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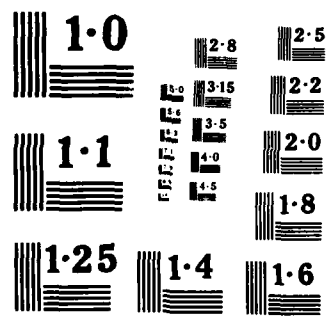
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THE PROBABILITY OF ACCIDENTAL NUCLEAR WAR:
A GRAPHICAL MODEL OF THE
BALLISTIC MISSILE EARLY WARNING SYSTEM

by

Barbara Y. Diegel Marsh
March 1985

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The results show that accidental nuclear war is not very probable with launch-under-attack, but significantly more likely if the United States adopts a launch-on-warning policy. The final decision and responsibility to use these policies, once they are implemented, rests entirely with the President of the United States.

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The Probability of Accidental Nuclear War:
A Graphical Model of the
Ballistic Missile Early Warning System

by

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Submitted in partial fulfillment of the
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ABSTRACT

→ Six false alarms occurred at NORAD in 1978, 1979, and 1980. These false alarms subsequently regenerated interest in launch policies and the increased possibility of accidental nuclear war, which motivated this investigation. We construct a new model to address several questions: What is the sequence of events and reasonable timing between events in the missile warning system? How much time do decision makers have to respond to a threat? What effects do United States launch policies have on decision-making time? How likely is accidental nuclear war?

The results show that accidental nuclear war is not very probable with launch-under-attack, but significantly more likely if the United States adopts a launch-on-warning policy. The final decision and responsibility to use these policies, once they are implemented, rests entirely with the President of the United States. *Kenneth*

*For the missile early warning system;
For the missile system. (Thesis)*

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I. INTRODUCTION

Early warning information provides decision makers with a description of enemy forces as they prepare for, or actually initiate, an attack. Given early warning, decision makers in the military and the government, including the President, can more adequately decide on a response during a crisis. When policy makers discuss changes to the regulations pertaining to the early warning system, they need to realize the implications of such policy changes on the system. This thesis presents the current early warning system, discusses proposed launch policies, and explores the possible results from implementing these policies.

Warning information is essential for the survival of the many parts of our arsenal and its related control systems. For example, the bomber force depends on timely early warning so that it may scramble from ground alert to airborne stations where it is less vulnerable to nuclear attack. But the use of warning to save the bomber force, or any other weapon system, addresses only a narrow aspect of warning. The most important aspect of early warning is to give advance warning of an enemy's attack, so that the decision maker has a chance to give the appropriate response to an attack. Both the United States and the Soviet Union continue to build systems of extreme complexity for early warning. Intelligence systems have merged with warning systems, yielding one overall system which is integrated vertically with military forces.

Future strategic technology is likely to make nuclear war more thinkable, especially as nuclear weapons spread to unstable countries less inclined to respect the nuclear threshold. The problem of nuclear weapons proliferation

concerns a large number of governments and is intimately related to the basic energy needs of both the developed and developing nations. It has fast become an issue of high politics on a global scale. Further, many of the developing nations claim that the United States, in the name of non-proliferation, seeks to implement policies that are highly discriminatory to the non-nuclear states and are designed to maintain American political, military, and economic power at the expense of the poorer nations. Hence, no global consensus exists on either the threat posed by nuclear proliferation or the steps that should be taken to deal with it. Instead, this issue inflames domestic debate in many nations, strains alliance relationships, sharpens the confrontation between East and West, and complicates concepts of national and international security. Within this framework of the threat of general nuclear war exists a concern for accidental or unintentional nuclear war.

We are rapidly approaching a decisive point of demarcation in the history of the nuclear arms race; namely, the first strike counter-force threshold. This means both the arsenals of the United States and the USSR will be highly vulnerable to surprise attack. As a result, efforts to control the momentum and direction of the nuclear arms race are increasingly complicated and the possibility for accidental war substantially grows.

Senator Mark Hatfield describes the threat as our perception of a Soviet weapons build-up, a nuclear blackmail [Ref. 1: p. 3]. He describes the Soviet Intercontinental Ballistic Missile (ICBM) threat as impressive, yet destabilizing, because we can no longer rely on technology to save us from war. Following a decade of massive arms spending, the Soviet Union comes to the current round of disarmament talks with a suffering economy. Still, Hatfield claims, the United States strategists point to the Soviet's apparent

superiority by counting the number of Soviet warheads and comparing this to the number of our warheads. In this paper, our real concern is not with the numbers question, but with how accurately and quickly we can discern if we are under attack and what should be the appropriate response.

e. Two Radars in the Southern United States

- long range phased array radars
- uses pattern recognition of current space objects
- back-up system performs a full search with human intervention
- operates on UHF frequencies
- supplements SLBM detection from the Gulf of Mexico
- receives inputs from BMEWS and the United States Navy Space Surveillance (SPASUR) network

f. Cobra Dane

- a large, real-time tracking phased array radar in the Aleutian Islands of Alaska
- detects and tracks ICBMs, SLBMs, and satellites
- predicts impact points
- primarily collects intelligence data

2. Ground Processing and Communication System

- ground stations in the continental United States and overseas which process the data from the sensors
- communication processing stations co-located with the sensors

A thorough discussion of the communication function follows later in this chapter.

3. Command Posts

a. North American Aerospace Defense Command (NORAD)

- described later in Section D of this chapter

--provides precise data on the character and magnitude of a missile attack

(2) Static Radar in Greenland and Alaska.

--evaluates missile position and velocity

--calculates the trajectory, impact point, impact time, and launch point

c. Pave Paws

--a large multi-targeting phased array radar in California and Massachusetts

--operated and maintained by the Strategic Air Command

--primarily detects SLBMs

--relays the characterization of the attack to NORAD, SAC, and the National Command Authorities (NCA)

--simultaneously detects and discriminates many objects while providing early warning data, launch, impact, position, and velocity information

--provides automatic detection, track initiation, and mission decisions

--operates at UHF frequencies

d. Perimeter Acquisition Radar Attack Characterization System (PARCS)

--located in North Dakota

--tracks incoming ICBMs

--directs the launching of missiles

--very accurate

III. DATA GATHERING MODEL

A. THE CURRENT MISSILE ATTACK WARNING SYSTEM

The Missile Attack Warning System consists of three parts: (1) sensors to detect a missile launch, (2) computer centers and communication links to process and distribute the data from the warning system, and (3) command posts which analyze data and assess the implications of the warning information and direct appropriate actions. Major components of each of the above parts follow:

1. Missile Warning Sensors

a. Satellite Early Warning System (SEWS)

- detects infrared trail of a burning missile motor
- provides overlapping coverage for the Soviet Union and China (for ICBMs)
- provides overlapping coverage for the Atlantic and Pacific Oceans (for SLBMs)
- transmits real-time information due to the nature of the SLBM detection problem
- ground stations process and forward data to the command posts

b. Ballistic Missile Early Warning System (BMEWS)

(1) Large Tracking Radar in Greenland, England, and Alaska.

- detects and continuously searches for an object
- operates on several UHF frequencies

over-simplified or overlooked many assumptions. Although these discussions thoroughly delineated the problem, little has been written to answer the questions they raise. We investigate and discuss these questions in Chapters III and IV.

B. METHODOLOGY OF THIS STUDY

In the next two chapters, we discuss two parts of the missile warning function--data gathering and decision making. These two separate, yet interrelated, parts demonstrate the role the man-in-the-loop plays and the importance of maintaining this role as we consider the implications of certain launch policies.

The Data Gathering Model completely covers all of the mechanical aspects--sensors, ground stations, command posts--as well as describing decision rules, such as dual phenomenology. The Data Gathering Model also presents several scenarios of interest with an accompanying sensitivity analysis to show how time affects the decision-making process.

The Decision Model adds decision points to the Data Gathering Model and incorporates in greater detail the same scenarios from the Data Gathering Model. The sensitivity analysis further directs attention toward the need for a policy to balance the current situation. In Chapter V, we discuss two types of launch policies and their implications.

more automatic. On that basis, the decision to launch is then automatically carried out by the computer system. This view misses the intimate relationship between warning and alert levels on the one hand, and control of offensive weapons on the other. It also fails to consider the checks and balances (that is, the man-in-the-loop) set up throughout the entire missile warning system.

Many differing opinions concerning different policy types and policy definitions exist among the authors cited. Sennott et al define launch-on-warning to mean if a situation can not be called a non-threat, then it is a threat; therefore, launch [Ref. 8: p. 2]. However, this definition does not completely cover the current decision process employed by NORAD. Steinbruner's definition is very vague; he defines launch-under-attack (equal to launch-on-warning) as launching missiles after acquiring reliable evidence that a Soviet attack is underway before its actual effects are felt [Ref. 9: p. 37]. Bracken uses the term automatic retaliation, but defines launch-on-warning to include the military decision makers, who are given emergency authority to use nuclear weapons in advance of hostilities, and who are further instructed to use this authority if indications of an attack arise. Then, Bracken states that a launch-on-warning strategy does not require any computers or radar, although they are necessary to implement such a strategy smoothly.

Although many different launch policies appear in different articles, only two stand out as viable alternatives--launch-under-attack and launch-on-warning. As described above, definitions of these policies vary widely, depending on the source. We offer clearer definitions in Chapter V and further pursue their implications.

In all the cited articles, the authors hardly considered NORAD, left out the actual decision process, and

with NORAD's definition of a false alarm (which is incorporated into our definition), and this difference may affect the conclusions of their research.

Steinbruner discusses the background of the launch-under-attack policy, an ICBM scenario, and then centers on the command, control, and communications (C³) problem [Ref. 9]. He also includes the Brookings model written by Morawski and Blair. This model simulates the performance of the C³ system under four kinds of damage conditions and investigates the ability of the system to retaliate. The article concludes by stating that even our considering a launch-under-attack policy demonstrates the increasing tensions between ourselves and the Soviets.

The authors mentioned above (as well as others referenced) hold the common view that the world is on the brink of accidental nuclear war. With increased international tension, coupled with the increasing number of missile displays, this conclusion might appear true on the surface. Even using the definition of a false alarm as delineated by Sennott et al, the apparent increase in these alarms may be explained by the following facts: (1) more sensitive sensors are on line and operators must continue to calibrate, test, and evaluate them; (2) the Soviets have increased their testing of missiles; and (3) the Joint Chiefs of Staff have revised the criteria for convening missile display conferences. Even if intelligence provides information regarding a test shot, NORAD continues to monitor, evaluate, and test its system on these live launches. Thus, the detection of any launch is added to the permanent record.

Several of the authors assumed that the man-in-the-loop would lose control of the decision-making process by being left out at certain points in the process, or that the data gathering system makes the man-in-the-loop's decision

This gigantic system contains four components--the United States warning system, the United States launch system, the Soviet warning system, and the Soviet launch system. Bereanu argues that if the United States warning system responds to an alarm, it will automatically trigger the United States launch system which automatically triggers the Soviet warning system which automatically triggers the Soviet launch system all of which leads to a nuclear war. And, if this was a false alarm, it would lead to an accidental nuclear war.

Bereanu's model also assumes that more and more of the human decision making will be turned over to a computer system. Thus, Bereanu implies that if the computer system errs and reports a missile launch when, in fact, no launch has occurred, the decision maker will automatically respond in kind; that is, launch a missile in retaliation. However, is the total system interlocked and automatic? This question will be addressed in the following chapters.

Sennott and Crissey developed a computer simulation model and a queuing theory model to show how increasing false alarms lead to an increase in the probability of accidental nuclear war [Ref. 8]. The basis of their study revolves around the apparent increasing number of false alarms, but using a different definition of false alarm than we use in this paper. Sennott and Crissey define "false alarms" as conferences called to evaluate possible threats (which are otherwise known as missile display conferences) and use the data to predict the frequency of such threats in their models. They then claim that accidental nuclear war will occur if a false alarm takes too long to resolve. That is, if the time required to resolve the alarm exceeds the use them or lose them point, then retaliation is automatic. They also equated false alerts with threat assessment conferences. However, these definitions do not coincide

alarms, since a false alarm that is not resolved could lead to accidental nuclear war.

Bereanu built an analytical model on the self-activation of a nuclear weapons system [Refs. 6,7]. His model assumes that both the United States and Soviet warning and launch systems are interconnected:

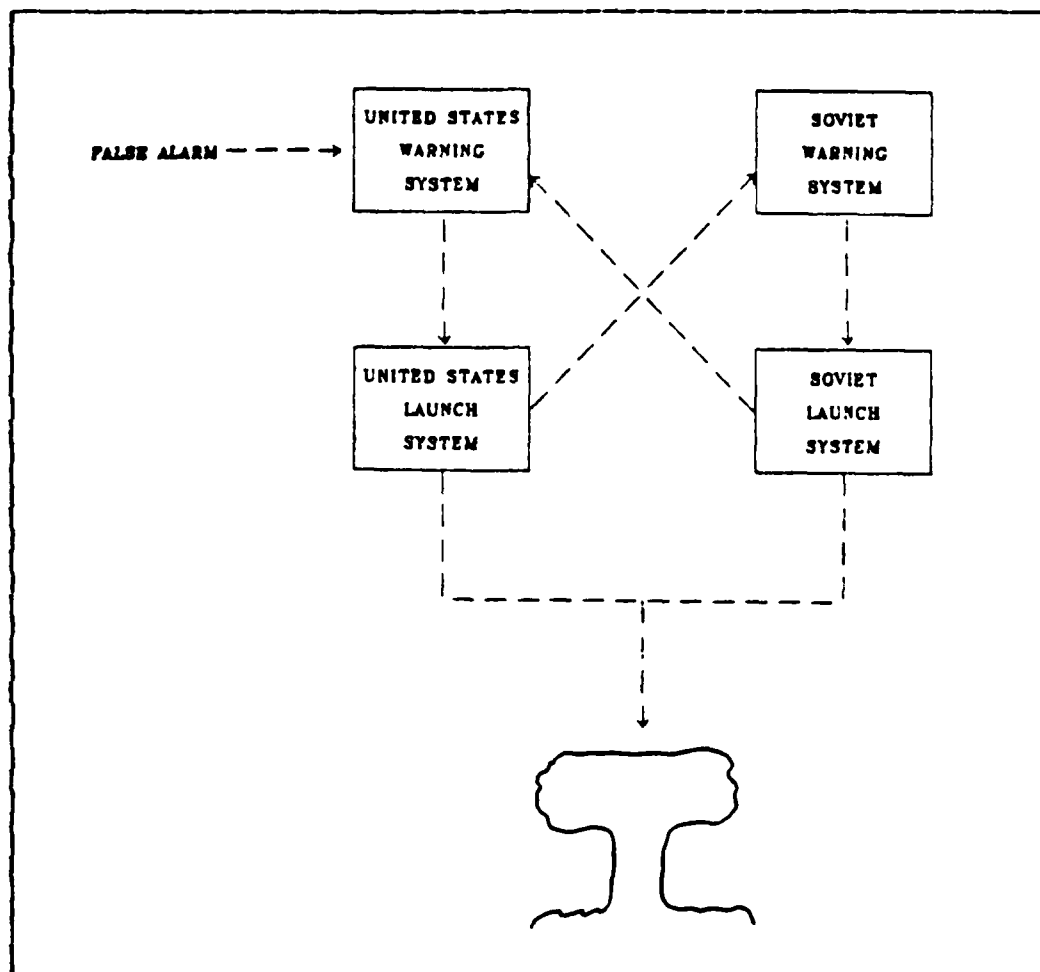


Figure 2.2 The Bereanu Model

	UNDER ATTACK	NO ATTACK
COUNTERSTRIKE	BANG AWAY!	TYPE II ERROR *
NO COUNTERSTRIKE	TYPE I ERROR *	REST EASY. . .

Figure 2.1 Type I/Type II Error Matrix

The two error types occur where the asterisks (*) are located. On the one hand, we want to lower the probability of not launching a retaliatory strike when we are under attack (the military does not want to make this mistake). On the other hand, we also want to lower the probability of launching a retaliatory strike when we are not under attack (i. e., causing an unintentional nuclear war). Note the trade-off involved with the two error types: we can not lower the probability of one error type without raising the probability of the other, due to the very nature of Type I/Type II errors. But we can continue to search for a policy which gives the best balance between Type I and Type II errors.

4. Previous Investigations of the Problem

The incidents of false alarms at NORAD generated several studies and sparked a renewed interest in launch policies. These studies focused on a need to watch false

taken in the entire missile warning system has helped to resolve incoming missile displays sooner, severely curtailing false alarms. No false alarms have occurred since 1980.

Another contribution to the cause of accidental nuclear war is the greater international tension brought about by our increased nuclear stance and the inclusion of the Star Wars weapons system in our arsenal. This means that the United States is willing to take a risk to protect itself from the threat of an attack by establishing a launch-under-attack policy. Most Americans believe that their nation is not morally capable of initiating a nuclear war under any situation. Yet, the initiation of a policy, like launch-under-attack or launch-on-warning, sends a signal to our potential enemies. It is important in the interest of peace that the Soviets clearly perceive our true intentions.

3. The Problem of Accidental Nuclear War

The main goal of the United States military is to enhance the capabilities of our weapons if we must use them, and to increase weapon survivability if we are pre-emptively attacked. But we also desire the possibility of launching our weapons to be zero when we are not under attack. We can describe this conflict using a Type I/Type II error model. A Type I error occurs when an attack is coming, but the warning process fails and indicates that we are not under attack; thus, no counter-strike is launched. A Type II error occurs when no attack is forthcoming, but the warning process fails and indicates that we are under attack; thus, a counter-strike is launched when no threat exists, leading to an accidental nuclear war. The matrix in Figure 2.1 below delineates the possibilities:

not the SLBM forces.) He claims that the deployment of missiles in Europe would limit this time span to 5-7 minutes; thus, precluding chances to avert an all-out confrontation. However, he fails to mention the SLBM threat which has about the same time span to avert a confrontation: 5-9 minutes versus 25-30 minutes for ICBMs. Although the Soviet ICBM threat is potentially more destructive to our retaliatory forces, the SLBM threat severely shortens decision-making time which affects the launching of retaliatory forces.

The mechanisms which might precipitate an unintentional or accidental nuclear war entail our steady progression of technological advances in equipment, such as satellite sensors, and increasingly sophisticated computer software. These enhanced capabilities allow faster evaluation of events that take place in the atmosphere or space, as well as on the ground, and they provide a clearer picture of the global military situation. Yet, errors in the data gathering function (which includes all sensors, communication links, and computer systems) already have caused false alarms at NORAD, our main surveillance center. In this discussion, a false alarm is a display from the data gathering system which indicates the launch of missiles towards a United States defended area with impact points in that area, but is, in fact, not real. Routine missile displays do occur every year, but NORAD does not label these as false alarms. Rather, NORAD resolves these routine missile displays using the usual surveillance procedures prior to any need for decisions from higher authority.

Four false alarms, occurring in the fall of 1979 and the spring of 1980, received international attention [Ref. 5: p. 8]. However, NORAD located and corrected the problems surrounding these alarms without an inadvertent launch of retaliatory forces. Since then, the added care

2. The Causes of the Concern

The major threatening influence on the evolution of our warning system is the stationing of Soviet nuclear-firing submarines near the coastlines of the United States. Up until the late 1960s, Soviet submarines were located under the Arctic ice cap. A launch of a Submarine-Launched Ballistic Missile (hereafter, SLBM) from that position provided some time for decision makers to discuss and recommend appropriate responses to that threat. Now, Soviet Yankee and Delta class submarines regularly patrol near our coasts [Ref. 3]. Depending on tactics and firing position, these submarines could fire SLBMs at our bomber bases and command centers with flight times ranging between 4 and 15 minutes. Then, they can aim at Washington, the North American Aerospace Defense Command (NORAD), and the Strategic Air Command (SAC) in an effort to paralyze the retaliatory forces of the United States. Even if our forces would be paralyzed only temporarily, an SLBM attack allows enough time to follow up with an all-out ICBM attack from Soviet missile fields.

Another cause for concern is Soviet rhetoric. In the spring of 1983, Anatoly Alexandrov, the President of the Soviet Academy of Sciences, announced:

"The Soviet Union will adopt a policy of automatic massive retaliation against all potential enemies if the new American medium-range nuclear missiles are deployed in Western Europe." [Ref. 4]

Although the Soviets frequently hint at using a launch-on-warning posture, Alexandrov's remarks are more definite than previous statements of the Soviet position. Alexandrov claims that the current balance of strategic forces allows roughly 30 minutes for both sides to take steps to avoid a nuclear confrontation. (This refers to the ICBM forces, but

should be denied the freedom of first use of nuclear weapons. At the same time, he hinted at renewed Soviet interest in a launch-on-warning policy. It is a mistake to discount Soviet statements as mere political bluff. Soviet threats contain exaggeration, but they also have a rationale that gives us insight into their thinking. Automatic or quick-launch systems are a preeminent design goal for the Soviet ICBM forces. These capabilities are not a by-product of Soviet technology; they are a guiding principle, and they continue to be an integral feature of the Strategic Rocket Forces (SRF).

The emphasis on pre-emption in Soviet peacetime doctrine is, of course, no guarantee that pre-emption would actually be used in a crisis. However, just the knowledge of a pre-emptive philosophy adds to our fear of surprise attack from Soviet forces. Also, it is unimaginable that the Soviets would operate their nuclear forces in a launch-on-warning mode during peacetime. The chief consequence of their emphasis on pre-emption may be that it serves as an indoctrinating force throughout their defense organization. However, once a country incorporates a view of war into the planning process, competing theories of conflict will probably receive less attention. By building an arsenal and a training system directed toward pre-emptive attack, the Soviets preclude alternative strategies from consideration. Thus, it becomes more unlikely that plans could change at the last moment in a crisis. Now, in the 1980s, the Soviets have reached a virtual nuclear parity with the United States. With an increase in the certainty of a successful pre-emptive attack may come an increase in the probability of nuclear war if East-West tensions are not reduced [Ref. 2].

II. BACKGROUND

A. WHY STUDY THE PROBABILITY OF ACCIDENTAL NUCLEAR WAR?

1. The Historical Perspective

From our everyday newspapers, we read about the increasing tension and anxiety surrounding the strategic forces of the United States. Since the close of World War II, the Western Alliance has feared attacks from the Soviet Union in Europe and in other United States defended territories, as well as the subjugation of its power and ideals to the Communist philosophy. Of course, the Soviet Union fears the same from the West. In between the super powers lie the smaller nations, each wanting to expand their own influence and power in the world in ways similar to the super powers, especially by building or buying nuclear weapons. Thus, early warning systems have grown to extreme importance over the last thirty years.

Looking at the Soviet warning system raises some deeply troubling issues. When it is examined as a system, and not merely as a physical collection of radars and computers, we see a consistency between doctrine and capability. The Soviet doctrine is one of pre-emptive attack, and the Soviet capability is a system of warning and command that supports such a strategy. The Soviet experience of invasion may help to explain the reason for this approach.

Ever since the Nazi's attack in 1941, the Kremlin proscribed to the concepts of surprise attack, pre-emptive attack, and automatic firing. These policies fuel our apprehensions about the Soviets, particularly during times of crisis. As recently as July 1982, Defense Minister Dimitri Ustinov iterated the idea that the United States

b. Strategic Air Command (SAC)

- located (underground) in Omaha, Nebraska
- has the authority and responsibility to launch the nuclear bomber force to protect it
- maintains a small percentage of the bomber force on constant alert
- operates and constantly maintains an airborne command post

c. National Military Command Center (NMCC)

- located in the Pentagon
- anticipates and evaluates foreign crises
- point of contact for the President to obtain information and command the nuclear forces

d. Alternate National Military Command Center (ANMCC)

- located (underground) in Fort Ritchie, Maryland
- acts as the alternate location for NMCC with the same functions as NMCC

The missile warning system employs a two-step process for identifying a missile launch and assessing the threat to the North American continent. First, the infrared warning satellites detect the infrared signature of a burning missile motor. Ground-based radars provide back-up confirmation data and rely on detection using a different physical phenomenon; i. e., radar tracking of a physical object as opposed to detecting the infrared signature. This two-step process is called dual phenomenology and minimizes the likelihood of mistaking some natural phenomenon for a launch of

an enemy's missile. For the purposes of this thesis, dual phenomenology means the use of different types or families of sensors to detect the same launch.

The BMEWS radar confirms and characterizes a polar ICBM attack. Pave Paws radar detects SLBM launches and SEWS covers both ICBMs and SLBMs. Thus, after the detection of an infrared signature, the BMEWS radars would be the first to detect ICBMs; the Pave Paws radar would be the first to detect SLBMs launched off either coast. The two radars in Florida perform the same function as the Pave Paws radar for missiles coming from the Gulf of Mexico.

The satellites and Pave Paws radar, the two sensors that detect the attack of SLBMs, feed their data directly to all four major command posts (so all four receive and evaluate the data simultaneously). In addition, NORAD transmits its analysis of any SLBM attack to the other three command posts. Thus, the duty officers at the other sites have two separate computations and displays of the SLBM launches. Data from all other warning sensors feed only into the NORAD command post, where it is analyzed. The other three command posts then receive the results of the NORAD analysis by transmission over the communication lines.

In order to ensure that the communication lines between NORAD and the other three command posts remain open, NORAD constantly transmits messages to the other sites over circuits that would transmit an actual attack. Normally, this message contains test data so that all three sites can monitor the condition of their communication links from NORAD. If the system works properly, all command posts receive similar information. When any indication of a real threat exists, including ambiguous data, the four command posts begin a conferencing procedure to evaluate and assess the data available.

If the Soviets launch SLBMs and ICBMs separately or simultaneously, the following sequence of events probably would occur:

1. Satellites detect launches of SLBMs or ICBMs shortly after launch.
2. Pave Paws radar picks up the SLBMs 2-5 minutes after launch.
3. BMEWS radar picks up the ICBMs within 10 minutes of their launch.
4. PARCS radar picks up the ICBMs in the terminal phase of flight.

Approximately 9-12 minutes exist between launch and impact of an SLBM. Time between launch and impact of an ICBM is approximately 25-30 minutes. Since an SLBM can destroy a large portion of our ground-based sensors and command posts, the time our current system is fully operational could be severely shortened. This does not mean that the entire system would disappear at the end of the approximate 9 minute period. But then we could only depend on those assets that survive the initial attack; that is, assets that are airborne in time to escape the attack. Thus, the short interim between detection of an attack and destruction of the major portion of our command and control structure puts a severe stress on the decision maker.

B. SENSOR PROCESSING

The sensor evaluation process entails the following steps:

1. An event triggers a sensor.
2. The satellite sensor relays a signal to its respective ground station.

3. The sensor ground station computer interprets the radar signals.
4. The computer system analyzes the signals.
5. The computer system relays its analysis to the system operator.
6. The computer system generates a message to the command posts.
7. The command post verifies if an actual message was sent.
8. The sensors continue to follow the path of the object and send update messages.

In every step of the above procedure, the man-in-the-loop observes and evaluates the processed data. Therefore, the processed data will be declared a false alarm if, in the experience of the man-in-the-loop, the processed warning data indicates a false display of a launch which may be caused by some natural phenomenon, or the man-in-the-loop has little confidence in what the computer system tells him about the supposed threat. Likewise, if a computer component fails, perhaps generating a false display, but the sensors never register a missile launch, then the man-in-the-loop will also recognize this as a false alarm.

C. COMMAND CENTER PROCESSING

Both NORAD and SAC receive missile warning data from SEWS and Pave Paws radars. NORAD receives data from BMEWS, Cobra Dane, and PARCS radars and sends summary messages to SAC. NMCC and ANMCC receive only a summary of the missile warning data from NORAD. Since NORAD obtains more information (ICBM and SLBM data) than any other command post in the

system, the Commander-in-Chief of NORAD (hereafter, CINC NORAD) assesses the sensor warning data.

If the data gathering system indicates a launch, specialized centers in the Cheyenne Mountain Complex are activated. The Missile Warning Center calls the individual sensor sites to confirm the validity of the indication of launched missiles. The Space Center states whether the indicator is or is not one of the over 4,000 objects already in space. The Solar Center reports any solar activity. The Intelligence Center discloses any information which would add to the definition of the indicator. With all this information combined, CINC NORAD makes a total assessment of whether the indicator is a real launch threat to North America.

If the satellites trigger the warning process, any one of the four command posts can call a conference. At the conference, CINC NORAD makes decisions regarding the threat/no threat situation evaluated by the sensors with inputs from the other command posts. We discuss this conferencing procedure in detail in Chapter IV.

D. NORAD'S ORGANIZATION AND MISSION

1. The Early History of NORAD

To better understand the Data Gathering Model, and later, the Decision Model, it is important to realize where NORAD fits into the picture and how NORAD's mission affects the question of accidental nuclear war.

By the mid-fifties, the United States Air Force had the technology of continuous warning information. Only by redesigning their formal organizational structure to fit this new information technology could the Air Force prosecute a war successfully. This resulted in the creation of NORAD in 1957. As the central processor of real-time

warning information, NORAD became a joint United States-Canadian command because of the location of radars and fighter bases in Canada. Its job included the integration of BMEWS, Sound Surveillance System (SOSUS), Distant Early Warning (DEW) Line, and other information sources for an overall warning estimate that would be relayed to other command centers, such as SAC and the Pentagon.

NORAD is the central command post for continuously monitoring warning and intelligence information from multiple sources. It is, then, the central coordinating institution responsible for determining when the United States is under attack.

NORAD serves a critical alerting role in an elaborate system of institutional checks and balances to prevent unauthorized or inadvertent use of nuclear weapons, either of which could lead to a nuclear war. The Commander-in-Chief of SAC (hereafter, CINC SAC) does have the authority to order the launch of the bomber force in order to prevent its destruction on the ground by incoming enemy missiles. However, this authority depends crucially on the threat of incoming enemy attack, a condition determined by CINC NORAD.

2. Today's NORAD

Today, NORAD is a bi-national partnership between the United States and Canada; CINC NORAD is also the commander of the United States component, the Aerospace Defense Command (ADCOM). Canadian forces come from the Canadian Forces Air Defense Group, headquartered at North Bay, Ontario. The senior representative of the Canadian Forces is the Vice Commander-in-Chief of NORAD. CINC NORAD reports to the Joint Chiefs of Staff (JCS) as representing the Specified Command, ADCOM. As the Commander of Aerospace Defense Center, he reports directly to the Chief of Staff of the Air Force.

The NORAD mission includes:

- (1) Tactical warning and attack assessment of bomber or ballistic missile attack on North America
- (2) Space surveillance, tracking, and cataloging of all human-made objects in space
- (3) Satellite protection of friendly satellites, providing collision-avoidance and other flight condition information
- (4) Satellite attack warning and verification for all United States satellites
- (5) Peacetime surveillance, detection, and identification of aircraft
- (6) Support for the Space Shuttle missions
- (7) Operational control of United States and Canadian Air Defense Forces

Also, NORAD has the responsibility to JCS to provide worldwide detection of missile launches and nuclear events. This includes the Pacific area and Europe, as well as the area adjacent to the North American Continent.

To accomplish its mission, NORAD exercises operational control of the detection and communications systems, and it operates and maintains the analytical systems in the NORAD Cheyenne Mountain Complex (NCMC). NCMC provides NCA and CINC SAC with real-time missile warning messages and NORAD confidence assessments.

The NORAD command post is in the underground Cheyenne Mountain Complex in Colorado. A worldwide network of sensors gathers and processes missile warning information and distributes warning messages to other United States and Canadian command posts.

NORAD does not engage in any active defense such as ballistic missile defenses designed to intercept ICBMs and SLBMs. This task is reserved for SAC. Specifically, NORAD employs passive defenses that protect targets by such means as warning, mobility, and sheltering forces.

E. DATA GATHERING MODEL FORMULATION

In order to formulate the Data Gathering Model, we must establish several basic assumptions about the data gathering process. Three examples then illustrate the importance of time: we will model an ICBM scenario, an SLBM scenario, and a test shot scenario.

First, we assume the timely detection of incoming missiles. Timely detection of missiles determines how quickly a response to an actual or imagined threat can be made. Success in preventing an accidental nuclear war, or in protecting strategic forces, depends on the fastest possible identification: the sooner an incoming object is identified as a threat or non-threat, the more time is available for decision makers to consider appropriate responses.

Second, we assume that communications remain intact over the entire system until the missiles impact. This assumption requires some explanation. As discussed in Steinbruner [Ref. 9: p. 40], an electromagnetic pulse (EMP) from an exoatmospheric nuclear explosion would cause interruption of non-hardened and long range (HF, LF) communications. To overcome the effects of EMP, redundant messages sent over the communication lines contain less information, ensuring that some information gets through the system. However, it takes at least 7 minutes after an SLBM launch before the first exoatmospheric explosion occurs. Also, we will not consider sabotage or human errors which could also disrupt communications.

t3 = second detection

t4 = assessment of launch by decision makers
(threat/no threat)

t5 = last possible time to decide on the
type of response (launch/no launch)

t6 = time of impact

The time line, over which observations are taking place, starts with the friendly forces detecting the launching of missiles, and ends with the impact of missiles. Each $t(i)$ is the time when the data gathering system detects, evaluates, and completes its analysis of the sensor data and passes along the information to the decision-making system so evaluation of the threat can be resolved prior to impact. The minimum time to resolution (that is, the minimum amount of time in which to make a decision to launch or not launch) = $(t5-t3)$. Note that $t0$, $t5$, and $t6$ are fixed points, and if $t4$ is greater than $t5$, a serious problem arises. In the following examples, the time sequence remains the same.

2. Examples

a. ICBM Scenario

Starting with the least stressful situation, an ICBM launch scenario, the model describes the following:

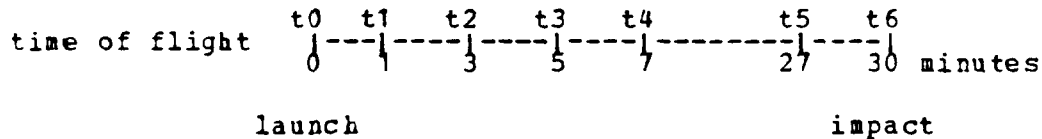


Figure 3.2 An ICBM Scenario

As in the general case above, the definitions of t_0 through t_6 remain the same. The minimum time to resolution of the threat is $(t_5 - t_3) = 22$ minutes.

b. SLBM Scenario

The model below describes an SLBM launch scenario:

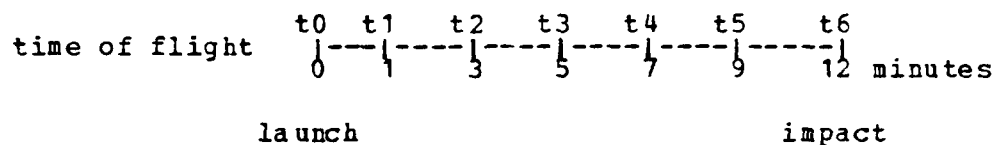


Figure 3.3 An SLBM Scenario

Again, the definitions for t_0 through t_6 remain the same. Notice that the time of flight for the SLBMs extremely shortens the amount of decision and response time. Here, the minimum time to resolution is $(t_5 - t_3) = 4$ minutes.

c. Test Shot Scenario

The model below describes the situation where the data gathering system monitors test shots of missiles:

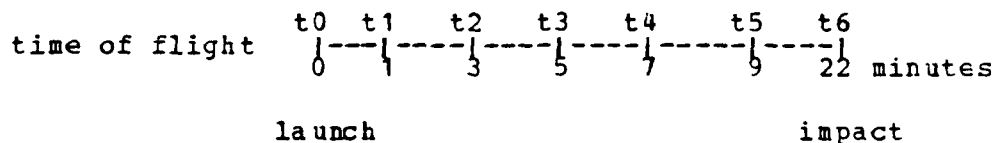


Figure 3.4 A Test Shot Scenario

Usually, in a test shot, the Intelligence Center informs CINC NORAD that a test shot has been scheduled. However, whether or not intelligence is available, the data gathering system treats a test shot as a regular launch and calculates an impact point. By t_3 , the decision makers realize it is a test shot, but continue the assessment

process for intelligence gathering. In this example, the minimum time to resolution is $(t_5 - t_3) = 4$ minutes.

F. SENSITIVITY ANALYSIS

The critical area of sensitivity analysis lies in the data processing times in the above three examples. The longer it takes to process incoming data, the less time remains to make important decisions on whether we should launch our missiles. Thus, shorter processing times buy more decision time (which becomes more precious as the scenarios get more complex).

Some uncertainty exists in the Data Gathering Model. For instance, sensors and computer hardware components do fail, computer software is not totally error free, and computer operators do make errors. All of these failures have occurred at least once at NORAD [Ref. 5: pp. 5-9]. However, in every case, NORAD did discover the error and improve its data gathering system.

In reality, the time segments of the above Data Gathering Model are not as neat and precise as described. As stated before, these segments overlap and, sometimes, one event will occur before another.

Since satellites view the world from one vantage point and ground stations view it from another, some discrepancies arise that could cause problems. For instance, if SEWS picks up a launch in one place, but Pave Paws picks it up in another, the system may display two launches even though only one has actually occurred. Sometimes 4-5 missiles look like 30, especially when debris is present. These possibilities make it harder for the decision maker to state high or low confidence in the assessment to the President and have an effect on the President's own response decision.

In the scenarios below, we explore the ramifications of the overlapping time segments.

1. The ICBM Threat

The interval between t_0 and t_1 is split into two parts. In the first 30 seconds, a quick look report flags some phenomenon which could be a launch. In the next 1.5 minutes, the initial report follows with the probable point of launch (the azimuth) and the direction of launch. This information assists the decision maker in determining whether the launch is real or the system has failed. Since processing occurs in the satellite and at ground stations, the time from t_0 to t_1 could be more than 2 minutes, when the system delays to discriminate between a natural phenomenon and a real launch, or when the decision maker calls a ground station to confirm the display on the command post's computer monitor. In any case, when several satellites pick up a possible launch, the data gathering system automatically attempts to merge the individual reports into a single message, then transmits this message to the decision maker.

In the interval between t_1 and t_2 (about 30 seconds), the data gathering system evaluates the possible launch, and by t_2 , labels it a threat/no threat. The next interval, from t_2 to t_3 , which allows time for a second detection, can become quite large. Depending on what sensor picks up the launch, and the launch trajectory, this interval could be anywhere between 3 and 7 minutes in length. The interval between t_3 and t_4 is approximately 30 seconds. Figure 3.5 graphically represents these overlapping intervals.

We now explain the reason for the 3-7 minute interval from t_2 to t_3 . There are four major phases in launching an ICBM: boost, post-boost, mid-course, and re-entry. The boost phase usually lasts several hundred

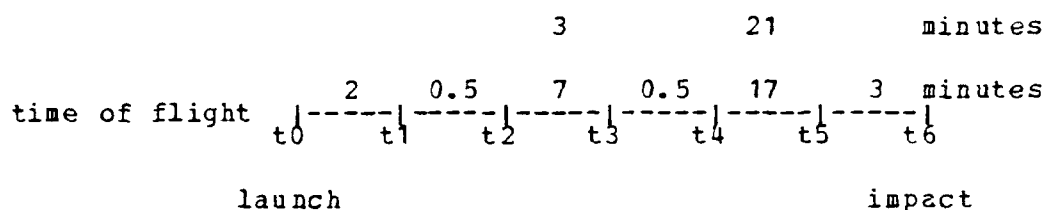


Figure 3.5 The ICBM Time Line

seconds, during which the missile starts at rest and accelerates to about 7 kilometers/second by the time it reaches an altitude of about 200 kilometers. Typically, an ICBM is a three-stage rocket, each stage contributing more than 2 kilometers/second to the missile velocity. During the boost phase, satellite sensors can easily detect the launch, and the missile is relatively vulnerable.

In sophisticated missile systems, a post-boost or deployment phase follows the boost. This phase may last another several hundred seconds. During this phase, a post-boost vehicle maneuvers to achieve a variety of very precise trajectories, and then deploys individual re-entry vehicles on each trajectory. The post-boost vehicle carries a very accurate inertial guidance system to determine its position and velocity. It maneuvers to correct any trajectory errors produced during the boost phase and places the individual re-entry vehicles on slightly different trajectories to attack different targets. The individual re-entry vehicles are commonly known as Multiple Independently Targetable Re-entry Vehicles (MIRVs). Since the post-boost vehicle uses a much lower thrust level than the booster, the rocket exhaust is much less visible to sensors.

After the re-entry vehicles are deployed, they follow their respective trajectories for approximately 1000 seconds, climbing to 1000 kilometers, and then falling towards the earth, eventually re-entering the atmosphere.

situation remains the same. The same scenarios presented in Chapter III are now re-visited below:

1. The Generic Model

This scenario describes a generic launch:

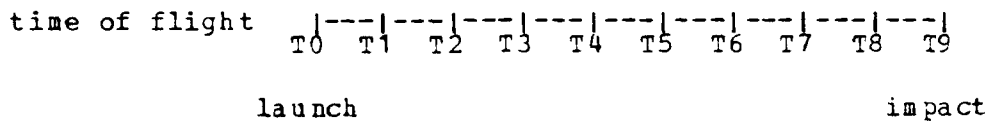


Figure 4.1 The Generic Decision Model

where

- T0 = time of launch
- T1 = first detection
- T2 = system evaluation of launch (threat/no threat)
- T3 = missile display conference called
- T4 = second detection
- T5 = threat assessment conference called
- T6 = assessment of launch by decision makers (threat/no threat)
- T7 = missile attack conference called
- T8 = last possible time to decide on the type of response (launch/no launch)
- T9 = time of impact

Thus, the minimum time to resolution is $(T_8 - T_4)$.

The suggested times in the following scenarios indicate reasonable times to impact for the purposes of discussion [Ref. 9: p. 39].

invoke confusion in humans that leads to a longer resolution time of the alarm. Since the problem with compound errors, especially human ones, also increases the number of possible outcomes, no system can protect against all combinations. The likelihood that multiple events lead to trouble increases as the activity around a possible threat increases. Thus, the complexity of the warning system may amplify mistakes when forces are placed on alert.

C. DECISION MODEL FORMULATION

Let us assume that the Soviets have the ability to launch successfully a coordinated attack. Such an attack requires proper timing in order to minimize interference between exploding warheads in the same general area [Ref. 9: p. 39].

Again, we use a simple time line to model the decision-making process. We illustrate the decision process by including three examples: (1) an ICBM scenario, (2) an SLBM scenario, and (3) a test shot scenario. We assume that the time of flight of a missile is independent of decision-making time. Also, we assume that the decision process presented in Section A of this chapter pertains here.

Again, we assume the timely detection of launched missiles. Timely detection and analysis by the sensors allows more time for the evaluation and decision-making process and for response to the threat as discussed in Chapter III. Also, we assume uninterrupted communications over the entire system.

The Decision Model time line includes the incorporation of the different conferences, and the minimum time to resolution is the minimum amount of time in which the decision makers must decide to launch or not launch a counter-strike. Recall that, in any scenario, the way NORAD handles a

politicians will act in the face of an actual attack. Arms control treaties enhance the uncertainty in intelligence and decision making when a possible launch arrives in the data gathering system, since a treaty is designed to "keep the peace." Because a surprise attack on our forces is practically unimaginable in peacetime, human operators may hesitate and rely on the peacetime checks and balances designed to keep our forces from going to war accidentally. The key problems here involve our belief that nuclear attack and war are unthinkable, dampening our response behavior to launch, which requires precise timing. Improving the warning sensors and the communication lines may ease the problem, but such improvements can not completely solve it. Because decades have passed without attack, and since the implications of authorizing a nuclear war are unthinkable, the President, as well as other senior military personnel in charge of the response, may be unwilling to launch any missiles immediately upon receipt of the news of an impending attack. This hesitation in response could seal our fate. The longer the assessment and conferencing procedures take, the more opportunity the first striker has to attack again and further disrupt the reactions of the victim. The victim would have to meet the attacker's first strike with carefully planned strikes against the attacking nation's sensor and warning systems, as well as against military forces, in order to disrupt the attacker's ability to engage in additional strikes. The victim must launch a retaliatory attack during, or soon after, the first strike.

Unavoidable false alarms from the data gathering system, or from human error, contribute to the slowing of the decision process, since it takes longer to confirm an alarm as false. While the complexity of the system does make us safer from accidental nuclear war, it only protects us against isolated failures. Multiple errors or malfunctions

preventing accidental or unauthorized use of weapons. Preventing errors of this type requires maintaining negative control. Negative control means that a variety of physical constraints and organizational procedures make it highly unlikely for any one individual to fire any nuclear weapons. It is equally improbable that the necessary combination of people required to fire these weapons, in the absence of proper authority, could be organized.

If war actually were to break out, the dominant objective changes to the execution of retaliatory attacks. It then becomes important to minimize failures to launch weapons against preassigned targets. Preventing errors of this type requires positive control: the smooth operation and precise timing required to launch missiles. Negative and positive control inherently conflict; enhancing one diminishes the other to an extent determined by the details of the command arrangements for particular weapon systems [Ref. 9: p. 38].

The issue of positive and negative control brings up additional uncertainty, in the form of proper timing of a launch. The decentralization problem made by the great destructiveness of nuclear weapons emphasizes the conflict between positive and negative control. A single location, or even a few locations, can not control a modern strategic arsenal since these locations may be identified by the enemy and pre-emptively destroyed. Thus, many military officers at numerous locations (some mobile) maintain the physical ability to fire nuclear weapons, although authorization must be given and elaborate procedures followed. Since the Soviets have reputed to do the same, more uncertainty involving many more people with access to nuclear weapons comes into play.

The response of the attacked nation is yet another uncertainty. It is impossible to predict in advance how the

personnel confer in order to determine the nature and magnitude of the threat to North America, and they direct preliminary steps to be taken to enhance force survivability (such as preparing for a SAC take-off.) CINC NORAD's assessment will contain either high or low confidence in what the sensors reveal. At this time, if the ground stations report a confirmation by more than one family of sensors, then CINC NORAD reports high confidence in the confirmed threat.

3. The Missile Attack Conference

If CINC NORAD's assessment to the President contains high confidence, CINC NORAD then convenes a missile attack conference which includes all senior personnel and the President. No missile attack conference has ever been called. To arrive at a missile attack conference, the conclusions of the two previous conferences revealed that an attack on North America is imminent. Since it takes time to convene these conferences, time is at a premium.

B. UNCERTAINTY IN THE DECISION-MAKING PROCESS

Nuclear deterrence depends on maintaining the survivability of strategic forces. Uncertainty involving the complete success of a missile attack on either the attacker's or defender's side acts as a powerful deterrent since a first strike represents an unprecedented gamble. Intelligence information is rarely complete and when decision makers confront the uncertainty of a launch during a conference, they must weigh the logical consequences of such an act and decide on a response to it. This deliberation continues to erode the time remaining before our missiles must be launched (or lost).

In deploying offensive forces for the purpose of deterring war, the dominant peacetime objective is that of

system (such as position or configuration changes to sensors), cause unusual information or conflicting data to appear.

Since we must maintain a highly sensitive system, many indications of detections arise that are evaluated as not being associated with a real missile launch. Every year many missile display conferences are called to deal with events other than potentially threatening or ambiguous missile launches.

CINC NORAD officially terminates a missile display conference when the decision makers judge the available data to indicate either the presence or absence of a threat to North America. If the perceived threat turns out to be some natural phenomenon such as a solar reflection, CINC NORAD terminates the missile display conference, declaring the situation as no threat. System operators at NORAD call the ground sites to confirm what appears on their displays. If nothing appears on the displays at the ground sites, the system operators at NORAD will then trace the problem, but CINC NORAD will not call a threat assessment conference (the next conference in the decision process). However, if the situation at NORAD agrees with the display at the ground stations, it is considered a threat. CINC NORAD then terminates the missile display conference and takes the next step by calling a threat assessment conference.

2. The Threat Assessment Conference

As stated above, if CINC NORAD judges a launch to be a threat by confirming the incoming data with the ground sites, he convenes a threat assessment conference. This conference requires the addition of more senior personnel to assist the duty officers at the various command posts in their evaluation of the confirmed threat. Senior personnel include the Chairman of the Joint Chiefs of Staff. These

them." On the other hand, the other two legs of the strategic triad, submarines and the bomber force, are less vulnerable when deployed. These forces also remain under strict human control at all times. Bombers can be recalled easily from their holding stations, but the submarine forces have more flexible instructions. These instructions restrain submarine commanders from launching missiles without authorization or allow them to maintain a neutral position.

Generally, the more missiles launched, the easier it is to decide a threat/no threat situation, since a massive launch strongly indicates a real attack. The problem arises when only one missile appears, if the sensors detect some natural phenomenon, if spurious warning data enters the data gathering system, or if a component in the system fails. If the indication of a launch comes from the ocean, this heightens the problem even more, since less time is available to evaluate, assess, and respond to the threat. If CINC NORAD assesses a single missile threat with high confidence, the President's decision problem becomes extremely difficult.

Next, we discuss three major components of the Decision Model conference procedure: (1) the missile display conference, (2) the threat assessment conference, and (3) the missile attack conference.

1. The Missile Display Conference

Upon detecting a possible launch, the missile warning system passes its analysis of threat/no threat to a decision maker, and a formal missile display conferencing procedure convenes to evaluate and assess the analysis. Any of the four duty officers at the command posts may call this initial conference, if the data gathering system at the command post indicates a possible threat. CINC NORAD calls a routine missile display conference whenever changes to the

IV. DECISION MODEL

A. DESCRIPTION OF THE CURRENT DECISION PROCESS

The missile warning function involves two major Air Force commands--NORAD and SAC. NORAD has the responsibility for the management, maintenance, and operation of all the early warning sensors, in addition to the overall air and space defense of the United States. CINC NORAD has the responsibility for the management and operation of the command post at the Cheyenne Mountain Complex, plus the responsibility for the interpretation of missile warning data sent from SAC.

SAC's responsibilities include maintaining the airborne command post, which conveys the launch order if the underground command post is wiped out. SAC is also responsible for operating its computer system, which receives missile warning data from SEWS and NORAD. CINC SAC is personally responsible for keeping the bomber and tanker forces in a ready status in case they must be launched for survivability. When launched, the bomber force does not proceed with an attack, but follows orders to go to holding positions where it waits for orders either to commence an attack or return to base. SAC repeatedly practices this launching procedure (using a small percentage of the force) to keep the bomber forces continually ready.

A number of questions concerning ICBM silo vulnerability and the missile accuracy of the Soviet SLBMs and ICBMs persist. The big question in the decision model is "Will our ICBMs be able to ride out an attack?" If we believe in silo vulnerability and decide to launch a percentage of the ICBMs in the event of a real threat, then the ICBMs are committed and can not be recalled. In this situation, the decision maker must face the decision to "use them or lose

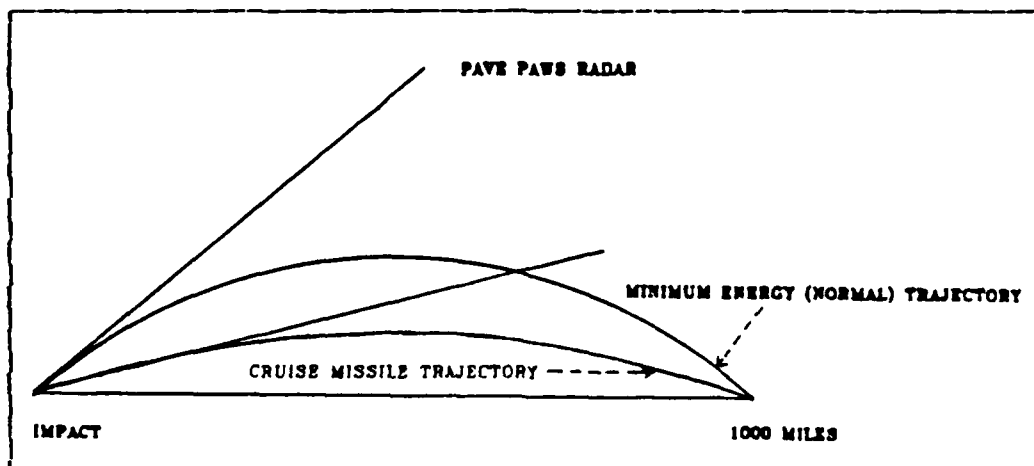


Figure 3.10 A Cruise Missile Trajectory

The table below summarizes the times discussed in the above analysis:

TABLE I
Time Remaining in the Data Gathering Model

<u>Interval</u>		<u>ICBM</u>	<u>SIBM</u>
First Detection		28	10
System Evaluation		27.5	9.5
Second Detection	minimum	24.5	2.5
	maximum	27.5	6.5
CINC NORAD's Assessment	minimum	24	2
	maximum	27	6
President's Time (3 minutes to impact)	minimum	17	0
	maximum	21	3
President's Time (6 minutes to impact)	minimum	14	0
	maximum	18	0

impact of the missile. The maximum time is $(t_3 - t_0) = 9.5$ minutes, which allows no decision-making time and 2.5 minutes to impact. This analysis explains why an SLBM launch is so stressful for the decision maker.

The decision maker will probably take about 30 seconds to make an assessment and state either high or low confidence. In the minimum case, this leaves 3 minutes for the President to take action. In the maximum case, the situation has advanced beyond the cut-off time to initiate a launch order.

With 6 minutes as the maximum time required to perform a launch sequence, that is, $(t_6 - t_5) = 6$ minutes, a decision maker would have sufficient time for assessment since the minimum resolution time $(t_3 - t_0) = 5.5$ minutes, but if the assessment takes the usual 30 seconds, no time remains for the President. If the resolution time is anywhere from the minimum $(t_3 - t_0) = 5.5$ minutes up to 6 minutes, the United States could still execute an actual launch order in time. This situation illustrates that the demand for reliability in dual phenomenology and reporting high confidence, plus the demand for reliability in a launch order, puts the decision maker in a severe time crunch. In the case where t_4 occurs after t_5 , or when an SLBM is launched from 500 miles vice 1000 miles, the overall system permits no decision-making time at all.

The new capabilities of the cruise missile present a worse case scenario shown in Figure 3.10. Currently, the United States has no policy to deal with cruise missile launches. With such a short warning time, a bomber attack may be the only response possible. Although the cruise missile is a limiting case (so we will not discuss it at length here), it is an important subject for future investigations.

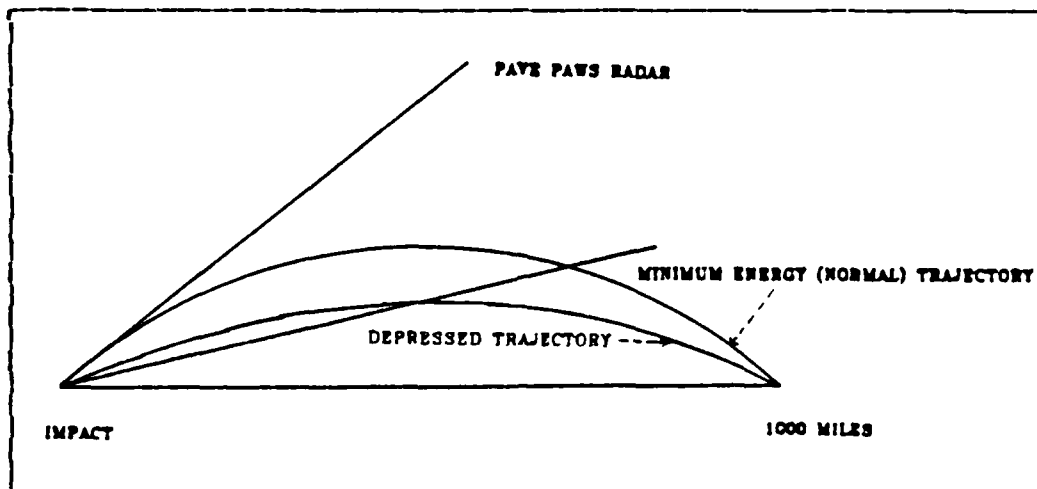


Figure 3.8 Two Possible SLBM Trajectories

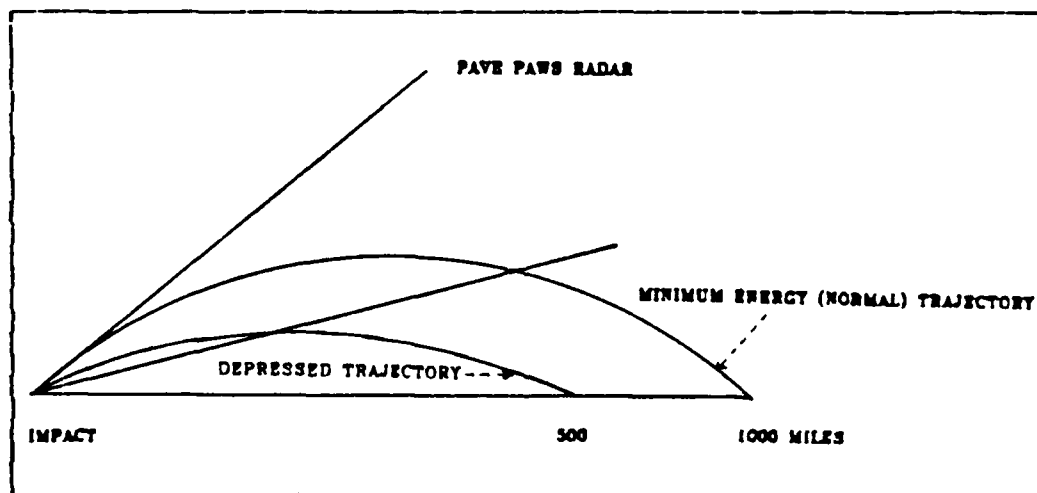


Figure 3.9 Two Possible SLBM Trajectories

Recall that the minimum time to reach t_3 is 5.5 minutes. In the SLBM scenario, this time leaves 3.5 minutes decision-making time before the last moment a response can initiate a retaliatory launch, and 6.5 minutes before the

2. The SLBM Threat

The time intervals up to and including t_3 remain the same here as in the ICBM scenario. However, the situation drastically changes in this scenario due to the much shorter time of flight of an SLBM:

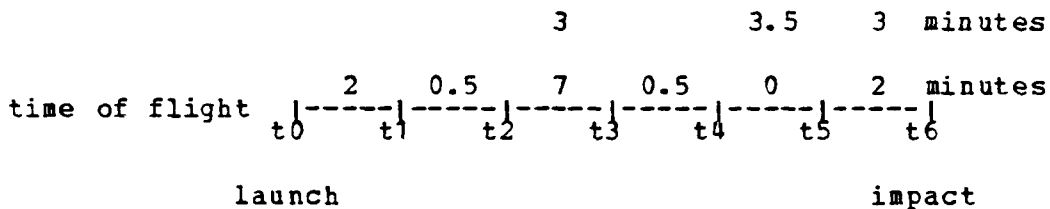


Figure 3.7 The SLBM Time Line

Figure 3.8 below depicts the usual SLBM trajectory (about 1000 miles from shore) together with a depressed SLBM trajectory. This graph reveals that to obtain dual phenomenology (using Pave Paws as an example), the time between t_2 and t_3 will increase with a depressed SLBM launch. This result severely shortens the time for the decision maker to assess the situation.

The graph in Figure 3.9 shows the usual SLBM trajectory together with an SLBM launch at 500 miles from the coast (about as close as a submarine can get to launch an SLBM if it is to hit its target). When launching an SLBM, the trajectory will probably be lofted to attain enough speed and height to successfully re-enter the atmosphere and hit its target. Although this lofted trajectory is less accurate in hitting the target, the interval between t_2 and t_3 increases while the overall time of flight (t_0 to t_6) decreases. This results in decreasing the decision makers' time. Therefore, the closer the launch is made to the coast, the less time remains for the decision maker.

A given booster delivers a given payload to its greatest range on the minimum energy trajectory and, hence, is the most likely trajectory. This means that the minimum time (shortest interval) to reach t_3 for a lofted or minimum energy trajectory is about 5.5 minutes. In the ICBM scenario, 21.5 minutes remain for decision-making time before a final response is required, and 24.5 minutes remain before impact of the missile. The maximum or longest interval of time, $(t_3 - t_0) = 9.5$ minutes. Since the decision maker will probably take 30 seconds to make an assessment of high or low confidence, this allows the President about 21 minutes in the minimum case, and 17 minutes in the maximum case, to make his response (see Table I).

The minimum interval between t_5 and t_6 is about 3 minutes. This covers the reaction time required to launch our missiles in a retaliatory strike. Reaction time includes the encryption of messages to launch, the decryption of those messages upon receipt, double-checking the messages for accuracy (that is, are they real orders?), and the required number of personnel on the scene to unlock and operate the missile system. Since we have never had to perform this function, other than in a training exercise, this minimum reaction time does not include any failures of components in the launch system preventing the launch, failures of any personnel to perform their duties, nor any other uncertainties that may occur. A more realistic time is closer to 6 minutes. This amount of time accounts for the completion of actions from the above 3 minutes, plus any extra time for shock, confusion, dismay, denial, and undue pressure that would arise from receiving a real launch order. However, using 6 minutes as a maximum time required to perform the launch sequence still leaves the President 18 minutes to decide a response to the threat in the minimum case, and 14 minutes in the maximum case.

This is the mid-course phase. The final phase is re-entry and lasts from 30 to 100 seconds, depending on the specific trajectory and drag characteristics of the re-entry vehicle. Figure 3.6 depicts three types of trajectories for an ICBM:

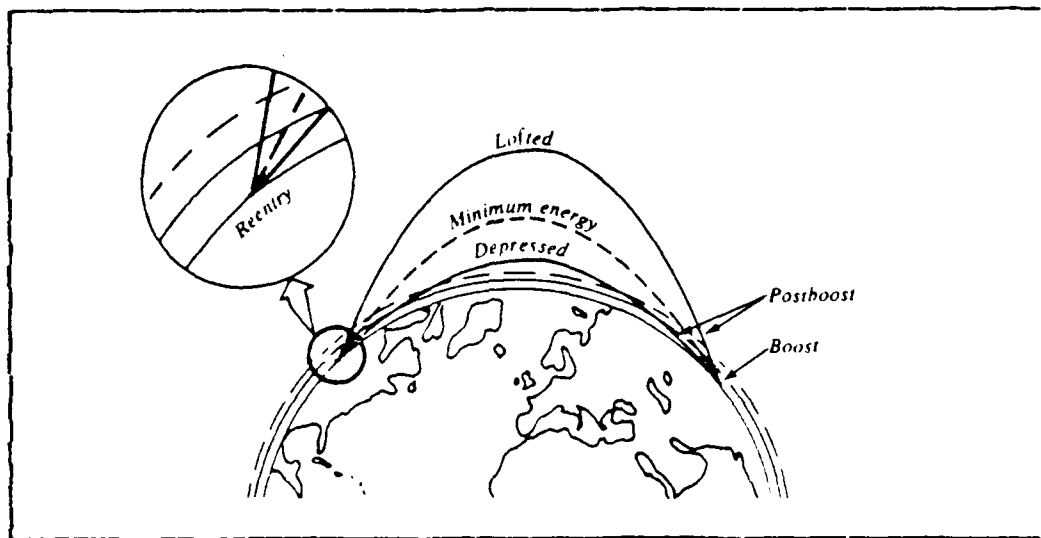


Figure 3.6 Three Possible ICBM Trajectories

Lofted trajectories (high re-entry angles) result in greater re-entry vehicle deceleration, thus, requiring an increased time of flight, since the flight path is longer. However, this results in a much higher accuracy in hitting the target.

In depressed trajectories (low re-entry angles), the re-entry vehicle heats up more, reducing the accuracy of the missile. Note that the Pave Paws radar (for example) will not pick up a depressed ICBM trajectory as quickly as it picks up the other two types of trajectories. For both radar and infrared sensors, the difficulty of the sensor's job increases with increased range and increased field of view.

2. Examples

a. ICBM Scenario

This scenario describes an ICBM launch:

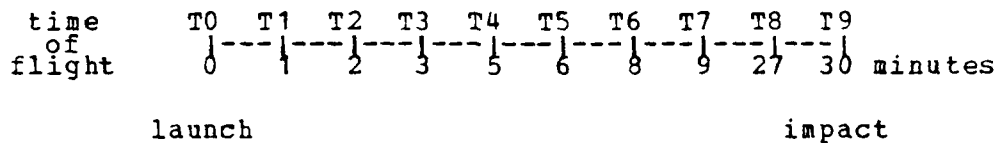


Figure 4.2 An ICBM Scenario

The definitions of T0 through T9 remain the same and the minimum time to resolution is $(T8 - T4) = 22$ minutes.

b. SLBM Scenario

This scenario describes an SLBM launch:

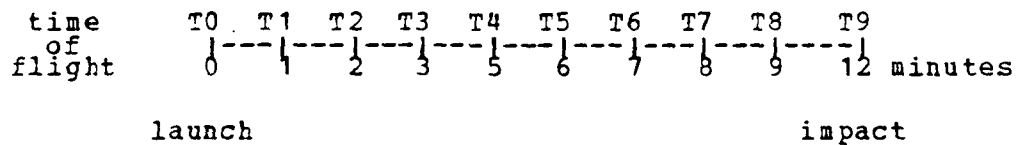


Figure 4.3 An SLBM Scenario

The definitions of T0 through T9 remain the same. Thus, the minimum time to resolution is $(T8 - T4) = 4$ minutes.

c. Test Shot Scenario

This scenario demonstrates how a test shot affects the decision-making process as shown in Figure 4.4 below. In this example, the minimum time to resolution is $(T8 - T4) = 4$ minutes. Even if intelligence reports a test shot, the conferencing procedure continues as if it is an unknown threat. At T4, the data gathering system evaluates no threat based on the projected point of impact (usually the ocean). Then, the decision makers realize it is a test

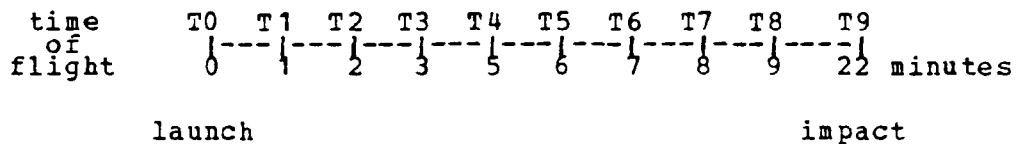


Figure 4.4 A Test Shot Scenario

shot, and CINC NORAD will not call a threat assessment conference. In this example, T5, T6, T7, and T8 may never occur; however the launch will continue to be monitored to gather as much intelligence data as possible.

In the case of a launch indicator lacking dual phenomenology, at T4, the decision makers assess the situation and state whether they have high or low confidence in what the data gathering system tells them. As before, the process continues until full confirmation is made or the sensors stop picking up the launch indicator.

In the Decision Model, human intervention plays a key role which can not be over-emphasized. Human intervention is both a positive and a negative aspect; positive because more minds influence the decision-making process and because a launch in retaliation is not automatic but requires human intervention to activate the launch mechanisms. The negative aspects include the increased time it takes for a decision to be made by a team of decision makers. Moreover, these decision makers are only human and, therefore, prone to error.

D. SENSITIVITY ANALYSIS

Since the Decision Model is an extension of the Data Gathering Model, we will transfer the ideas from the sensitivity analysis of the Data Gathering Model to the sensitivity analysis of the Decision Model. In Figure 4.5 below, the corresponding points of the two models are shown:

time of flight t₀---t₁---t₂---|---t₃---|---t₄---|---t₅---t₆
 launch impact

```

time of flight  T0-----T1-----T2-----T3-----T4-----T5-----T6-----T7-----T8-----T9
                launch                                     impact

```

From our analysis of the Data Gathering Model, we observed that the time segments of the Decision Model are not as precise as shown in Section C of this chapter. These segments also overlap and one event may occur before another. We discuss this overlap problem in the examples below.

The events T0, T1, and T2 (which correspond to t0, t1, and t2 in the Data Gathering Model) take the same amount of time as described in Section F of Chapter III. However, the missile display conference T3 can not be called until T2 = t2 occurs. At the point T3, the duty officers of all the command posts confer to decide if the threat is real or false. If no conflicting information arises, and the decision makers readily agree, this decision-making process, which includes confirmation from the ground site, will take about 2 minutes. Figure 4.6 displays the time span and will be explained below. Note the independent overlap of T4 with T5, T6, and T7:

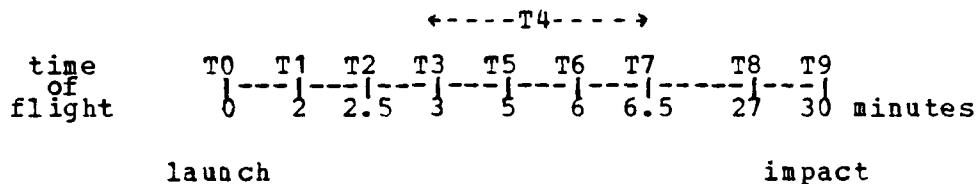


Figure 4.6 Decision Model Time Line for an ICBM Scenario

During this conferencing procedure, the data gathering system continues to monitor the launch phenomenon. As stated previously in the Data Gathering Model, the time to obtain a second detection at T4 (dual phenomenology) could take anywhere from 3 to 7 minutes, depending on the missile's trajectory. (Here, T4 corresponds to t3 in the Data Gathering Model.) This means that the minimum time (shortest interval) to T4 is still about 5.5 minutes and the maximum time (longest interval) is about 9.5 minutes, but the missile display conference T3 will occur prior to the second detection T4. Even if dual phenomenology does not occur after T3, CINC NORAD will call a threat assessment conference at T5. If T4 = 5.5 minutes, then CINC NORAD will have high confidence before going on to T5, and the threat assessment conference will probably last about one minute. However, if T4 = 9.5 minutes (or longer), this will not be the case. The decision makers will probably want more time to assess the situation, hoping to obtain dual phenomenology before going on to the missile attack conference at T7. By T6, however, the decision makers will have made their assessment (with or without dual phenomenology). Then, CINC NORAD will call the missile attack conference, reporting either high or low confidence in the assessment to the President.

In the minimum (shortest interval) case, with T4 = 5.5 minutes, if the missile display conference and the threat assessment conference take 1 minute each (overlapping

with T4), $(T7-T6) = 30$ seconds, and if the missile attack conference takes about 1 minute, then the President would have $(T8-T7) = 20.5$ minutes to decide on his response and 23.5 minutes to impact at T9. However, if any of the conferences (T3, T5, T7) take longer than above, the time between T7 and T8 will be shortened, leaving less time for the President to make his decision.

In the maximum case, without waiting for dual phenomenology, the President would still have 20.5 minutes to decide on his response, but he would be working with a low confidence assessment. Any President is likely to be reluctant in giving an order to retaliate without high confidence. Thus, if $T4 = 9.5$ minutes and CINC NORAD waits for dual phenomenology (although T5, T6, and T7 would still occur while waiting), then the President would have $(T8-T7) = 17.5$ minutes. If the interval between T8 and T9 is actually 6 minutes (as proposed in Section F of Chapter III), this would allow the President 17.5 minutes in the minimum case and 13.5 minutes in the maximum case. The question of waiting for dual phenomenology, therefore, becomes an important one. We discuss the implications of various launch policies which bear on this issue in Chapter V.

2. The SLBM Threat

The time intervals up to and including T6 remain the same here as in the ICBM scenario. But the situation becomes more stressful with the shorter time of flight for an SLBM with the addition of conferences. Again, the situation regarding depressed, lofted, and minimum energy trajectories of SLBMs applies here. The requirement for dual phenomenology increases the time between T2 and T4 (corresponding to t_2 and t_3 in the Data Gathering Model) when the SLBM is in a depressed trajectory. The same result occurs if a submarine launches its SLBMs close to the coast

```

time      T0      T1      T2      T3      T4      T5      T6      T7      T8      T9
of        |      |      |      |      |      |      |      |      |
flight    0      2      2.5    3      ?      5      6      6.5    9      12 minutes
launch    |-----|-----|-----|-----|-----|-----|-----|-----|
impact    |-----|-----|-----|-----|-----|-----|-----|-----|

```

The minimum time to T4 is 5.5 minutes. This time permits only 3.5 minutes total decision-making time before a response is required from the President and only 6.5 minutes before impact of the missile. If the maximum time is $(T4-T0) = 9.5$ minutes, then no decision-making time exists, and only 2.5 minutes remain to impact. As we mentioned earlier, T4 overlaps T5 (T3 has already occurred). The events T6, T7, and T8 can occur prior to T4 if the President is willing to make a decision with a low confidence assessment. However, if he requires dual phenomenology, T8 can not occur until T4 occurs, thus, shortening the final decision-making time. Any President with peaceful intentions will wait until T4 occurs before giving an order to retaliate. In the minimum case, the President has $(T8-T7) = 2.5$ minutes to make his response. In the maximum case, the President has no time left.

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a decision with a low confidence assessment from CINC NORAD,
if dual phenomenology does not occur within 9 minutes after
a launch of an SLBM attack.

V. THE PROBABILITY OF ACCIDENTAL NUCLEAR WAR

A. INTRODUCTION

In this chapter, we combine the Data Gathering Model and the Decision Model to show the implications of policies such as launch-on-warning and launch-under-attack for the early warning system. We first describe the segment of the time line that affects the decision to use one of these policies. We assume the United States is operating under peacetime conditions in this discussion. The time lines in Figure 5.1 represent the intervals of time during which launch policies affect future decisions:

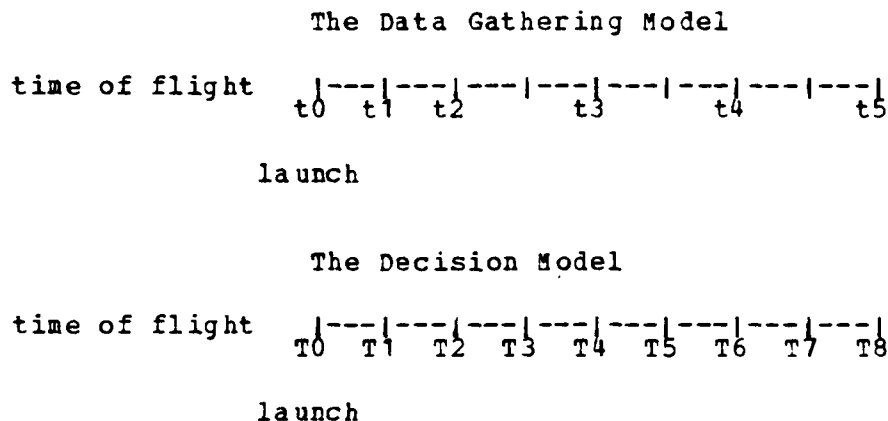


Figure 5.1 Affective Segment of the Time Line

The affective time lines do not include impact since after T8 (t5), no time remains to launch effectively a retaliatory strike. Also, recall that a false alarm occurs if (1) a launch detection occurs; (2) the data gathering system labels it a threat by T2 when no threat exists; and (3) a threat assessment conference is called at T5 before confirmation of the threat.

The following data comes from NORAD [Ref. 10] and shows the number of conferences called from 1977-1983, including the false alarms discussed earlier in Chapter II:

TABLE II
Emergency Action Conferences by Year

<u>YEAR</u>	<u>ROUTINE MISSILE DISPLAY CONFERENCES</u>	<u>CONFERENCES CALLED TO EVALUATE POSSIBLE THREATS</u>	<u>THREAT ASSESSMENT CONFERENCES</u>
1977	1567	43	0
1978	1009	70	2
1979	1544	78	2
1980	3815	149	2
1981	2851	186	0
1982	3716	218	0
1983	3294	255	0

The routine missile display conferences do not fit any of the previous definitions we used and, therefore, will not be considered in this analysis. Note the number of conferences called to evaluate possible threats (these are the missile display conferences, as we defined them earlier). The numbers appear to increase as the years progress. However, we explained the cause of this behavior in Chapter II. The false alarms that occurred in 1978, 1979, and 1980 resulted in the threat assessment conferences that were called. However, in those cases, confirmation of the threat was not made: in each case, the response from the site indicated that a threat did not exist. In fact, the site had absolutely no indication of a launch on their display.

The procedures followed in those years differ from the way CINC NORAD currently calls threat assessment conferences. Today, if no confirmation comes from the site, CINC NORAD probably will stop the conferencing process at that point to determine if there is a failure at NCMC. Thus, a threat assessment conference may not be called. If the site reports launch and impact points in close agreement with NORAD's incoming data, this confirmation gives at least a low confidence assessment, and CINC NORAD will continue the conferencing procedure by calling a threat assessment conference. Nevertheless, in the analysis of the next two sections, we use the above table as if the threat assessment conferencing situations are the same (as described in Chapter IV).

B. POLICY TYPES AND DISCUSSION

We begin this discussion with the launch-on-warning case, because of its simplicity. The United States does not currently have such a policy; however, there are many advocates of launch-on-warning, since this policy improves reaction time in performing a counter-strike launch.

1. Launch-On-Warning

Launch-on-warning means that upon detecting the launch of an enemy's missiles and confirming the threat at the site (albeit with low confidence), we would launch some fraction of the threatened ICBM force before those missiles reached any of their targets.

This extremely broad definition contains several important implications. For instance, to carry out a launch-on-warning policy in the event of an actual enemy missile launch, the decision makers must declare the threat confirmed; that is, the data gathering system and the

must persist long enough without dual phenomenology to convince the President to act with only a low confidence assessment.

In any case, launch-on-warning is a high risk policy, especially when great international tensions exist between the United States and the USSR, as they do today. In peacetime, a single failure without dual phenomenology puts the President in the extremely difficult position of deciding how long to wait before giving an order to launch a counter-strike.

2. Launch-Under-Attack

The presence of dual phenomenology (the confirmation of a launch by two families of sensors) gives much more reliability to a confirmed threat. In previous chapters, we demonstrated how much the decision makers rely on dual phenomenology to reduce the chance of an incorrect response. We now discuss how much better the warning system actually becomes.

Currently, the United States has a launch-under-attack policy. In this thesis, launch-under-attack means launching some fraction of the threatened ICBM force when the early warning system confirms a threat and that threat is assessed with high confidence. Again, the data gathering system and the decision makers must agree in their assessment that the threat is confirmed, as in launch-on-warning. The conditions of dual phenomenology and a predicted impact point in friendly territory define the confirmed threat. The difference in this policy arises from CINC NORAD's assessment to the President: here, CINC NORAD reports high confidence in what the sensors reveal, since dual phenomenology is required. The President is still the responsible authority for the initiation of the launch: whether it is one missile or many missiles, the decision to implement a

launch-under-attack rests with the President. An advantage to this policy is that a launch-under-attack lessens the probability of accidental nuclear war while maintaining a strong deterrence.

If the United States continues to follow a launch-under-attack policy, what sequence of events must occur to cause an accidental nuclear war? Since under launch-under-attack, the United States would not launch a retaliatory strike if only one system failed, a necessary condition for accidental nuclear war, in this case, is for two different false alarms on two different sensors to occur. Plus, the false alarm on one system must overlap the false alarm on the other system. Moreover, the two systems must agree approximately on the launch and impact points, so that the decision maker sees the same launch phenomenon on two separate systems. The overlap time must also be of sufficient duration to allow enough time to launch a counter-strike. In Chapter IV, we assumed three minutes (initially) to carry out the launch order.

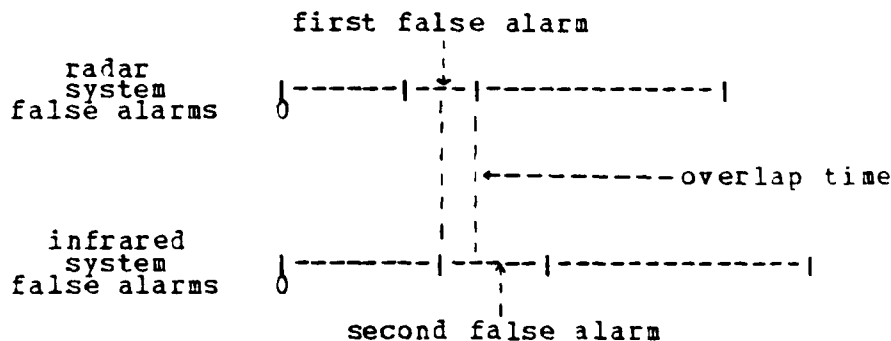


Figure 5.3 The Interval Overlap

The minimum overlap time, then, is defined as the intersection of two false alarm intervals for at least 3 minutes. In Figure 5.3 above, we assume that the time intervals are stochastically independent, and so are the false alarms in

the two systems. If we assume that the arrival process of the false alarms is a Poisson process, the intervals between arrivals are exponentially distributed.

In order to calculate an upper bound for the probability of a double false alarm using dual phenomenology (a double false alarm on two different systems), we assume the following:

1. We disregard the difference between the false alarms on the two different systems (assumed above).
2. The combined rate of the radar false alarms and infrared false alarms is one false alarm per year.
3. The time between arrivals of the combined false alarms is exponentially distributed.

If all these false alarms involve ICBM launches only, what is the probability that two successive false alarms occur within 27 minutes of each other (i. e., a 3 minute overlap)? Let

X = the time between false alarms

then

$$\begin{aligned} P(X \leq k \text{ minutes}) &= 1 - e^{-\lambda k} \\ &= 1 - \{1 + (-\lambda k) + (-\lambda k)^2/2! + \dots\} \end{aligned}$$

where λ is one per year (that is, the mean time to wait for a false alarm is 6/6, or one year). Dropping all but the first three terms gives

$$P(X \leq k \text{ minutes}) \sim \lambda k$$

in minutes. Note that the units for λ and k must conform. Since we assumed that it takes at least 3 minutes to execute a counter-strike launch, at least a 3 minute overlap is necessary. This is the "worst case" situation.

The upper bound (worst case) for an ICBM scenario is in the situation where a 3 minute overlap occurs. Here, the calculation gives

$$\begin{aligned} P(X \leq 27 \text{ minutes}) &= 27/(365)(24)(60) \\ &= 0.000051 \end{aligned}$$

Therefore, a lower bound for the expected waiting time of this event is $1/0.000051$ which is approximately 19,467 years. These calculations are very restrictive since we have assumed a combined false alarm rate. This assumption means that two sensors could fail in the same family. From what we have described, we must have false alarms from two families of sensors. This makes the probability even lower than 0.000051 and the expected waiting time greater than 19,467 years.

The upper bound for an SLBM scenario is for a 3 minute overlap to occur:

$$\begin{aligned} P(\text{second false alarm occurs} \leq 9 \text{ minutes}) &= 9/(365)(24)(60) \\ &= 0.000017 \end{aligned}$$

In this case, the expected waiting time to a double false alarm is approximately 58,400 years. The upper and lower bounds of the ICBM scenario cover this and all other situations.

In conclusion, the United States will probably never accidentally launch a retaliatory strike with a launch-under-attack policy, if the false alarm rate remains the same as in Table II. The graph in Figure 5.4 shows how the

expected waiting time varies with different lambdas. However, Adding sabotage and nuclear proliferation raises the probability and decreases the expected waiting time. Nevertheless, with these probabilities as upper bounds, a decision maker will pause and take time to analyze false alarms under these conditions.

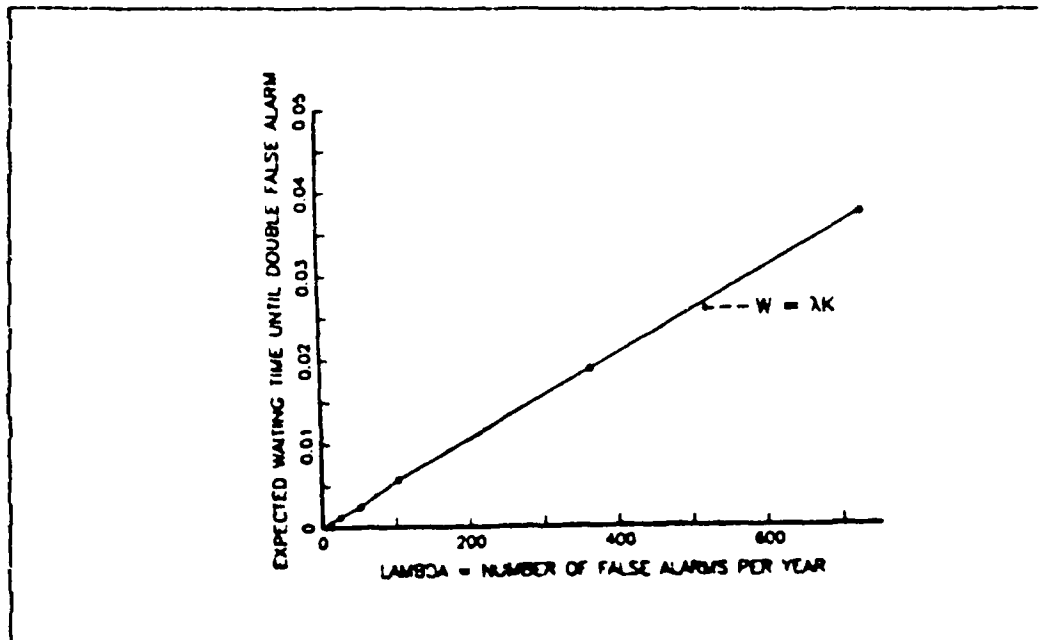


Figure 5.4 Expected Waiting Time Versus Lambda

These same calculations assist the decision maker in determining whether an alarm is real or false by adding the conferencing procedure. If the decision maker decides the first alarm is false, then when a second alarm occurs, it merely supports the fact that a system failure has occurred. Also, including the conferencing procedure may add more time to the process, allowing for the possibility of the alarm being confirmed by dual phenomenology, or evaluated as no threat.

This addition of time to the decision-making process could be a blessing in disguise. If the system gives a 10 minute impact time, but the decision-making process already has taken 15 minutes, then probably no launch has occurred. Thus, if no impact materializes by the 10 minute limit, and the decision makers still have not reached a decision, the conferencing procedure, again, will probably stop.

C. SUMMARY

Sophisticated systems to warn of nuclear attack are necessary for the protection of the United States. Also, if the Soviets know that the United States has an effective warning system, they are less likely to initiate an attack. Since both the United States and the USSR possess effective warning systems, both sides have less incentive to launch an attack, and the world is more stable as a result.

The Missile Attack Warning System is designed to make sure that the decision to go to war is not driven by a flock of geese or a defective computer chip. A human is always in the decision loop.

Although the launch-on-warning policy would improve reaction time in performing a counter-strike launch, it seriously impairs rational decision making in a time of extreme stress. A launch-on-warning policy puts the President in the "hot" seat nearly once per year. But such a burden, even once every 4-year term, would be enough for any President. The risk of accidental nuclear war under launch-on-warning is great enough to make this policy very unattractive.

Launch-under-attack, on the other hand, is much safer, given its requirement for dual phenomenology. The conditions necessary for a double false alarm (a false alarm in two separate systems) to occur in a time overlap of at least

3 minutes make the probability of accidental nuclear war extremely small. The President must still undergo immense pressure, but he can be virtually assured of making the correct response decision.

APPENDIX A
ACRONYMS AND ABBREVIATIONS

ADCOM	Aerospace Defense Command
ANMCC	Alternate National Military Command Center
BMEWS	Ballistic Missile Early Warning System
CINC NORAD	Commander-in-Chief, North American Aerospace Defense Command
CINC SAC	Commander-in-Chief, Strategic Air Command
DEW	Distant Early Warning Line
EMP	Electromagnetic Pulse
ICBM	Intercontinental Ballistic Missile
JCS	Joint Chiefs of Staff
MIRV	Multiple Independently Targeted Re-entry Vehicle
NCA	National Command Authority
NCMC	North American Aerospace Defense Command Cheyenne Mountain Complex
NMCC	National Military Command Center
NORAD	North American Aerospace Defense Command
PARCS	Perimeter Acquisition Radar Attack Characterization System
SAC	Strategic Air Command
SEWS	Satellite Early Warning System

SLBM	Submarine-Launched Ballistic Missile
SOSUS	Sound Surveillance System
SPASUR	United States Navy Space Surveillance Network
SRF	(Soviet) Strategic Rocket Forces

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