit from Forward Replenishment (FR) to Launch Area (LA). For $i > 0$ it launches i missiles if it is not destroyed on the first transit from FR to LA, nor on any of the next $(i-1)$ cycles starting at LA, and is destroyed on the next cycle. Thus

$$\begin{aligned} \text{Pr}\{C_i=n\} &= 1 - q_1 && \text{if } n = 0, \\ &= q_1(q_1q_2)^{i-1}(1 - q_1q_2) && \text{if } n = 1, 2, 3, \dots \end{aligned}$$

The expected value of C_i is

$$E[C_i] = q_1 / (1 - q_1q_2) \quad (1)$$

and the variance is

$$\text{Var}(C_i) = [q_1 - q_1^2(1 - q_2)] / (1 - q_1q_2)^2. \quad (2)$$

A mobile launcher has a very limited field reload capability, especially in a hostile environment. Although on a given cycle it is possible to reload and fire more than one missile this is not observed to occur in practise. We therefore assume that on each cycle a launcher attempts at most one launch. It follows that the expected number of missile launches by launcher i before destruction will equal the expected number of cycles the launcher survives. Figure 2 shows a plot of the expected number of missile launches by launcher i as a function of q_2 with q_1 held constant at various feasible values (1, 0.95, 0.9, 0.85). The interpretation of the plot follows shortly.

Define the random variable R as the total missile launches by all n mobile launchers during a conflict, so

$$R = \sum_{i=1}^n C_i.$$

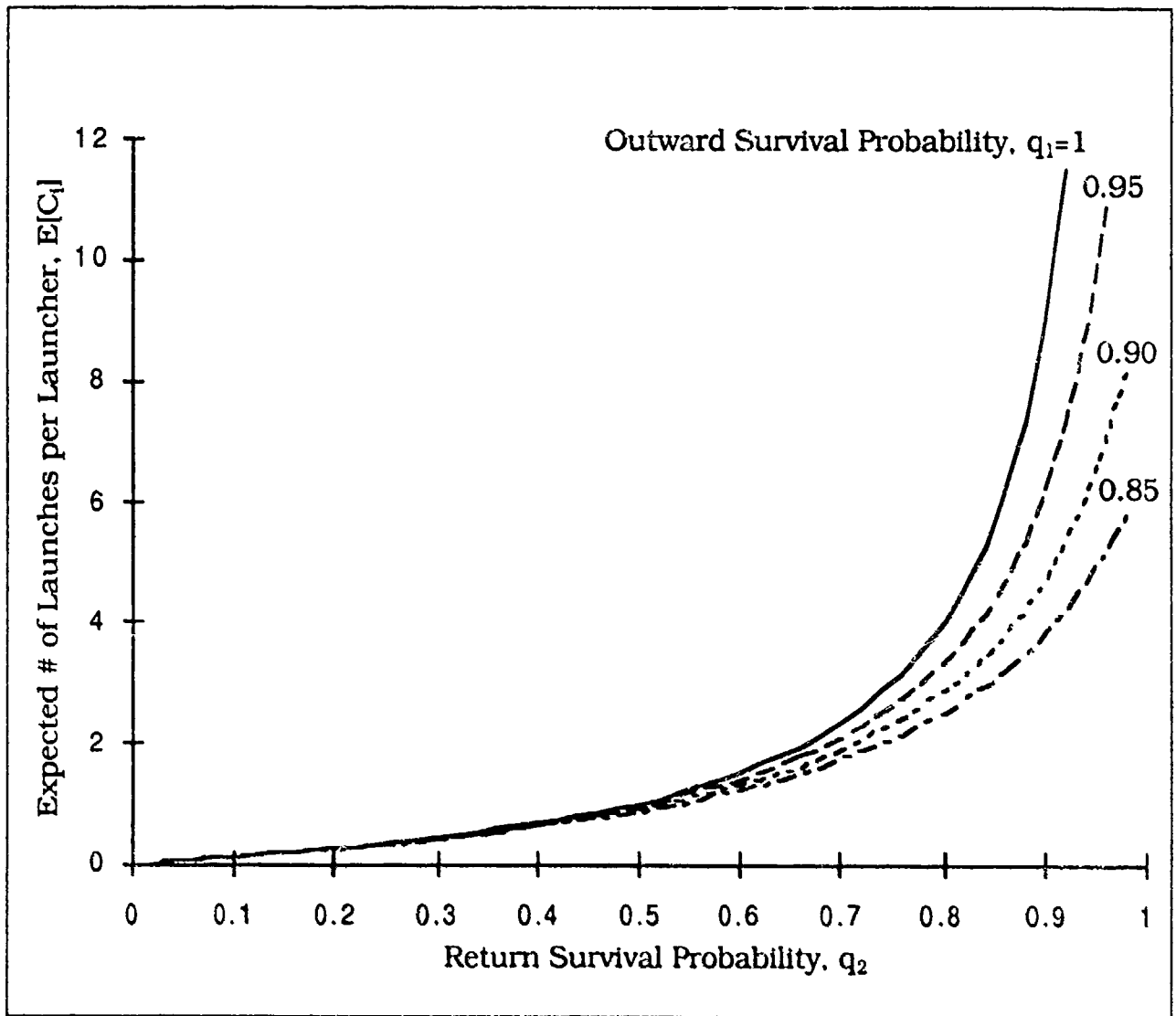


Figure 2: Expected Missiles Launched per Launcher

From Equation (1) the expected total missile launches by all mobile launchers in a conflict is

$$E[R] = nq_1 / (1 - q_1q_2). \quad (3)$$

This model assumes an extended conflict where the probability of launcher survival on each leg remains the same for every cycle, each cycle is independent of the others, and 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.

3.2 Circulation Model Results

An important result of our analysis of the circulation model is displayed in Figure 2. As mentioned earlier, the current emphasis 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 that q_1 would be approximately equal to 1. Referring to the $q_1=1.0$ curve in Figure 2, it is seen as q_2 increases above about 0.6, the expected number of launches by launcher i begins to increase geometrically. A simple interpretation of this is, if the flaming datum tactic is unable to obtain a probability of mobile launcher kill of at least 0.4, the expected number of missile launches may be unacceptably high. As q_1 decreases due to pre-launch tactics and pre-hostility intelligence, the critical q_2 value increases, and the maximum expected missile launches decrease considerably. For example, for $q_2=0.9$ reducing q_1 from 1.0 to 0.85 reduces the expected missiles launched per launcher from 10.0 to 3.6, or approximately two thirds.

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. Air defense systems of the future are predicted to have no greater than 90% efficiency in defeating incoming missiles, leaving up to 10% of those launched to reach their destination without interception. Therefore it is also of interest to examine the effect of pre-missile launch effort on the expected number of missiles that penetrate the air defense system. This is the focus of the following subsection.

3.3 Model Parameter Effects

After launch, each missile is subject to interception by an air defense network (PATRIOT, for example) that attempts to destroy the missile prior to reaching its targeted area. Assuming that missile destructions are independent

events (destruction of a missile tells us nothing about the likelihood of destruction of any other missile) they can be modeled as Bernoulli trials. Let $X_j=1$ if a missile j is not destroyed, $X_j=0$ if it is, and let $\Pr(X_j=1)=q_3$ (see Figure 1). The total number of missiles from launcher i not destroyed will be the sum of these X_j 's where j ranges from 1 to C_i . If S_i is the number of missiles launched from launcher i that are not destroyed by the air defense network, the probability distribution for S_i , given C_i , is binomial with parameters C_i and q_3 . Thus

$$E[S_i | C_i] = C_i q_3 \text{ and } \text{Var}(S_i | C_i) = C_i q_3 (1 - q_3).$$

To find $E[S_i]$ and $\text{Var}(S_i)$ we need to remove the condition on C_i using the theory of conditional probability. The results are

$$E[S_i] = q_1 q_3 / (1 - q_1 q_2) \quad (4)$$

and

$$\text{Var}(S_i) = \frac{q_1 q_3 (1 - q_1 q_2 + 2 q_1 q_2 q_3 - q_1 q_3)}{(1 - q_1 q_2)^2}. \quad (5)$$

Finally let the random variable T represent the total number of enemy missiles which successfully penetrate the air defense network and reach their targeted area from all n enemy launchers. Since

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

the expected value of T is n times the expression in Equation (4),

$$E[T] = n q_1 q_3 / (1 - q_1 q_2). \quad (6)$$

If we assume that there is no correlation among the S_i 's the variance of T is n times the expression in Equation (5).

Equation (6) 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 search and destroy tactics,
- (iv) reducing q_2 through increasing the success rate of the flaming datum tactic.

Note that $E[T]$ is linear in q_3 , but geometric in both q_1 and q_2 . Thus one can expect far higher payoff from a reduction in either of the latter two parameters compared to q_3 . It is better to destroy the bow than try to shoot down the arrows in flight. Table 1 demonstrates this by showing the expected number of missiles that survive the air defense network, $E[T]$, using various values for parameters. Recall

q_1	q_3								
	.1			.3			.5		
	q_2			q_2			q_2		
	.5	.7	.9	.5	.7	.9	.5	.7	.9
1.0	20	33	100	60	100	300	100	167	500
.9	16	24	47	49	73	142	82	121	236
.8	13	20		40	61		66	102	
.7	11	19		32	59		53	98	
.6	9			26			43		
.5	7			20			33		

Table 1: Expected Number Of Missiles Reaching Target Area

that we assume $q_1 \geq q_2$ so that some of the cells are empty. We also assume that the initial number of launchers, n , is 100. Three values of q_3 , the *missile* survival probability, are listed across the second row of the table. For each q_3 , three values of q_2 , the *launcher* return transit survival probability, are listed in the third row. Six values of q_1 , the outbound *launcher* survival probability, from 1.0 to 0.5, are listed down the first column.

Examining the row of Table 1 that 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 0.9, in cases where q_2 also equals 0.9 (under any value of q_3), results in a greater than 50% reduction in $E[T]$!

Table 1 can also be used to determine the probabilities required to obtain a determined acceptable level of missile hits. For example, the shaded cells in Table 1 show different combinations of parameters that yield an expected number of missile hits of approximately 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 $E[T]$.

Many of the principles that have led to success in ASW include pre-hostility intelligence effort. As mentioned in this section, this is often a sensitive option and its use must be carefully planned and based on informed decisions only. The focus of Section 4 is on the development of a decision model to gain insight into the determination of pre-hostility intelligence gathering policies. It is shown how these depend on estimates of hostilities occurring relative to the ratio of expected missiles launched under differing conditions. Section 5 ties together the circulation model results with the decision model results to help the decision maker understand the effect of resource allocation before hostilities commence.

4. The Pre-Hostilities Decision Model

Having formulated the circulation model in Section 3 it is not obvious how its results apply in a given situation. The United States does not have the resources to monitor all possible areas where mobile missile launchers may be deployed. The decision to expend resources in a given area before any hostilities break out, the level of resource allocation, and the methods of employing it,

all must depend on the likelihood of hostilities in the area that would affect US national interests. The purpose of this section is to present methods and models intended to aid a decision maker better understand the trade-offs and risks involved. The overall problem is complex, and the models presented here are intended to show the basic structure. Influence diagrams and decision trees are the tools used to help formulate and analyze the problem.

4.1 Problem Structure

The first assumption made is that the path to hostilities follows the three stages of peacetime, mobilization, hostile action. The second assumption is that two distinct decisions must be made. The first is whether or not to gather intelligence in peacetime, and how to carry this out. The second is what action to take against the mobile missile launchers during mobilization. In this report it is assumed that if hostiles occur the US would be involved¹ in reducing the expected number of SRBM's launched against friendly nations to a minimum.

Let D_1 be the set of alternatives available to the decision maker during peacetime with elements $d_1 \in D_1$. We assume that it consists of three elements:

$d_1 = 0$ if no action is taken to gain intelligence.

$d_1 = 1$ if covert intelligence effort is undertaken.

$d_1 = 2$ if overt intelligence effort is undertaken.

Let D_2 be the set of decisions available during mobilization with elements $d_2 \in D_2$. We assume that it consists of three elements:

$d_2 = 0$ if no action is taken to gain intelligence

$d_2 = 1$ if overt intelligence effort is undertaken.

$d_2 = 2$ if interdiction of mobile launchers is undertaken.

1. The political questions of possible coalition involvement are not relevant to this report. Our objective is to model the effects of pre-hostilities intelligence gathering on a possible future conflict.

It is a model assumption that interdiction at the mobilization decision stage is an option only if there has been intelligence performed during peacetime. Interdiction can take many forms. At this stage we do not specify how it is carried out, but simply assume that it will result in a lowering of the expected numbers of missiles launched.

Whichever decision is made during peacetime, the enemy decision to mobilizes is uncertain. Let $M = 1$ 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. The distribution of M is assumed to depend on the first decision with

$$\Pr(M=1 \mid d_1=i) = m_1 \quad \text{if } i = 0, 1,$$

$$\Pr(M=1 \mid d_1=2) = m_2.$$

Similarly, whichever decision is made during mobilization, the enemy decision to start hostilities is uncertain. Let H be a Bernoulli random variable that is 1 if hostilities break out and 0 if they do not. The distribution of H is assumed to depend on both decisions and on M with

$$\Pr(H=1 \mid d_1=0, M=1, d_2=0) = h_1,$$

$$\Pr(H=1 \mid d_1=i, M=1, d_2=2) = h_2 \quad \text{if } i = 0, 1, 2.$$

We assume that if $d_2=3$ (interdiction after observing mobilization) hostilities are assumed to have broken out, or $H=1$ with probability 1.

Let R be the set of possible results of the decision process with elements $r \in R$. An element r represents the expected number of SRBM's launched. Clearly this will depend on the decisions made and on the behavior of the enemy. Let

$r = 0$ if hostilities do not break out,

$r = r_1$ if no intelligence effort is applied during peacetime or mobilization and hostilities break out,

$r = r_2$ if no intelligence effort is applied during peacetime but is carried out covertly during mobilization, and hostilities break out,

$r = r_3$ if covert intelligence effort is applied during both peacetime and mobilization, and hostilities break out,

$r = r_4$ if overt intelligence effort is applied during both peacetime and mobilization, and hostilities break out,

$r = r_5$ if covert or overt intelligence effort is applied during peacetime and launcher interdiction is undertaken during mobilization.

Figure 3 shows the structure of the decision problem in an influence diagram. This figure shows the sequence of events in time from left to right, and the pos-

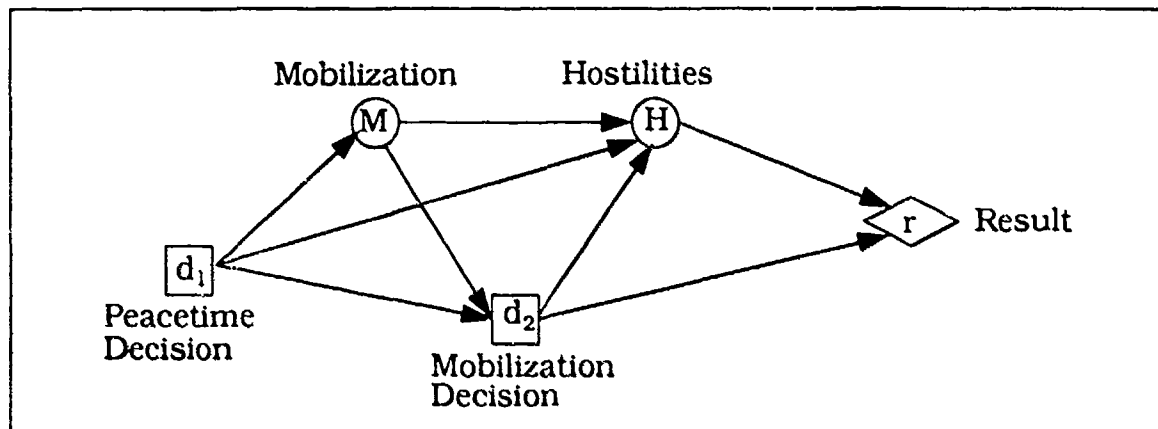


Figure 3: Influence Diagram for the Decision Problem

sible interactions among the events. The first event is the decision d_1 (decisions are depicted with square nodes) as to the type, if any, of intelligence gathering to undertake in peacetime. The next event is M , whether or not the enemy mobilizes (uncertain events are depicted by circles). This is followed by the mobilization decision d_2 , then the observation of whether or not hostilities break out, H , and finally the result r is observed (shown as a diamond node).

Directed arcs between nodes imply possible dependence. Consider the three arcs leaving d_1 . The one that ends at d_2 indicates that the mobilization decision can be affected by the peacetime decision. For example, if the peacetime

decision is not to undertake intelligence gathering ($d_1 = 0$), the mobilization decision cannot be interdiction since we have no knowledge of the whereabouts of the missile launchers. If the peacetime decision is overt intelligence gathering ($d_1 = 2$) the overt character of these efforts may affect the enemy's decision to mobilize (change the distribution of H). If the peacetime decision is covert intelligence gathering ($d_1 = 1$) since these efforts would be unknown to the enemy they cannot affect H or M .² The arc from M to d_2 shows that the enemy mobilization decision is known before the US decision on intelligence gathering in this period is made. The arc from M to H shows that these random events are dependent. The arc from d_2 to H indicates the dependence of H on d_2 . Finally, once d_2 has been made and the outcome of H is known ($H=1$ if hostilities break out, 0 if not), the resulting expected number of SRBM's launched is known.

The decision tree for this problem is shown in Figure 6. The sequence of the nodes follows that shown in the influence diagram. Extending from each decision node are branches that represent all possible decision options at that stage. Each of the decision branches terminates at a random event node representing possible mobilization.

The decision nodes are marked d_1 for the peacetime decision and d_2 for the mobilization decision. The random event nodes are labeled M for mobilization and H for hostilities. Extending from each decision node is a branch for each decision alternative in the sets D_1 and D_2 , and from each random event node are two branches that represent the uncertain outcome, 1 or 0. The result values shown at the terminal diamond nodes, and the conditional probabilities on the branches leaving the M and H nodes, are those defined earlier in this section.

2. Note that if overt operations were not considered from the outset we could remove the directed arcs between d_1 and both M and H , and from d_2 to H , thus simplifying the problem.

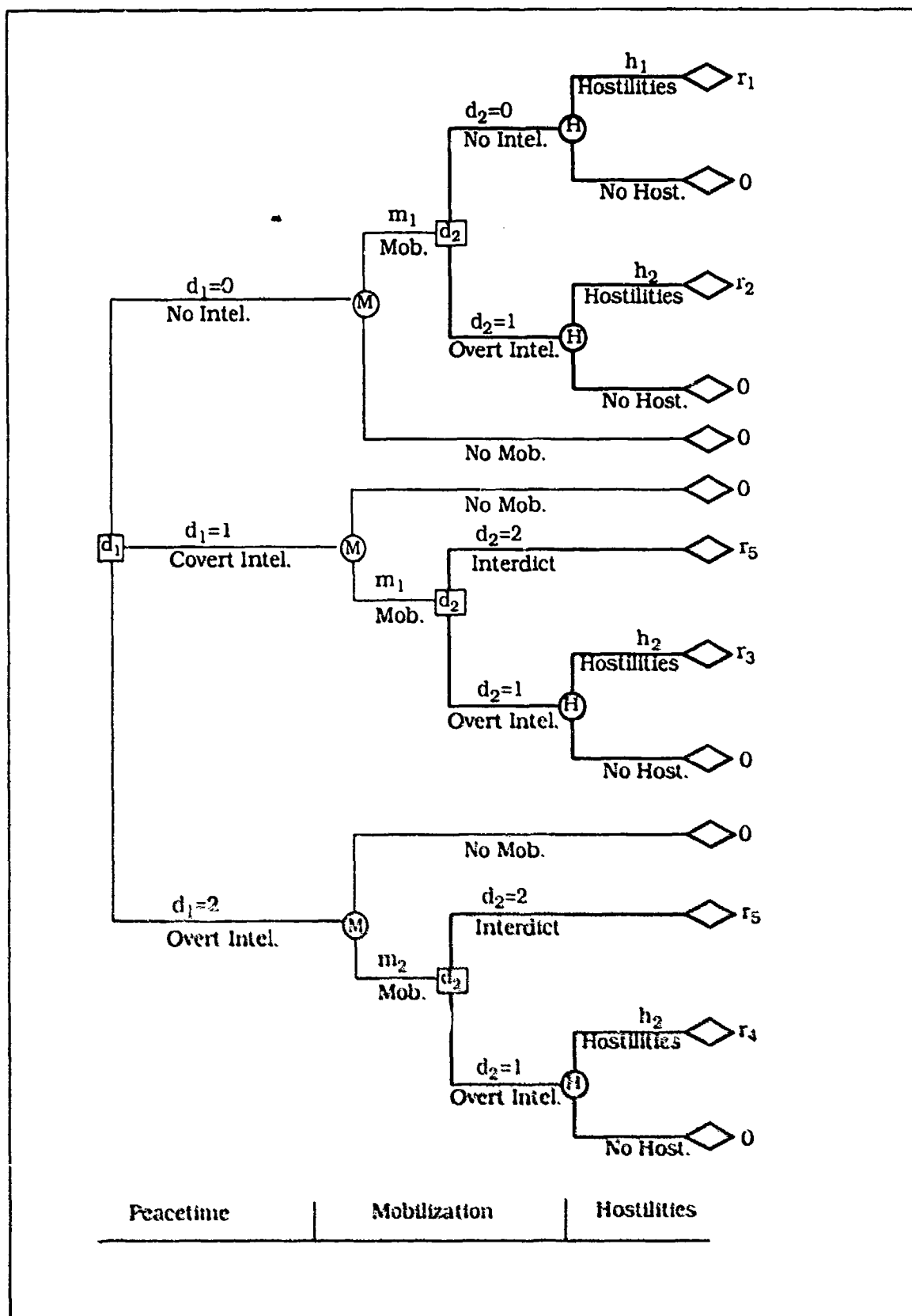


Figure 4: The Intelligence Effort Decision Tree

The notation m and h have been used to represent the probabilities of mobilization and hostilities occurring respectively. Subscripts are used to differentiate between estimated parameters under different policies. The following probabilities are required:

$$m_1 = \Pr\{\text{mobilization occurs, given no or covert intelligence effort in peacetime}\}$$

$$= \Pr\{M=1 \mid d_1=0\} = \Pr\{M=1 \mid d_1=1\},$$

$$m_2 = \Pr\{M=1 \mid d_1=2\}.$$

$$h_1 = \Pr\{\text{hostilities occur, given no intelligence effort in either peacetime or mobilization}\}$$

$$= \Pr\{H=1 \mid d_1=0, M=1, d_2=0\}.$$

$$h_2 = \Pr\{\text{hostilities occur, given overt intelligence during mobilization}\}$$

$$= \Pr\{H=1 \mid M=1, d_2=1\}.$$

These probabilities are attached to the appropriate branches of the decision tree.

4.2 Parameter Ordering Assumptions

From the structure of the problem thus far it is reasonable to make some assumptions on the relative values of the m_i 's, h_i 's and r_i 's. First we assume that overt intelligence gathering in peacetime and/or mobilization acts as deterrence. It results in a probability of mobilization that is no larger than, and quite likely smaller than, what it would be if no intelligence were gathered or it was gathered covertly. This implies that

$$m_1 \geq m_2. \quad (7)$$

Similarly, once mobilization has begun, it is assumed that overt intelligence will result in lowering (or at least not raising) the likelihood that hostilities break out. Thus

$$h_1 \geq h_2. \quad (8)$$

Second we assume that the more information we have the more successful we will be in reducing the expected number of missiles launched if hostilities break out. We also assume that the most effective way to reduce this number is to interdict the launchers during mobilization. Thus

$$r_1 \geq r_2 \geq r_3 \geq r_4 \geq r_5. \quad (9)$$

These assumptions play an important role in the next subsection.

4.3 Problem Solution

As in solving any decision tree we start at the terminal nodes in Figure 4. As we work back to the d_1 node we take expected values at the random nodes and minima at decision nodes. At the three d_2 nodes starting at the top of the diagram, the expected result for each is $\text{Min}[h_1 r_1, h_2 r_2]$, $\text{Min}[r_5, h_2 r_3]$, and $\text{Min}[r_5, h_2 r_4]$. From the inequalities in (8) and (9) the first of these minima can be resolved immediately. The optimal policy to pursue if no intelligence is gathered in peacetime and mobilization occurs, is to start overt intelligence gathering immediately with an expected result equal to $h_2 r_2$. Resolution of the other two minima will depend on the relative value of h_2 , and we look at three cases.

Case I: $(r_5/r_4) \leq h_2 \leq 1$.

This immediately implies that $r_5 \leq h_2 r_4$, and with (9) that $r_5 \leq h_2 r_3$. This shows us that if intelligence has been gathered in peacetime no matter whether it be covert or overt, if mobilization occurs the optimal policy for this case is to interdict the launchers.

Case II: $0 \leq h_2 \leq (r_5/r_3)$.

For this case $r_5 \geq h_2 r_3$ and $r_5 \geq h_2 r_4$. These show us that if intelligence has been gathered in peacetime no matter whether it be covert or overt, if mobilization occurs the optimal policy for this case is to continue gathering intelligence, but overtly.

Case III: $(r_5/r_3) \leq h_2 \leq (r_5/r_4)$.

For this case $r_5 \leq h_2 r_3$ and $r_5 \geq h_2 r_4$. These show us that if covert intelligence has been gathered in peacetime and mobilization occurs, the optimal policy for this case is to interdict the launchers. If overt intelligence has been gathered in peacetime and mobilization occurs, the optimal policy for this case is to continue overt intelligence.

With the minima resolved at the d_2 nodes we can take expectations at the M nodes and finally find the minimum at the d_1 node. At the top M node the expected return is $m_1 h_2 r_2$. At the other two M nodes it will depend which of the three cases pertains, so each must be analyzed separately.

Case I: $(r_5/r_4) \leq h_2 \leq 1$.

At the middle M node the expected payoff is $m_1 r_5$ and at the lower one $m_2 r_5$. At node d_1 we need to find

$$\text{Min}\{m_1 h_2 r_2, m_1 r_5, m_2 r_5\}$$

Using the inequalities in (7), (8) and (9), if we denote by r^* the minimum expected result,

$$r^* = m_2 r_5.$$

Case II: $0 \leq h_2 \leq (r_5/r_3)$.

At the middle and lower M nodes the expected payoffs are $m_1 h_2 r_3$ and $m_2 h_2 r_4$ respectively. We find the minimum of these and $m_1 h_2 r_2$, so that

$$r^* = m_2 h_2 r_4.$$

Case III: $(r_5/r_3) \leq h_2 \leq (r_5/r_4)$.

At the middle and lower M nodes the expected payoffs are $m_1 r_5$ and $m_2 h_2 r_4$ respectively. We find the minimum of these and $m_1 h_2 r_2$, so that again

$$r^* = m_2 h_2 r_4.$$

To summarize the results,

1. In peacetime undertake overt intelligence gathering ($d_1^*=2$)
2. If mobilization occurs
 - a. If $h_2 \leq (r_5/r_4)$, continue overt intelligence until hostilities occur ($d_2^*=1$),
 - b. If $h_2 \geq (r_5/r_4)$, interdict launchers ($d_2^*=2$).

Figure 5 shows these results graphically, together with the expected result if no action is taken prior to hostilities.

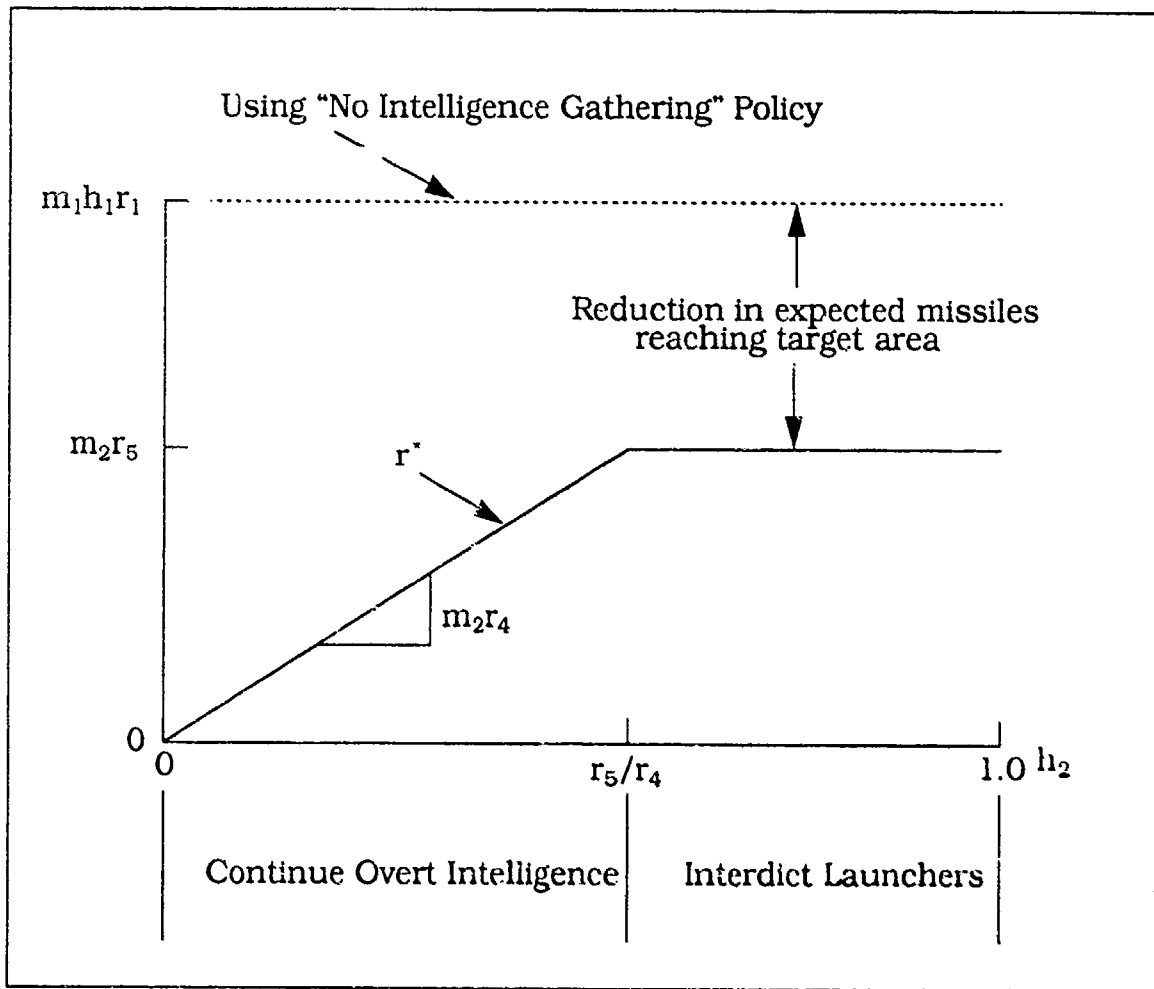


Figure 5: Optimal Policies and Expected Payoff Function

5. Circulation and Decision Model Synthesis

In the decision model in the previous section the payoffs are measured in expected numbers of missiles launched. Recall that Equation (1) in Section 3 gives the expected number of missile launched by launcher i . Combining the notation from Sections 3 and 4, the result measures from the decision model, (r_1 through r_5) can be expressed as

$$r_j = \frac{n^{(j)} q_1^{(j)}}{1 - q_1^{(j)} q_2^{(j)}} , \quad j=1,2,3,4,5. \quad (10)$$

where the superscript (j) on the parameters refers to the subscript on r . For example, $n^{(1)}$ represents the estimated number of launchers remaining given the peacetime decision is no effort ($d_1=0$), mobilization occurs ($M = 1$), the mobilization decision is no effort ($d_2=0$), and hostilities occur ($H = 1$). It follows that

$$n^{(1)} = n^{(2)} = n^{(3)} = n^{(4)} = n, \quad (11)$$

as nothing is done prior to hostilities to reduce the number of launchers in these instances. If the interdiction decision is made we assume that action is taken against launchers on their way from storage to the forward staging area resulting in $n^{(5)} < n$.

It is assumed in this report that more intelligence leads to a reduced chance of launcher survival during the outbound leg of the cycle. This is expressed as

$$1 = q_1^{(1)} \geq q_1^{(2)} \geq q_1^{(3)} = q_1^{(4)} = q_1^{(5)}. \quad (12)$$

Once hostilities start, it is assumed the launcher survival probability q_1 on the outbound leg of the cycle is approximately the same whether peacetime intelligence is followed by more intelligence, or by interdiction upon threat mobilization. Since post-missile-launch counter effort tactics are based on the flaming datum, they are assumed to be independent of pre-hostility intelligence effort.

Therefore, it follows that all return transit launcher survival probabilities would be equal,

$$q_2^{(j)} = q_2, \quad (13)$$

for all j .

To determine the optimal policy, Figure 5 in Section 4 shows that the ratio r_5/r_4 is a critical quantity. Using Equation (1), the ratio can be expressed as

$$\frac{r_5}{r_4} = \frac{n^{(5)} q_1^{(5)} (1 - q_1^{(4)} q_2^{(4)})}{n^4 q_1^{(4)} (1 - q_1^{(5)} q_2^{(5)})}.$$

From (11), (12), and (13) this equation reduces to

$$\frac{r_5}{r_4} = \frac{n^{(5)}}{n}$$

which is the estimated fraction of launchers remaining after interdiction. This result is shown in Figure 6, and can be stated as follows:

Given that mobilization has occurred and intelligence is being gathered overtly in this period, if the decision maker assesses the probability that hostilities will occur to be higher than the fraction of missile launchers that are expected to survive preemptive interdiction, then preemptive interdiction of the launchers is the optimal course of action.

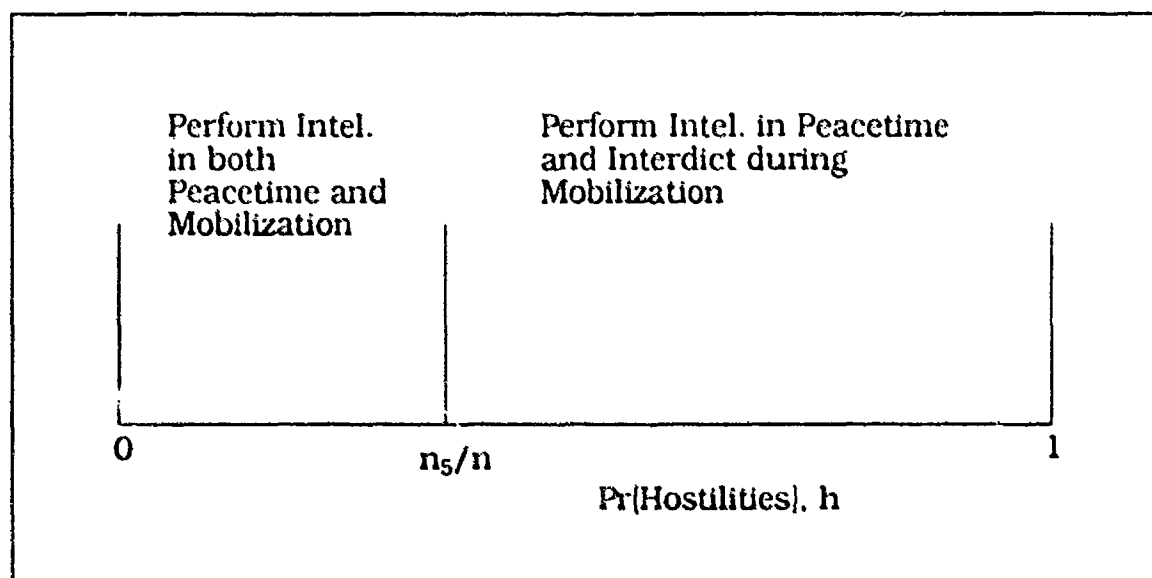


Figure 6: Optimal Policy in Terms of Fraction of Launchers Remaining

5.1 Intelligence Effort Level

Nothing has been said to this point about the type or level intelligence effort. A detailed discussion of this topic is beyond the scope of this report, but we include some remarks that show the relation between critical model parameters and resources spent on intelligence gathering.

Figure 7 shows a typical curve of how the fraction of launchers that survive interdiction during mobilization is reduced by increasing intelligence gathering efforts. Also shown is a line depicting the effect of deterrence (and a

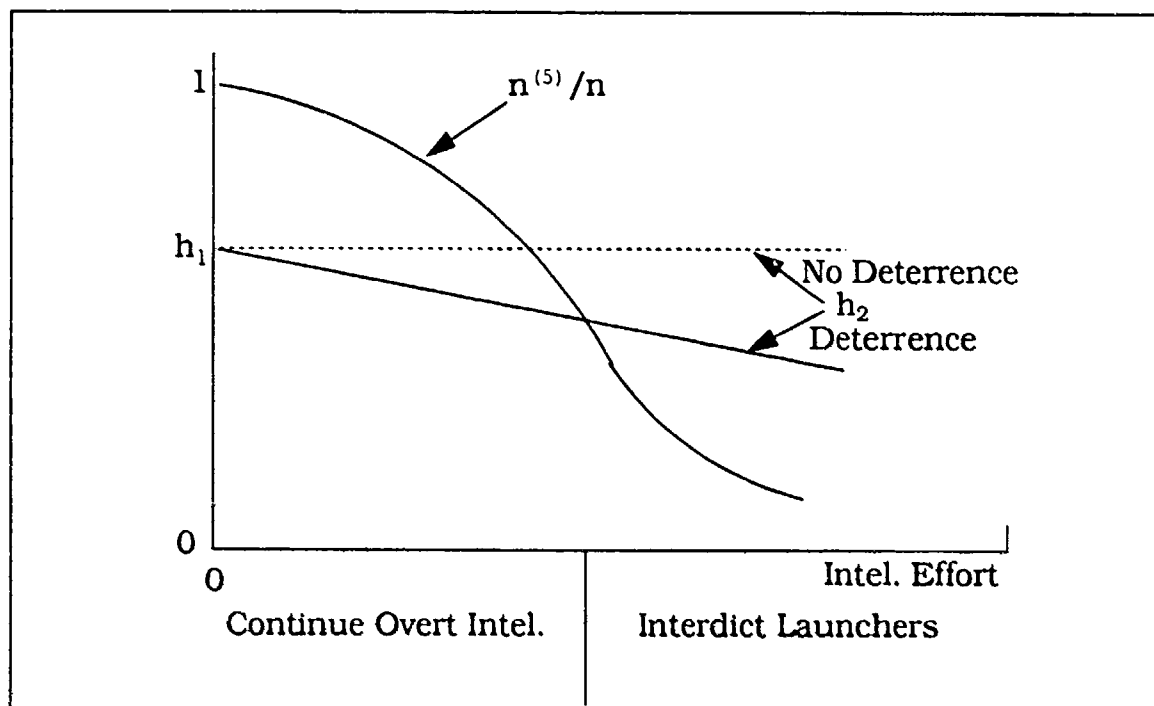


Figure 7: Optimal Policies in Terms of Intelligence Effort

dashed line showing no deterrence effect). For intelligence efforts at levels above this cross-over point the optimal strategy is to interdict launchers during mobilization.

The particular shape of the curve and the units used to measure the intelligence effort cannot be discussed in this report. An obvious unit is man-hours of effort; another might be surveillance flight hours. The S-shaped curve shown is typical of what one might expect, indicating little effect from small

amounts in intelligence effort and little effect from amounts above a certain threshold. We can say little more at this preliminary stage of modeling.

6. Conclusions

Model construction and assumptions 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 payoff from pre-hostility intelligence effort in reducing 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. No point estimates or specific solutions are included in the insight gained through analysis of the model; rather, regions of preference are stressed. 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.

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 could be used 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.

7. Future Work

The models presented in this report are clearly basic. The intent is to introduce the reader interested in countering SRBM's to the ideas of ASW Search and decision modeling. The result of any real decision problem concerning SRBM's will probably be measured with multiple attributes, not simply expected missiles launched. Acceptable levels of launches will depend on many

factors including warhead type (conventional, chemical, biological, nuclear). If the curve in Figure 7 can be better defined and quantified, the decision tree in Figure 4 can include more decision alternatives and/or stages. These might include multiple levels and methods of intelligence gathering as well as various types of search methods. Real decision trees tend to become very large, but modern techniques and software are available for their rapid solution and interactive use on personal computers (Ref. [5]). Some model parameters, such as the probability that hostilities will break out given a certain course of action, will remain to be estimated by the decision maker. The power of decision analysis using decision trees and influence diagrams is that it involves the decision maker in the modelling process; the model acts as a means to show rapidly the (sometimes unexpected) results of certain actions and assumptions.

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