SURFACE ACTION GROUP DEFENSE MODEL

by

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(ABSTRACT)

The purpose of this project is to examine, through the use of Systems Engineering techniques, the ability of navy warships to operate in areas of low or medium threat when no friendly aircraft carriers are present. The major effort of the project is directed at developing a computer model that can evaluate this ability.

The current U. S. Navy budget mandates a reduction in the number of operational aircraft carrier battlegroups. However, the Navy still has commitments to provide a forward military presence to the same degree as it had during the Cold War. To address the deficiency the Navy issued a white paper emphasizing the need to do more with fewer assets. In an attempt to identify an alternative means of maintaining the Navy's overseas commitments, the author proposes to design and evaluate a new and smaller battlegroup centered on the latest generation of surface combatants. This battlegroup would serve as a replacement for the carrier battlegroup when

certain established pre-conditions were met.

The Systems Engineering process is initiated by defining a particular problem and translating it into a statement of need. In this case, develop an alternative to sending limited aircraft carrier assets to conflict areas where the threat to naval forces is not high. A set of operational requirements is defined and used as guidelines to determine feasible solutions. Evaluation criteria is established and a mathematical model constructed to ascertain the validity of a particular approach.

The project examines how the definition of need through conceptual systems design stage of the Systems Engineering process is used to evaluate feasible solutions, the focus being the use of modeling techniques to evaluate those alternatives.

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INTRODUCTION

Purpose of the Project

The purpose of this project is to examine, through the use of Systems Engineering techniques, the ability of navy warships to operate in areas of low or medium threat when no friendly aircraft carriers are present. The major effort of the project was directed at developing a computer model that could evaluate this ability. The process was initiated by defining a particular problem and translating it into a statement of need: develop an alternative to sending limited aircraft carrier assets to conflict areas where the threat to naval forces is not high. A set of operational requirements was defined and used as guidelines to determine feasible solutions. Evaluation criteria were established and a mathematical model constructed to ascertain the validity of a particular approach. This paper examines how the definition of need through conceptual systems design stage of the Systems Engineering process is used to evaluate feasible solutions, the focus being the use of modeling techniques to evaluate those alternatives.

Use of Computer Model

The development of the Surface Action Group Defense Model (SAGDEM) was central to the evaluation of an alternative to deploying an aircraft carrier battlegroup (CVBG) to an area of low threat. The emphasis of the model was to determine how much of what type of armament, specifically offensive and defensive missiles, was required for a force to survive in a given hostile environment. Variables within the model were altered to ascertain their impact on the scenario. The result was the ability to predict the composition of such a force, a surface action group (SAG), and the missile mix required to ensure the survival of the SAG and its ability to carry out offensive operations.

A causal diagram was first developed to evaluate the relationship between various threats to the SAG, missile capabilities and availability, and other own-ship capabilities. A system dynamics computer model was then constructed to evaluate the number and type of missiles required to counter various threats. This in turn provided a viable weapons loadout. Based on the ability of some ships to customize their weapons mix, this loadout could then be used to determine the minimum number of ships necessary to comprise the SAG. The model also determined the type and intensity of various threats over time and indicated how long the SAG could remain on-station without assistance, to include the amount of damage that could be expected to incur. Threats to the SAG were broken down by their point of origin; i.e. from land, air, surface, or sub-surface. The model evaluated how the various ship weapons systems interacted to provide a layered defense against the threat and the weapons that provided that best defense. A database was established that defined the military capabilities of several potential aggressor nations with medium sized armed forces. Scenarios were then constructed to determine the number of ships and their missile mix required to counter that threat.

The software package used to construct the computer model was Professional DYNAMO Plus (IBM PC version). This software is designed to evaluate real world systems via computer simulation by modeling cause and effect and system feedback dynamics. Professional DYNAMO Plus was chosen because of the ease in which causal effects in a feedback system can be translated into algebraic form.

Topic Background and History

Since the early 1800's, United States Navy warships have been used to protect and advance national interests abroad. To effectively carry out that role, these ships have been deployed or based throughout the world and positioned so as to be ready to act with speed and effective force. In a developing or active conflict, naval forces are the only national assets which can remain within hours of a trouble spot for weeks at a time, without the political complications and military risks of putting forces on land. Since World War II, the aircraft carrier battle group has formed this forward military presence. Armed with aircraft that can deliver substantial firepower, and escorted by combatants to defend it and replenishment ships to keep it supplied, the CVBG is a formidable force capable of influencing military and political events. However, the current military and political climate suggests the possibility that there will no longer be enough aircraft carriers or forward military bases available to provide a military presence everywhere it is desired. The recent collapse of the Soviet Union as a military and political superpower has removed the only global, blue water threat to American political and economic interests. Consequentially, the need for a large navy has been questioned. In spite of the US Navy's role in Operation Desert Shield/Storm, conducting offensive operations, maintaining a naval quarantine, supporting Marine forces, and maintaining friendly sea lines of communications, many believe that the navy is too big and too expensive for the missions it will be called upon to perform in the future.

President Clinton has stated his wishes to reduce the number of aircraft carrier battlegroups from the current number of fourteen down to ten.[1] Should this come to pass, it is quite possible that the Navy will not be able to have a carrier on-call in all the areas where national interests abroad are at stake. Consequently, forces would not be available to give military weight to political foreign policy decisions at the time and place of crises. The need to maintain such forces now is at least as important as it was when the primary threat to national interests was the Soviet Union.

Faced with having too few CVBGs to patrol too much ocean, and the need to have some military presence capable of responding quickly in a crisis, a viable alternative must be found. In an attempt to identify an alternative means of maintaining the Navy's overseas commitments, the author proposes to design and evaluate a new and smaller battlegroup centered on the latest generation of surface combatants. This battlegroup would serve as a replacement for the carrier battlegroup when certain established pre-conditions were met.

SECTION 2

DEVELOPING THE SYSTEM

Utilizing the Systems Engineering Process

The emphasis of this paper lies in utilizing the early stages of the Systems Engineering process, from identifying a problem through the conceptual design phase, in order to find a solution to a specific problem. The process leads to the development of a computer model used to determine the feasibility of one solution to the problem. The results obtained from the model are then evaluated so that a decision can be made as to whether further action should be taken on this solution.

The Systems Engineering process begins by identifying a particular problem in the system that has arisen because of some observed deficiency. The system in question must be defined and then studied in order to identify the relevant variables in the system and its environment. A firm understanding of the problem results in an accurate and concise definition of need. Once the problem has been identified, requirements which any potential solution must meet and objectives that the solution should be designed to can be established.

With the problem defined and initial requirements established, potential system designs are developed. These designs are evaluated against the initial system constraints and the ones that appear to meet these requirements are considered feasible alternatives. Each feasible alternative is evaluated to determine its potential level of performance. Since neither the time nor the resources are available to create a working prototype of each alternative, another method must be used to calculate expected performance. One such method makes use of dynamic modeling techniques in order to simulate the desired system. To make the model effective and truly representative of the system being simulated, the pertinent variables determined during the initial study of the system must be correlated. Once the model has been developed, individual variables can be altered to ascertain their effect on the overall system. In this way, many iterations of the simulation can be run so that the best configuration of that particular problem solution can be identified.

Definition of Need

The initial Systems Engineering process begins with the identification of a need. A need arises from a desire to correct some existing deficiency. An organization, in this case the United States Navy, identifies a need for a function to be performed, so that a new or modified system can be procured to fulfill that requirement.[2] A Navy and Marine Corps White Paper, published in September 1992, titled "...From the Sea" defines the reasons for maintaining forward deployed naval forces in light of the current world political and military situation. The thrust of the paper is that the Navy must re-evaluate its role in implementing foreign policy and must seek to define how those missions can be accomplished with fewer assets. The following points expressed in that document can be used to define a statement of need:[3]

> Although the prospect of global war is diminished, the United States is entering a period of enormous uncertainty in regions critical to national interest. In an era of arms proliferation where Third World nations possess sophisticated weaponry, a wide range of potential challenges will tax the capabilities of existing systems and force structures.
>
> Naval forces can provide a powerful, yet unobtrusive, presence overseas, maintain control of the seas, provide extended and continuous on-scene crises response, and project precise power from the sea. As the United States withdraws from overseas bases, naval forces will become more relevant in demonstrating American commitment overseas and promoting American interests.
>
> A fundamental shift is being made from fighting on the sea to fighting from the sea. The Navy will thus be better able to respond to crises and provide the initial forces upon which larger, joint operations are initiated. Naval forces provide a wide range of response options, most of which have the advantage of being easily reversible. Remaining ready indefinitely to strike, this force is a useful tool for diplomacy and influence. The arrival of a naval strike group in an area of heightened U.S. interest sends a clear signal. If diplomatic activities resolve a crises, naval forces can easily and quickly be withdrawn from

action.

> If diplomacy fails, forward operating forces can project U.S. combat power as required. Aircraft carriers and cruise missile platforms can operate independently to provide a quick, retaliatory strike capability. Such power projection requires "...mobility, flexibility, and technology to mass strength and weakness." Naval forces can be tailored to match a specific situation. "The answer to every situation may not be a carrier battle group. It may be [a] ...surface battle group with Tomahawk missiles."
>
> The key to effective crises response is the ability of the available force to be flexible in its actions and adaptable to changing conditions. To that end, naval forces must possess the capability of controlling the local sea and air. Achieving battlespace dominance is paramount so that the force can carry out the full range of its potential missions.

Navy policy in "...From the Sea" clearly defined the need to maintain deployed naval forces in order to protect United States interests against a variety of potential threats. The policy also acknowledged the inevitable reduction in the number of aircraft carriers and that carrier battlegroups are no longer the automatic response to all situations. In the future certain obligations would have to be met with other forces.

Although aircraft carriers are the current weapon of choice, they may not be available to respond at all if force levels are reduced too much as a result of Navy budget cuts. Aircraft carriers are expensive to build, maintain, operate and equip. Cost associated with the carrier also includes the costs of the battlegroup required to defend it. By the end of 1992, fourteen aircraft carriers were available for duty. That number is reduced by the normal 18 month ship operating cycle. Navy ships are prohibited in peacetime from being deployed from homeport for more than six months at a time. The Navy learned in the 1970's that ships deployed for greatly extended periods of time, i.e. nine to twelve months, suffered poor morale and low retention.[4] As a result, it would not be practical or cost effective to make a smaller carrier fleet maintain the current operating tempo. With the other twelve months taken up in overhaul or in otherwise preparing for the next deployment, only three or four carriers are available for deployment on a continual basis. A smaller carrier force would result in either longer deployments, not desirable for reasons listed above, or gaps in the time that a carrier would be on-station in a particular region. The danger in not having a full time presence is the speed in which a crisis can erupt and escalate and the amount of time it takes to deploy a battlegroup thousands of miles. A battlegroup in homeport that must respond to such a situation can thus lose much of its ability to impact events because any military action or presence after such a time may no longer be an option.

From the above discussion, a statement of need can be drafted. That need would be to form a naval force as an alternative to the carrier battlegroup that possesses the characteristics necessary to effectively project American military power from the sea. The system itself is defined as this naval force, specifically the ships that will operate together to provide a mutual offensive and defensive capability. The environment in which the naval force will operate is the area of ocean from which it can launch cruise missile strikes against land targets and where it will engage the various military threats it is likely to encounter. Hostile weapons and weapon platforms, i.e. cruise missiles, ships, and aircraft, are part of that environment.

Establishing System Requirements

Once the need has been identified, requirements are established in order to determine what solutions are viable to pursue for further study. Because the carrier is rather effective in the role that it performs, many of these requirements are based on ones already applicable to the carrier battlegroup and include the following:

> The new battlegroup must be able counter threats originating on and under the sea, from land, and from the air and survive as a fighting force. It must therefor possess the defensive weapons necessary to destroy surface combatants, submarines, and aircraft (to include cruise missiles).
>
> The new battlegroup must be able to carry out offensive operations against hostile territory, i.e. to be able to fight <u>from</u> the sea.

> The costs involved in deploying ships overseas for long periods of time are high, and include the costs of personnel, fuel, provisions, and a higher degree of maintenance upkeep. Given the constraint that access to ports will be extremely limited while engaged in a conflict, supplies will have to be brought to the battlegroup via fleet replenishment ships, another cost. As a result, the battlegroup should be as small as possible to reduce the financial costs while still being able to comply with the requirements stated above.

> The shrinking Navy budget has two effects on developing an alternative. A lack of sufficient funding could result in a rapid drop in carrier force levels and with fewer dollars to invest in new ship and weapons design. As a result, the new battlegroup must be formed soon from assets that are available now.

Given the requirements listed above, further constraints present themselves that reduce the number of alternatives which may prove to be an acceptable solution. The ability to defend against all threats requires the presence of multiple ships, each with the capacity to engage several types of threats, if not all of them. Such a task is too complex to be accomplished by a solitary ship. To maximize the effectiveness of multiple ships working together requires a sophisticated command and control capability. AEGIS equipped warships are multi-warfare ships equipped with the best command and control system in the world and are thus a logical choice to be included in the battlegroup.

Assuming that no carrier attack aircraft would be available, the only other possible strike capability would be the possession of large quantities of TOMAHAWK land-attack missiles (TLAM). Ships equipped with the Vertical Launching System (VLS) would be necessary to carry sufficient numbers of TLAMs to make a credible strike capability. Fortuitously, most AEGIS ships are also equipped with VLS.

Identifying Solutions

One good way of identifying alternatives is to review any existing related systems to see if they can provide useful ideas or possible solutions. Having the advantage of already being operational, such systems can provide valuable information on how to meet new system requirements and whether or not any part of the existing system can be adapted to the new. Two such similar battlegroups have already been implemented by the Navy and can provide insight on how the new requirements can be satisfied.

The first of the two systems is the battleship surface action group. In the late 1970's, the Navy envisioned a battlegroup that could operate in hostile areas where the threat of air attack was deemed low enough that the protection afforded by carrier aircraft was not required. The battlegroup had to be capable of conducting offensive operations against targets ashore as well as at sea. In 1982, the Navy began taking out of mothballs four World War II era

Iowa class battleships and equipping each of them with 32 TOMAHAWK cruise missiles. These battleships, armed with cruise missiles and 16" guns, became the only ships, other than aircraft carriers, able to deliver a significant amount of ordnance to enemy territory. It was determined that the battleship, accompanied by other TOMAHAWK equipped destroyers and cruisers, would form the backbone of new surface action groups. The battleship SAG was first actively used in this role when the USS NEW JERSEY was deployed off the coasts of Nicaragua and later Lebanon in 1983 as a show of US interest in the region. By 1991, however, the decision had been made to decommission the battleships. Manpower intensive, and no longer the dominant cruise missile platform, they became too expensive to maintain in an era of reduced Navy operating budgets.

The second related system, the Maritime Action Group (MAG), was first established in mid-1991. It was comprised of ships and aircraft originally assigned to the CVBG then operating in the Mediterranean. The MAG was designed to respond to various tasking when the aircraft carrier itself could not be spared for that duty. Various at-sea exercises helped define the preferred composition of the MAG, which was to include an AEGIS/VLS cruiser, a frigate, a nuclear submarine, and long-range patrol aircraft. These exercises, which included choke-point transit and small surface combatant engagements, demonstrated that such a force operated more effectively using stealth tactics to remain unobserved until ready to engage the enemy. The results of these exercises were favorable and were then tested by the Pacific Fleet in mid-1992. The tactics and lessons learned have since been published as official doctrine. One point that was noted, however, was that the MAG was too small to fully substitute for a sea-control or carrier battlegroup.[5]

Constraints identified from initial system requirements are also useful in highlighting a specific approach to solving the problem. Of particular interest is the need for ships equipped with the Vertical Launching System (in order to carry TOMAHAWKs) and the AEGIS weapon system (to provide effective command and control functions). Both of these systems are relatively new, each becoming operational in the 1980's.

In 1986, The USS BUNKER HILL was commissioned as the first ship equipped with the VLS. The BUNKER HILL is a Ticonderoga class cruiser equipped with two 61 cell VLS magazine/launchers. A new technological advance in navy weapon system design, each VLS has either 61 or 29 cells and can store and launch one missile. Ship type determines the number and size of the VLS installed (up to 122 available cells). There are currently three missile types compatible for use with the VLS: TOMAHAWK cruise missiles, SM-2 anti-aircraft missiles, and ASROC anti-submarine torpedoes.

The introduction of VLS is important for several reasons. Compared to older ship classes, the number of missiles that can be stored onboard is increased by at least 50%. A VLS ship can carry more types of missiles than ships equipped with conventional magazines, and new missile types are being developed to be VLS compatible. TOMAHAWK cruise missiles, previously housed in 4 cell armored box launchers (of which two each were installed on selected ships and eight on the battleships), can now be loaded in large numbers on a single ship.

In older ships, missile loadouts are standardized and emphasize air defense, with most of the offensive capabilities of a deployed battlegroup residing with the carrier's aircraft. The ability of VLS ships to deploy with large numbers of TOMAHAWK cruise missiles gives these ships an offensive capability not previously available. This capacity to launch a large number of a variety of missile types makes VLS equipped ships extremely capable and flexible. In addition to Ticonderoga class cruisers, the new Arleigh Burke class destroyers are being fitted out with two VLS with a total of 90 cells and a 61 cell VLS is being back-fitted onto existing Spruance class destroyers.

The value of the VLS was established during Operation Desert Storm when 206 of 288 TOMAHAWK missiles were launched from VLS equipped cruisers and destroyers.[6] The USS FIFE, a

Spruance class destroyer, deployed with a full load of TOMAHAWK's and launched all 61 during the course of the war.[7] When the USS SAN JACINTO, a Ticonderoga class cruiser, sailed for the Persian Gulf, the US Government strongly hinted at the fact that she was carrying nuclear armed TOMAHAWK cruise missiles. The premise being to use this ship, carrying up to 122 nuclear weapons, as a credible deterrent against the Iraqi use of chemical weapons.

In addition to VLS, Ticonderoga class cruisers and Arleigh Burke class destroyers are also equipped with the AEGIS combat weapons system. A highly sophisticated computer system, it is designed to integrate ship sensors, weapons, and communication systems in order to effectively detect, track, and destroy a variety of threats. The VLS/AEGIS combination provides the ship a potent offensive and defensive capability that greatly enhances the ship's ability to survive in a hostile environment.

The fact that both AEGIS and VLS are combat proven systems is an important aspect in considering them appropriate for use in the new battlegroup. Because of time and money constraints, it is advantageous to use existing ships and weapon systems. The various naval involvements and combat engagements in the Persian Gulf over the past six years have provided a wealth of information on the actual capabilities of many weapon systems, both friendly and hostile. Even failures in procedures and doctrine that did occur have resulted in new tactics that have improved ship survivability and system efficiency. With the collapse of the Soviet Union, the primary source of hostile weapons is no longer producing new technologies. The threats to the battlegroup would thus be composed of weapons and technologies which are already known and for which defenses or countermeasures already exist. As a result, a good case can be made for using existing systems in the makeup of the new battlegroup.

<u>Proposal to establish VLS/AEGIS Surface Action Group</u>

It is proposed that a Surface Action Group centered on an AEGIS/VLS cruiser or destroyer be established. Such a unit might consist of one or two AEGIS/VLS ships, a VLS Spruance class destroyer, and a frigate. The generic warfighting capabilities of each of the different warship types are listed in Table 1. The unique flexibility afforded by the VLS in the ability to support a customized mix of both offensive and defensive missiles now makes it worthwhile to determine under what combat conditions such a force could effectively replace the presence of an aircraft carrier battlegroup. By simulating combat engagements with hostile forces via a computer model, the best mix of ships to form a SAG based upon a particular threat can be determined.

TABLE 1 SHIP CHARACTERISTICS

	AEGIS	VLS	AREA AAW	POINT DEFENSE	HELO	ASW
CG-47 CRUISER	YES	122	YES	YES	2	YES
DDG-51 DESTROYER	YES	90	YES	YES	0	YES
DD-963 DESTROYER	NO	61	NO	YES	2	YES
FFG-7 FRIGATE	NO	N/A	YES	YES	2	YES

Notes:

1. AEGIS indicates the presence of the AEGIS Combat Weapons System onboard.
2. VLS indicates the number of missile cells available on that ship. VLS can support SM-2, ASROC and TOMAHAWK missiles.
3. AREA AAW indicates those ships equipped with SM-2 anti-air missile systems.
4. POINT DEFENSE weapons include 3" and 5" guns, PHALANX Close-In Weapon System, and NATO SEASPARROW missiles used for air defense.
5. HELO is the maximum number of helicopters which can be operated by that ship. Most ships deploy with only one helicopter.
6. ASW indicates the ability to perform anti-submarine warfare duties.

SECTION 3

SIMULATION MODELING AND ANALYSIS

Background

Modeling is the means by which a system is defined as a grouping of relationships. Assumptions are made as to the nature of those relationships and take the form of mathematical or logical statements. Most real world systems are too complex to be solved by analytical means and are thus studied via simulation. Simulation is defined as the process of using a computer to evaluate the model numerically and the data gathered in order to estimate the desired true characteristics of the model.[8]

Simulation modeling to determine the viability of a particular system is useful for several reasons. Most often, actual experimentation is too expensive or too disruptive to be implemented. Simulation provides the ability to evaluate multiple alternatives with a degree of control not otherwise available. Long term effects can be evaluated within a compressed time frame and a simulation can maintain control over experimental conditions better than an operating system itself. Additionally, the system being evaluated might not yet be in existence. It is therefor necessary to build a model as a representation of the system and study it as a surrogate for the actual system.

Most simulation programs operate the same way, with a simulation clock and an event list determining which event will be processed next. The clock is advanced to the time of this event and the computer executes the event logic. This can include updating state variables, manipulating lists for queues and events, generating random numbers, and collecting statistics. The simulation is sequential; the logic being executed in the order of the events simulated time of occurrence. Discrete event simulation, the type utilized in the Surface Action Group Defense Model, concerns the modeling of a system as it evolves over a period of time by a representation in which the state variables change instantaneously at separate points in time. These points in time are the ones in which an event occurs, where an event is defined as an instantaneous occurrence that may change the state of the system.[9]

Military Modeling

The military community has made considerable use of simulation modeling techniques in order to obtain decision making information on existing or proposed systems. In the context of naval warfare, models have been used to provide the framework in which weapon system capabilities, force sizes, or alternative courses of action and their potential consequences have been evaluated. Whereas it is often desirable to obtain first hand information on the performance of a given weapon system or tactic by conducting fleet exercises utilizing actual ships and aircraft at sea, certain constraints limit the employment of fleet exercises for this purpose.[10] Fleet exercises are time consuming and expensive to conduct in terms of material costs and the availability of assets to participate. Often a compromise must be reached between a units ability to perform as it wishes and the need to force interaction to obtained some desired information. Limits in the size of the exercise area and the ability to represent enemy actions and abilities, such as simulating a large multi-missile cruise missile attack, can affect the accuracy and reliability of information obtained. Simulation modeling is thus an attractive alternative to conducting fleet exercises as a way of obtaining necessary data on the effects of various policies.

Naval warfare models in general possess many of the following characteristics.[11] They are threat oriented, designed to evaluate the relative capabilities of alternative forces and weapon systems over a wide range of highly structured tactical situations. They include precise scenario parameters, such as a specific operational environment and rules of engagement, in order to obtain reliable data.

Environmental considerations include the size of the naval operating area, which impacts the ability to detect and be detected, and the effects of atmospheric conditions on weapon performance. Rules of engagement define the conditions in which force can be used and the level of force that is appropriate to that condition. In modeling actual combat engagements, consideration must be given to the geographic location of the event, surveillance capabilities, mobility of units, and the weapon/electronic systems available.

Naval simulation models can be broken down into four major types; Phenomenological, Tactical, Single Mission, and Campaign, each of which differs in terms of scope and complexity. Given the right circumstances, lower level models can be incorporated into higher order models as macros to give the higher level model a greater degree of detail. Of particular interest are Tactical and Single-Mission models because SAGDEM incorporates some of the characteristics of each.

Tactical engagement models are characterized by one-on-one or many versus one engagements in a tactical environment. They are generally used to evaluate the effects of single combat engagements, such as a submarine versus a destroyer. Data for these models are strongly supported by at-sea testing using sophisticated monitoring and data gathering techniques. One-on-one models usually contain a great deal of detail concerning the physical aspects of the environment as well as the performance characteristics of the opposing units. Such characteristics include sensor capabilities, engagement envelopes, rules of engagement, ship speed and maneuverability, and weapon performance estimates. Such inputs are part of the model. The outcomes of interactions between friendly and enemy systems are subject to the variation of system performance. It is important to realize that the sensitivity of the results is based on the level of variation involved.

Similar to one-on one engagement situations, and using identical modeling techniques, is the many-versus-one or many-versus-many engagement. In such instances, units performing the same tasks, such as area anti-submarine warfare, are modeled as one composite entity. The characteristics for the whole are then derived from evaluating the performance of the individual units and their interaction with units involved with other tasks. The effectiveness of the composite, including alternative components and configurations, is then evaluated for a wide variety of target types and environments. This concept is embodied in the model by varying the number and type of ships in the SAG and evaluating the SAG against different threats. The accuracy of these models may be checked by comparing predicted values against results obtained in previous naval exercises or actual combat. Although such data can be limited, enough information is usually available to be able to roughly calibrate the model predictions.[12]

Because performance characteristics of individual systems are relatively well established, tactical engagement models are well suited for large scale mathematical evaluation and computed-aided simulation, and most large scale simulations are of this type of battle. They can also be used to provide input data to higher level mission or campaign models.

Single Mission models are characterized by multiple systems engaging simultaneously or sequentially in a single mission or warfare area and are useful in comparing several candidate systems in a given mission area. The major difference between these and tactical models is the wide range and variety of engaging systems employed in a single mission. An example would be integrating aircraft, area and point defense missiles, guns, electronic warfare, and decoys, to provide air defense for a battlegroup. A convoy protection model would include the multi-mission integration of anti-air and anti-submarine warfare for the overall protection of the convoy. The model usually consists of several layers of engagement envelopes that determine the probability of a threat to engage a target after transiting each layer of defense. The performance of each layer is normally estimated by use of tactical engagement models previously described. This is the way SAGDEM was constructed. Both offensive and defensive weapon systems were evaluated and assigned values to define their effectiveness against other systems. Defensive weapon systems were integrated to provide a layered defense against the threat they were designed for. Offensive systems were evaluated for their ability to penetrate defenses and cause damage. Damage inflicted during a time iteration affects the number of units available for the next so that simulation results are attrition oriented. The evaluation of weapon systems was done for anti-air, anti-surface, anti-submarine, and strike warfare areas. The model was essentially created by defining the engagement sequence for each of the given warfare areas and melding them together where variables had impact in multiple areas.

Modeling at this level also requires that more strategic factors be considered. These would include the effects of command and control functions on the coordination between different weapon systems (AEGIS capabilities), and the cumulative effects of attrition during the engagement (loss of SAG cohesiveness and defensive capability).

Care must be taken to properly account for the overwhelming number of critical tactical and environmental interactions that make up this level of engagement and that the data used are appropriate to the situation.[13] It is useful to use weapon system performance results obtained from lower level models as input to these models in order to realistically account for the tactical complexities involved.

Integrating Naval Warfare into the Model

The process of transforming actual tactical naval warfare into a mathematical model requires an understanding of the basic tenants of war at sea. The first point which must be addressed is defining the mission which the SAG is to perform. The political mission of the SAG is to show the flag and act as a military deterrence. Credibility in this role is dependent on how other nations perceive the potential capabilities of the SAG in relation to the known capabilities of carrier battlegroups. Should this mission fail and the SAG become involved in hostilities, its mission changes to that of survival and being an effective, as well as the first, offensive striking force. SAGDEM evaluates survival as a function of attrition suffered and effective striking force as the number of TOMAHAWKS required to accomplish their missions.

In such a conflict, the initial objective is the destruction of the enemy's fleet and air threat in a decisive battle. This can be the desired end in itself, or the prelude for other courses of action, such as diplomatic negotiations or the safe landing of troops. Decisive naval battles, however, seldom occur unless both sides choose to fight.[14] The model assumes that the SAG will not open hostilities, but that it is governed by rules of engagement which specify the actions that can be taken in response to a given hostile act. The model thus represents a worst case scenario where the vast majority of hostile forces are able to carry out at least on attack on the SAG. That hostile action is initiated when the leadership of a nation determines that the given political situation requires military action and that their military forces are capable of mounting a successful attack on the SAG. It may be deemed sufficient merely to cripple the SAG in such a way that American political and military prestige suffers to the point that American attempts to influence events in that country or region are discontinued. To prevent this, the composition of the SAG must be such that it able to survive such an attack and continue to carry out its assigned mission. The best composition of the SAG is what the model attempts to determine.

Since the model represents the interaction between two forces, each of which possesses the offensive capability to destroy the other, one consideration to be evaluated is force firepower. Firepower consists of a unit's offensive and defensive weapon capabilities and represents the unit's ability to defend itself and inflict damage on the enemy.[15] The primary weapons present in the model, torpedoes, cruise missiles and surface-to-air missiles, are described by their effective range, payload and level of sophistication.

Each side also has a defensive power in hard and soft kill systems, which include missiles, guns, chaff, and jamming. For the SAG, shipboard defenses are treated as a filter by which incoming weapons are sequentially destroyed, leaving a net number of weapons that hit the SAG. Hostile forces are assigned a net defensive value based on their aggregate defense capability, which in turn results in the attrition of incoming weapons.

Also important is the correlation of force, defined as the elements of force that describe its capabilities and effectiveness as a function of more than its order of battle.[16] Such factors include leadership, training and morale. These are qualitative comparisons of the personnel involved on both sides. They affect such variables in the model as shipboard damage control, hardware material readiness, and the ability to effectively deploy and use available weapons. Other factors are force endurance and resilience, representing the ability of a force to remain onstation and perform its mission, and have access to fuel, weapons, and spares. It also includes the ability of a unit to sustain damage, execute effective damage control measures, and continue to carry out its mission.

Another important factor is the effectiveness and availability of search and reconnaissance assets. Neither side can deliver weapons without scouting information obtained from electronic, acoustic, or visual means. The speed and sea-skimming flight profile of cruise missiles, and the stealth in which modern submarines operate, demand quick defensive reaction times in order to neutralize the threat. Reaction time is dependent upon an effective search and detection capability, which in turn is a function of the nature of the target, environmental conditions, tactics employed, and the type of sensors available. The search capabilities of the SAG consist of shipboard search radars and electronic surveillance equipment coupled with limited spy satellite reports. Because it is in the best interest of the SAG to be emitting significant electronic noise, threat forces will have a relatively easy time in detecting the SAG. Detecting a target, however, is not necessarily enough to launch an effective attack.

Scouting information can be classified as either detection, tracking, or targeting, based on its accuracy and the ability to act on it.[17] Detection is the knowledge that enemy forces are present. Tracking is not having complete knowledge of the enemy's composition or location, but having sufficient to launch an attack with some probability of success. Targeting represents the ability to identify and attack individual units and maximize the effectiveness of the attack. Both forces' search and reconnaissance measures have the potential to give away more tactical information than they collect, and each side can influence the effectiveness of search activities by means of deception, cover, and electronic stealth. Scouting is handled in the model by determining a unit's probability of detecting opposing units and whether or not it has sufficient information to launch an attack. For this reason, not all hostile units that sortie will be in position to attack the SAG.

In addition to the above listed warfare concepts, an effort was made to incorporate into the model certain trends that have become apparent in modern naval warfare. They provide a basis by which the model is structured and for which decision variables are identified. These trends are based upon the lessons learned from the following naval operations: the 1982 Falkland Islands War, the incidents involving the USS STARK and USS VINCENNES, the reflagging and escorting of Kuwaiti oil tankers in 1987-1988, and Operation Desert Storm in 1991.

Some of the more relevant trends in tactical naval warfare include the following:[18]

> Speed of the weapon platform is subordinate to speed of the weapon delivery. Weapon delivery is a function of Command and Control and the velocity of the weapon.
>
> Effective weapon range is dominant over weight of firepower.
>
> Weapons lethality and range have increased the distance between forces.

The trend in shipboard defense is away from staying power and armor, and toward defensive force.

Ships in port and aircraft on ground are vulnerable to attack from the sea.

Applying sufficient salvo size, an inferior force can win with superior scouting.

Sophisticated Command and Control is required to improve the timing of decisions and to compress the time it takes to make them.

In modern naval combat, effective scouting is the key to effective weapon delivery.

Naval battle is attrition oriented.

The model is therefore structured in such a way as to evaluate the two forces facing one another. Often, qualitative assessments may determine values as much as quantitative knowledge. It is the comparison of force, rather than the forces themselves, to include weapons and weapon range, reconnaissance, command and control, and tactical ability, that will determine the outcome.

SECTION 4

THE COMPUTER MODEL

Overview of Model

The Surface Action Group Defense Model was constructed from a causal diagram developed to express the relationship between the various factors relevant to the system (Figures 1-8). The causal diagram was then divided into modules that represented one of the several major aspects of the system, generally based on a specific warfare area (Figure 9). The breakdown of the model into modules allowed the various parts of the model to be tested and verified independently, making it easier to detect and correct discovered problems.

There are four threat modules: air threat, surface threat, submarine threat, and ground launched cruise missile threat. The air threat module evaluates the ability of hostile aircraft to damage the SAG with cruise missiles or conventional gravity bombs. The surface threat module deals exclusively with ships armed with surface launched anti-ship missiles. The submarine threat module evaluates a submarines's ability to damage the SAG with either cruise missiles or torpedoes. The ground launched cruise missile threat represents the capabilities of land based mobile launchers configured to launch anti-ship missiles. The

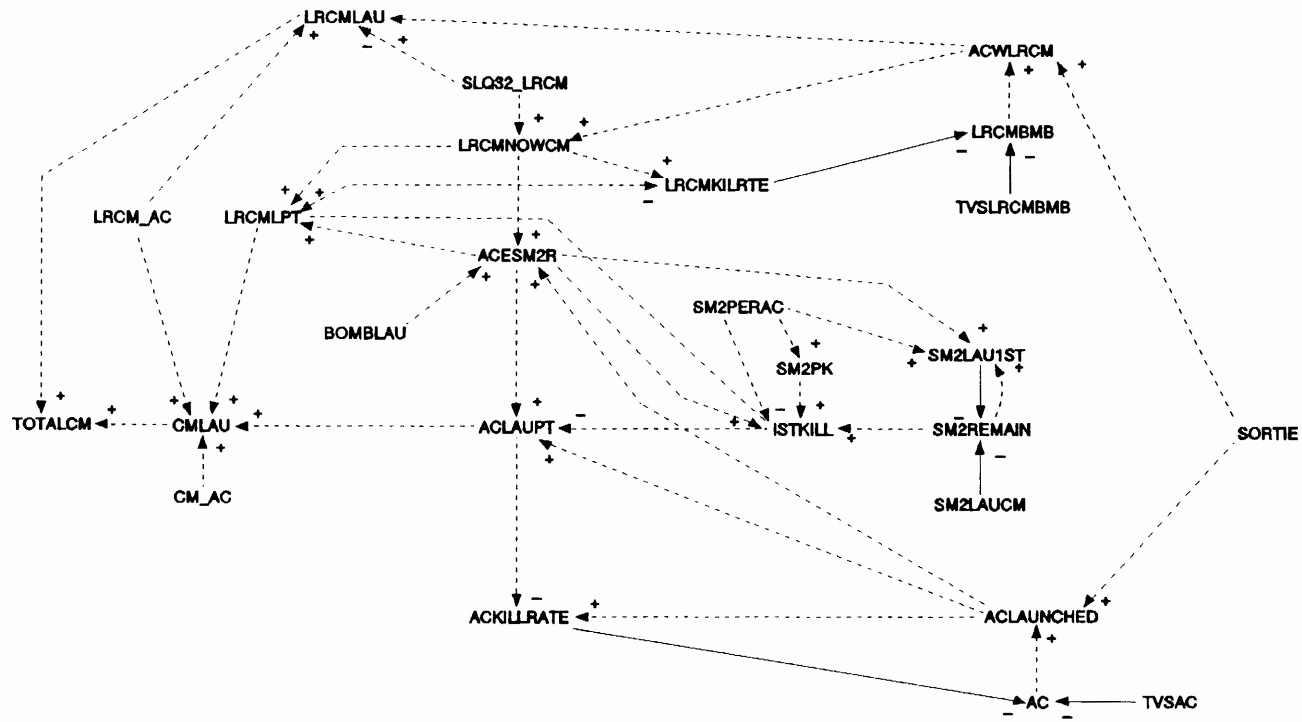

Figure 1 - Engagement Sequence for Aircraft Armed with Cruise Missiles

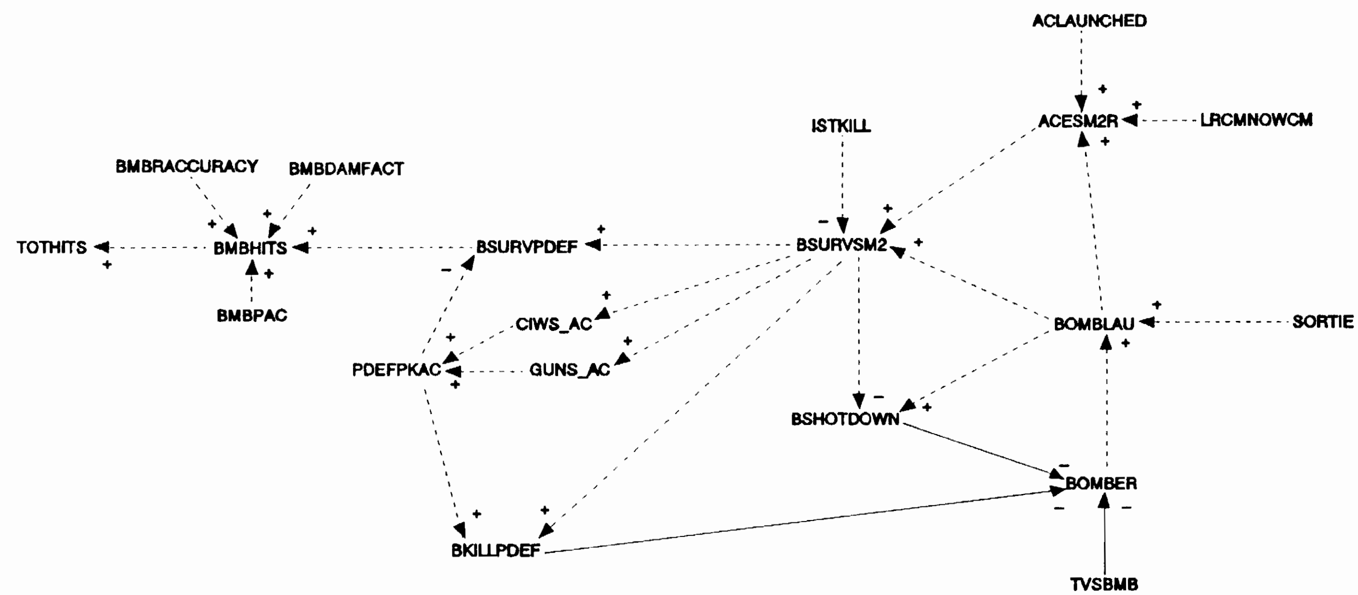

Figure 2 - Engagement Sequence for Aircraft Armed with Conventional Bombs

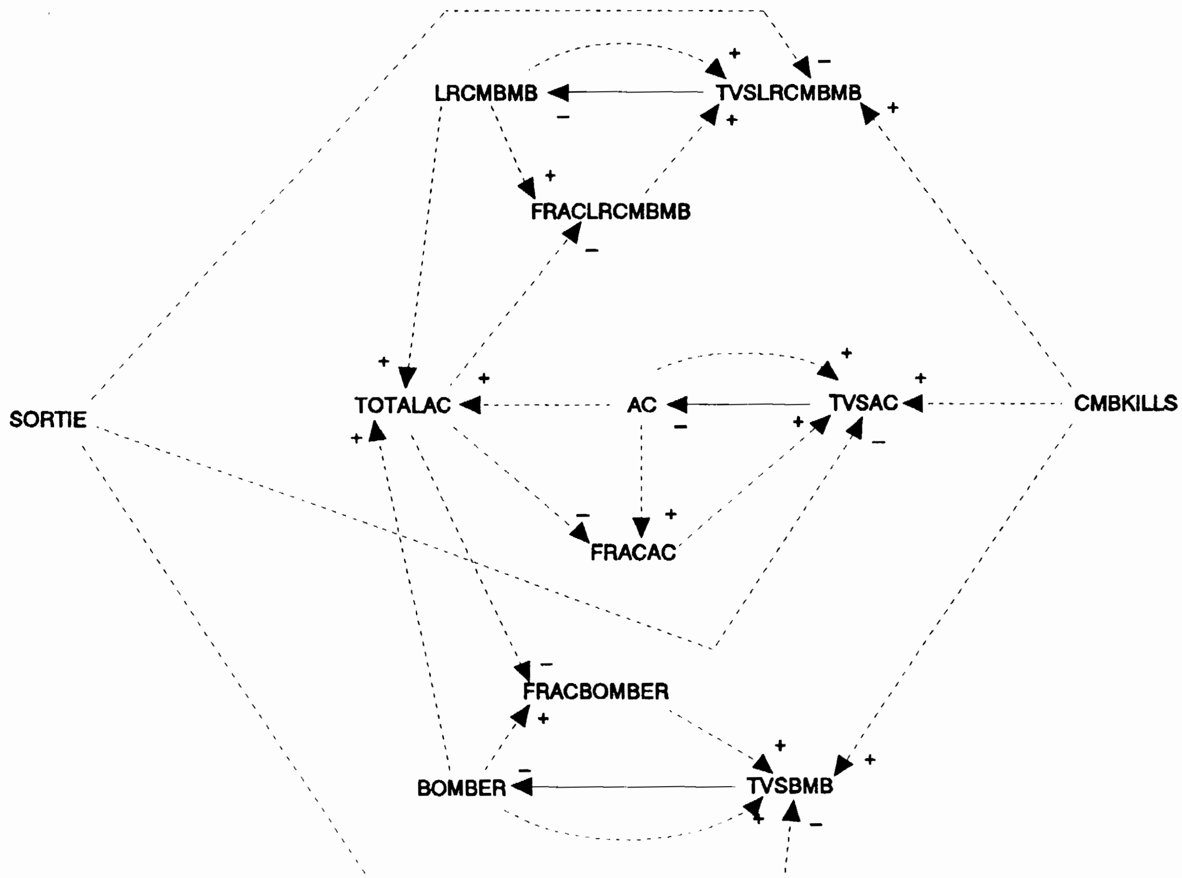

Figure 3 - Impact of TOMAHAWK Strike on Aircraft Availability

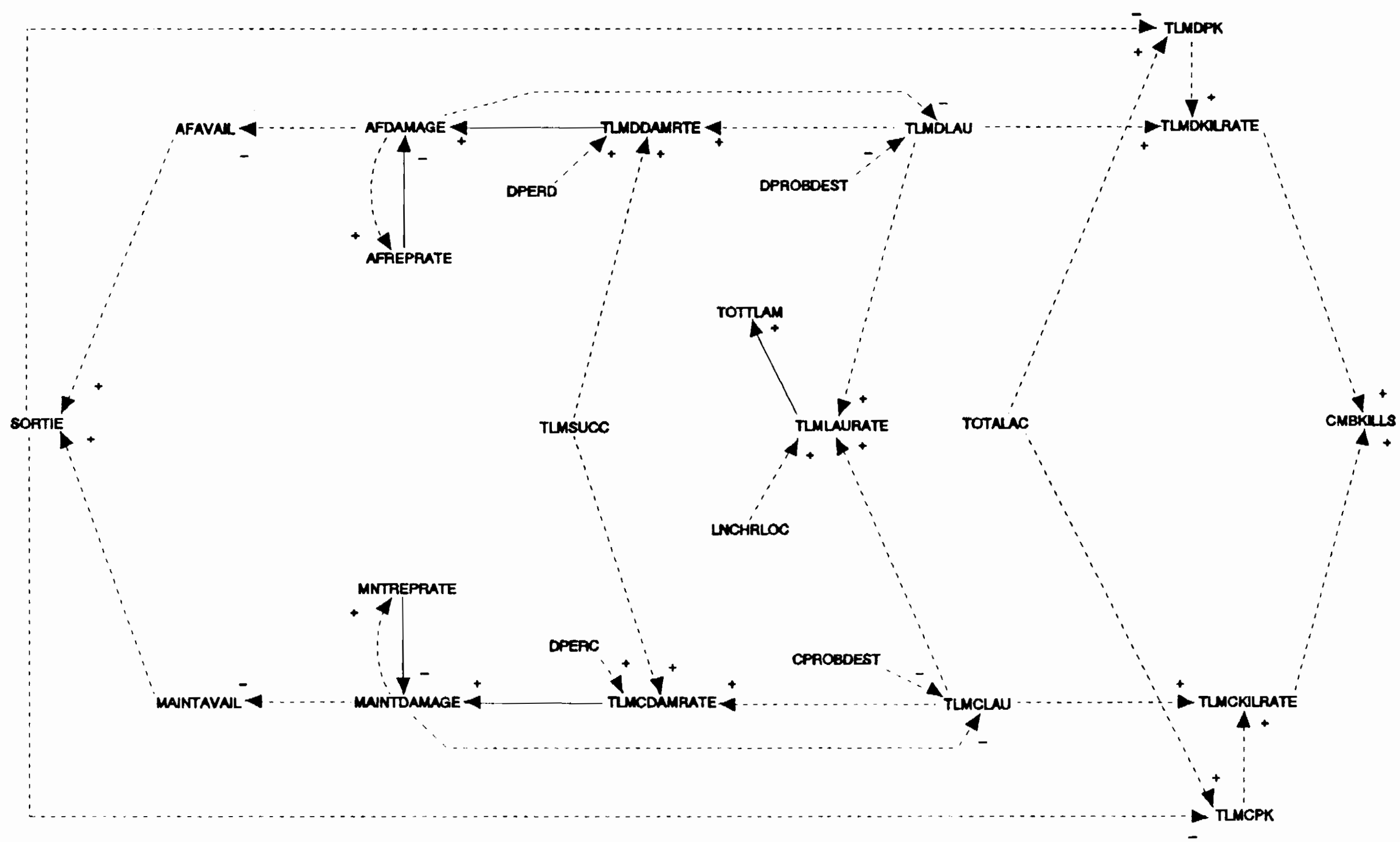

Figure 4 - TOMAHAWK Strike Against Airfield

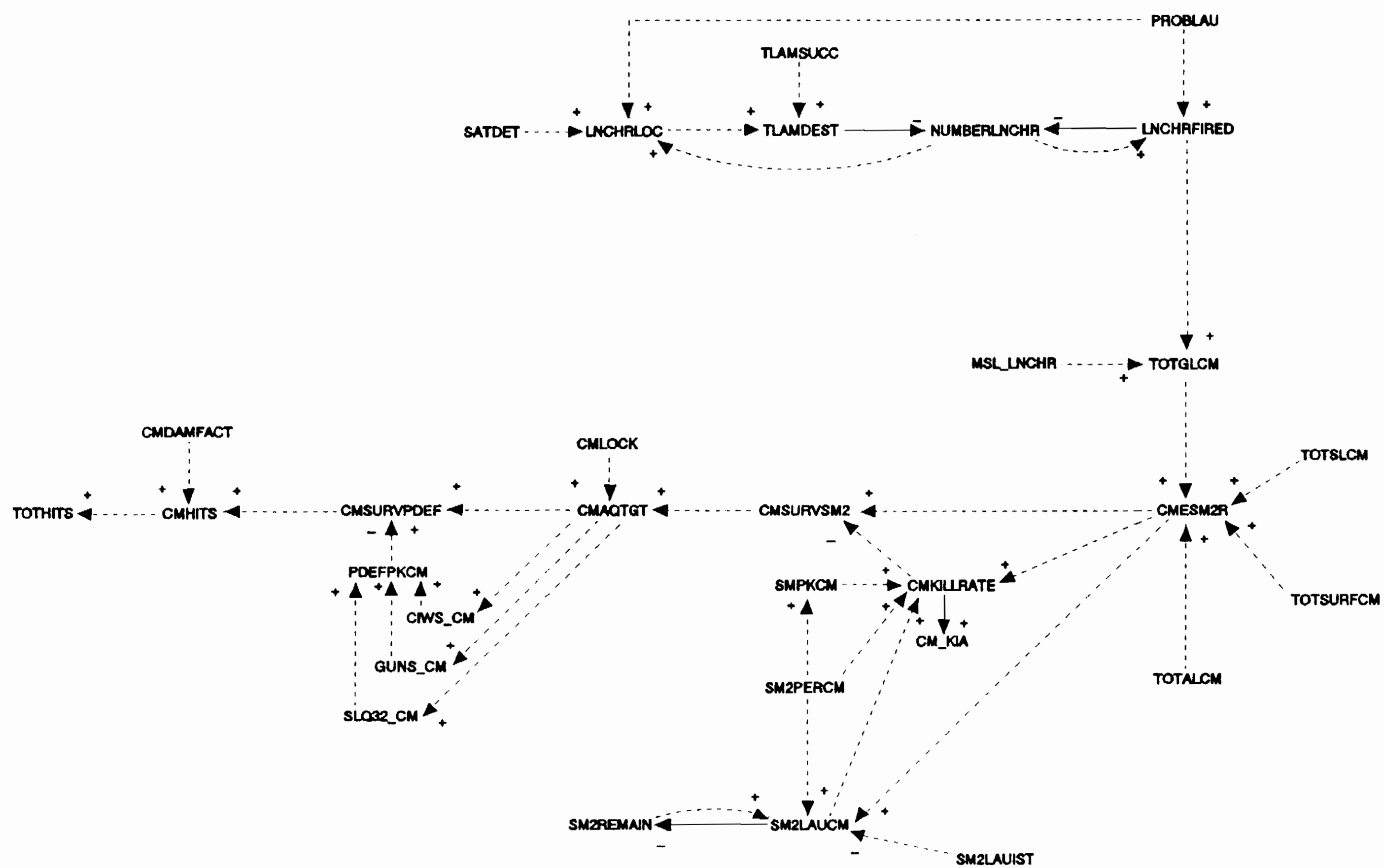

Figure 5 - Engagement Sequence for GLCMs and All Cruise Missiles Entering SM2 Range

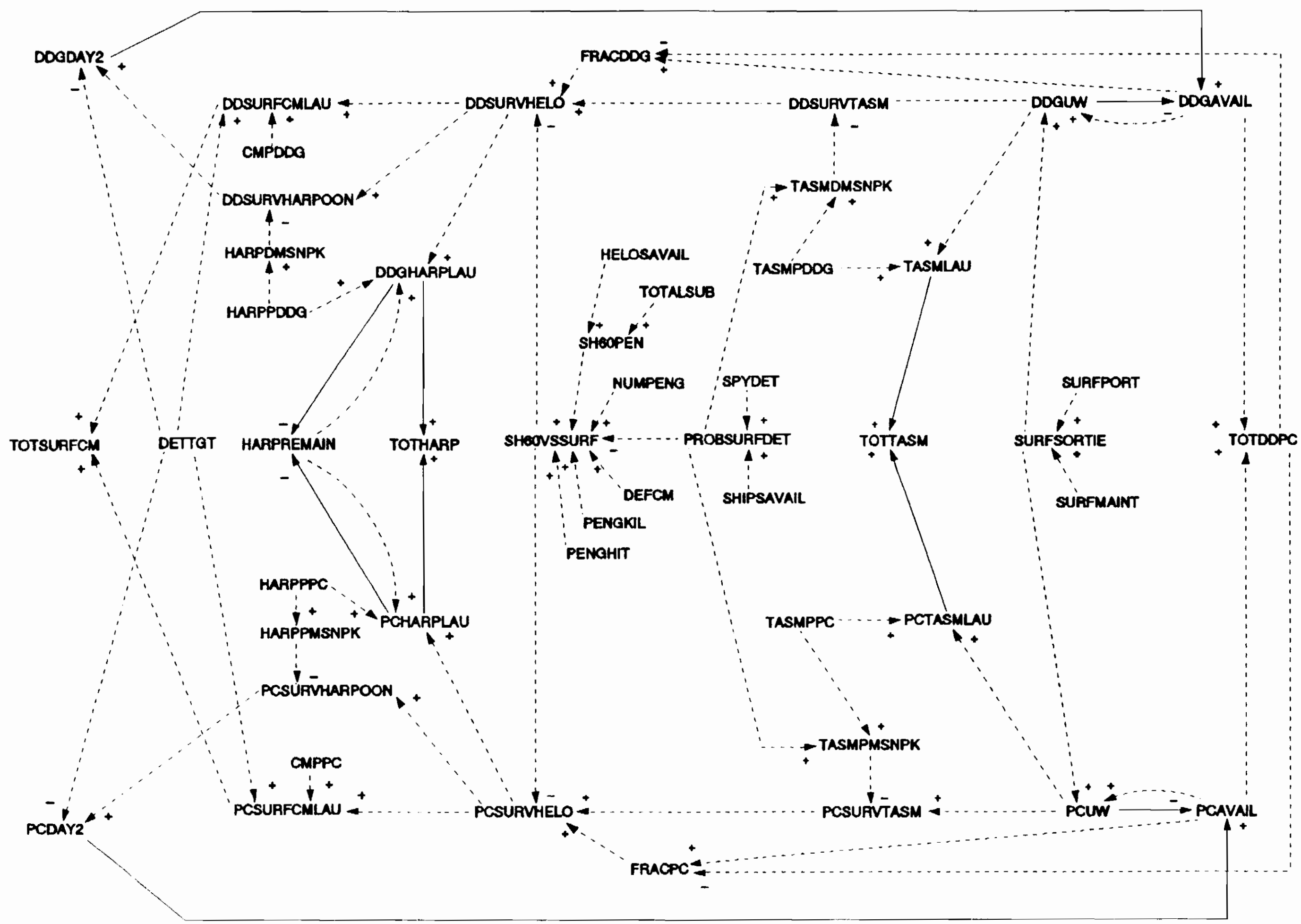

Figure 6 - Engagement Sequence for Hostile Surface Ships

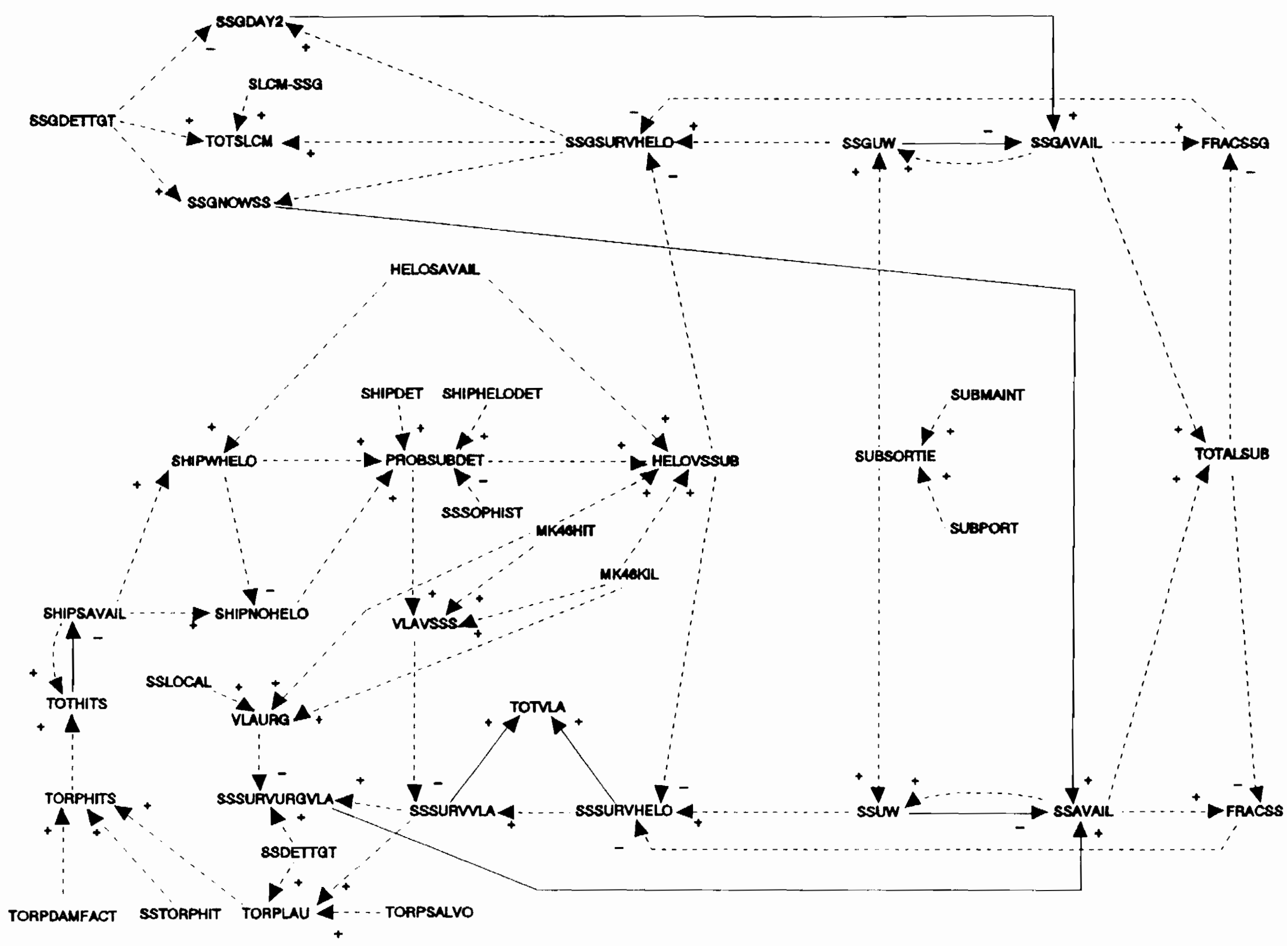

Figure 7 - Engagement Sequence for Submarines

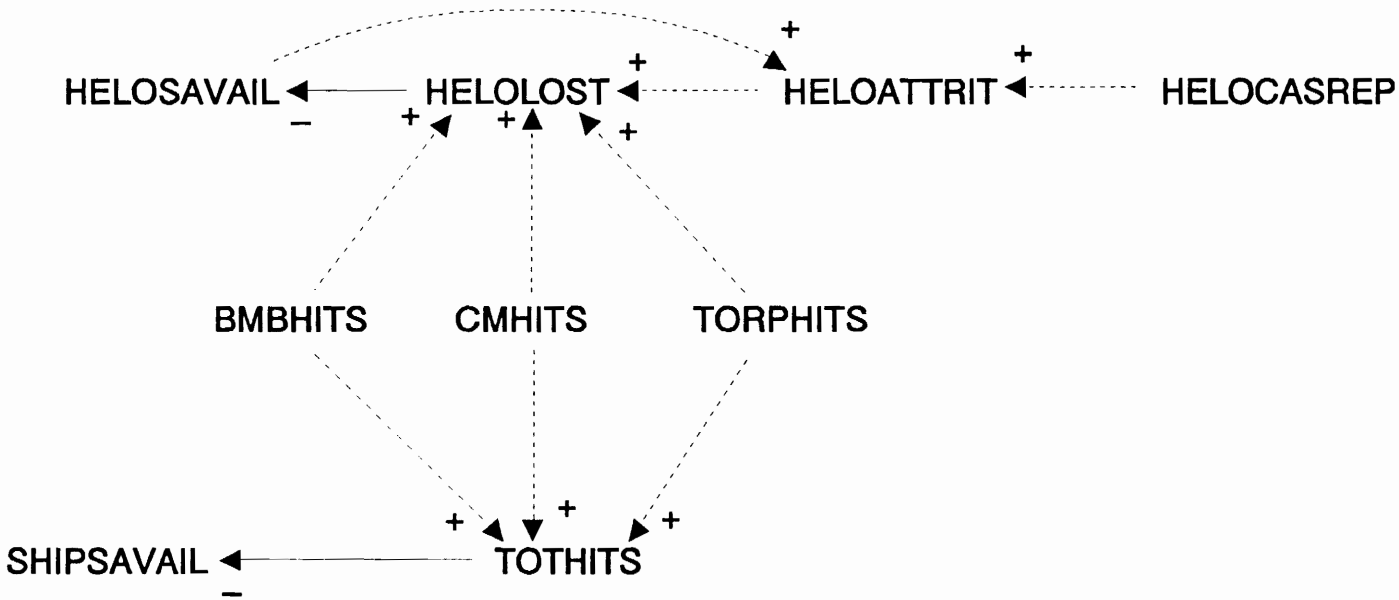

Figure 8 - SAG Ship and Helicopter Availability

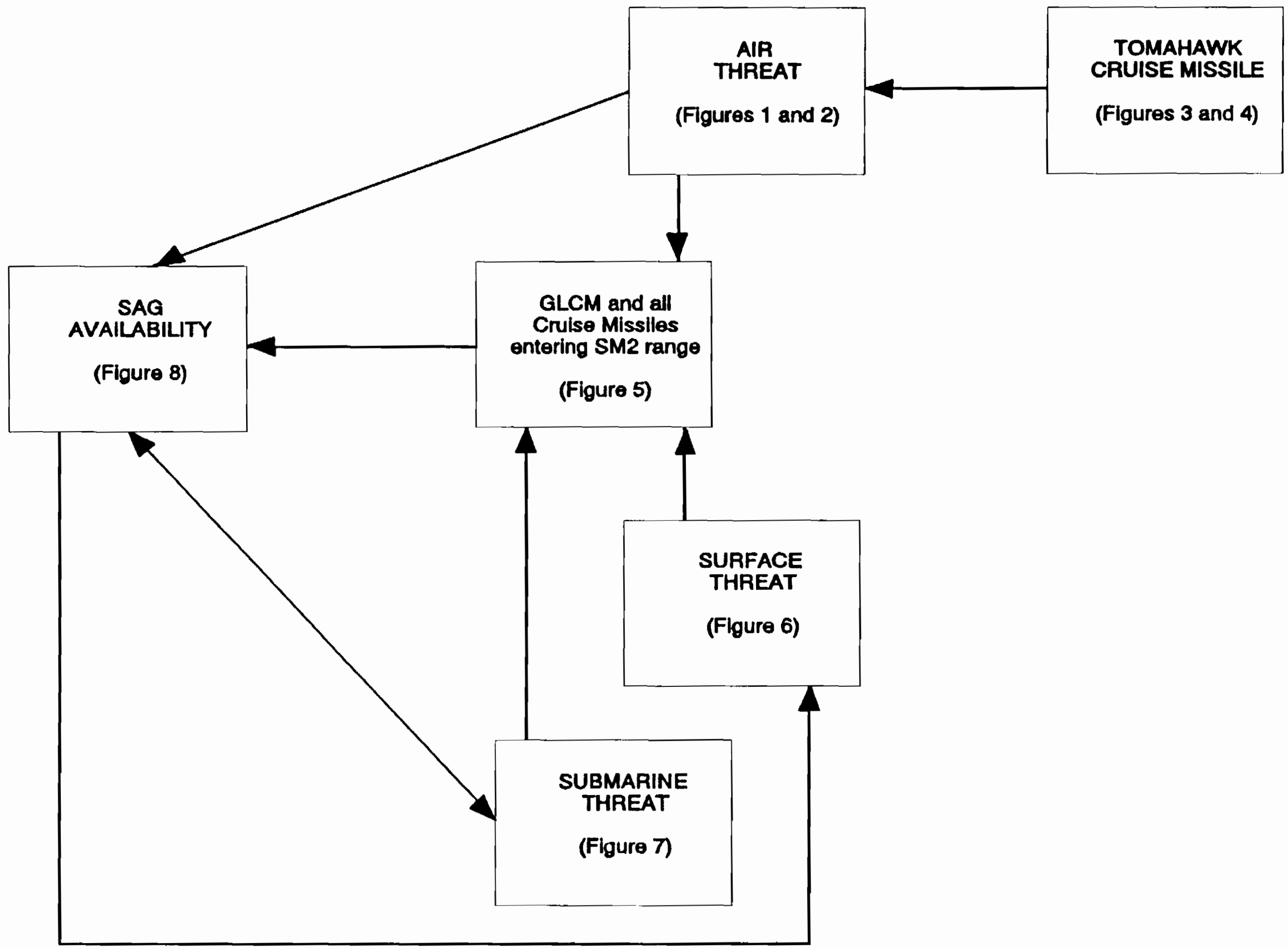

Figure 9 - Relationship Between Modules

TOMAHAWK module examines the ability of the land-attack version of the missile to damage airfield runways, maintenance facilities, and aircraft on the ground.

The basic time iteration used in the model is one day and each hostile weapon platform has the opportunity to engage the SAG once per iteration. This engagement rate for hostile forces is based on several inherent concepts; personnel training and the material readiness of equipment being the primary factors involved. That a nation possesses high tech weapons is not necessarily the primary concern of the SAG. More important is how effectively those weapons will be employed. Iraqi military forces during Operation Desert Storm were well equipped with modern hardware but were unable to use it effectively. The hostile forces to be encountered by the SAG in the model are similarly equipped, maintained, and manned. This means that aircraft which perform combat missions will require considerable turn around time prior to being able to sortie again. Ships and aircraft may not be available if properly trained technicians or parts are not available. Pilots and ship's crew may not use their weapons effectively due to receiving inadequate training in the use of their weapons or in combat tactics. Thus, weapon platforms will not always be available to carry out offensive operations even though they exist, and the decision making process required to activate these systems is degraded by the lack technical and tactical information. While it can be predicted that such weapon systems will not be operated at their most efficient level, it can also be predicted that a certain number of weapons will be launched at the SAG.

The model provides four ways for the SAG to protect itself. It can launch TOMAHAWK land-attack missiles to damage or destroy the facilities that allow combat forces to operate, specifically ports and airbases. It can attack the weapon platform prior to its launching its own weapons. TOMAHAWK anti-ship missiles can target surface ships up to 300 nautical miles (hereafter referred to as miles) away, well outside the range of hostile ship-launched cruise missiles. Submarines can be countered outside the range of their missiles or torpedoes through the use of ASW helicopters. A third means is to destroy the weapon itself with the various defensive systems onboard, such as anti-air missiles and guns. The ship can also defend itself with passive systems, such as chaff, electronic jamming, and noisemakers, all designed to decoy the weapon away from the ship.

The model thus describes the relationship between the offensive and defensive capabilities of the SAG and those of a given hostile nation. The resulting data of interest are the number of ships that remain combat effective and the number of missiles expended by the SAG in neutralizing the threat. This would determine the number of ships required to ensure those missiles were available (TOMAHAWK land-attack missiles for use against strategic targets that do not pose a direct threat to the SAG are not included).

Air Threat Module

The air threat module is concerned with the ability of hostile aircraft to deliver ordnance to the SAG and the ability of the SAG to shoot down those aircraft (Figures 1 and 2). The model evaluates the weapons engagement procedure against three general types of aircraft. The first type of aircraft is one that can carry long-ranged, air launched cruise missiles. Long-ranged is defined as those missiles with a range exceeding 50 miles. The primary air defense weapon of the SAG is the SM-2 anti-air missile, which has a range of approximately 40 miles and is the longest ranged anti-air weapon carried by the SAG. Aircraft armed with long-ranged cruise missiles will generally not be engaged by the SAG, although the cruise missile itself will be upon entering the SM-2's engagement range. The second type of aircraft are those armed with cruise missiles that have a range less than that of the SM-2. These aircraft will be engaged by SM-2s prior to launching their cruise missiles and may be shot down prior to launching their missiles. The SAG will then have the opportunity to engage those cruise missiles that are launched.

The third type of aircraft is armed with gravity bombs and is required to come extremely close to the SAG in order to drop its weapons.

Aircraft carrying long-ranged cruise missiles (LRCM) have the simplest engagement sequence. These aircraft are generally Soviet made multi-engine bombers equipped with one large Soviet made cruise missile. The various cruise missiles carried by these aircraft have a range of over 90 miles, with several having ranges of several hundred miles. The number of long-range cruise missiles that enter the SAG's engagement zone per day is dependent upon the number of aircraft carrying LRCMs that launch per day and the number of LRCMs that can be carried per aircraft. Although LRCM aircraft that are able launch their missiles at extreme range are not vulnerable to being shot down, they are susceptible active electronic jamming. Powerful electronic ships, such as AEGIS cruisers and destroyers, are electronic liabilities unless they are able to use these systems. Since the presence of the SAG will be known prior to hostilities breaking out as a result of normal surveillance, electronic warfare tactics should be geared toward complicating the enemy's efforts to track and target the SAG. The model therefore assumes that the SAG will give up stealth in order to employ its defensive systems cooperatively. Active jamming and radiating decoys are the primary means in which the SAG can inhibit targeting by hostile search and homing radars and lure weapons away from the ship. The SLQ-32 (V)3 electronic warfare system carried onboard Ticonderoga class cruisers has such an active jamming capability. By preventing an aircraft and its missile from obtaining a radar lock on its target, it forces the aircraft to fly closer to the target so that its radar has the power to "burn through" the jamming and see the target. The role of electronic jamming in the model is to force these aircraft to fly inside the SM-2 engagement range prior to launching its missile and therefore risk being shot down before the weapon is launched.

The second type of cruise missile carrying aircraft is a one or two man attack aircraft or fighter/bomber. Normally these aircraft carry one or two short to medium range cruise missiles, such as the American made HARPOON or French built EXOCET. A good example of this combination is the French Super Etendard attack aircraft mated with the EXOCET missile, used with some success by the Argentines during the Falkland Islands War. The standard flight profile is to make a low level approach (under 50 ft) to take advantage of the gap created where the earth's surface curves down and away from the radar's line of sight. This also allows the aircraft to hide in the electronic background "noise" caused by the reflection of radar signals from the surface of the water once it comes closer to the ship. Depending on the sophistication of the air search radar, this technique can effectively mask the presence of the aircraft until it is within approximately 20 miles. At this point, or earlier if the aircraft knows it has been detected, the aircraft gains altitude in order to use its own radar to lock-on the target, feed that information to the missile, and launch it.

These aircraft will have to survive engagements with SM-2 anti-aircraft missiles prior to launching their own weapons. This is due to the shorter range of the cruise missile and the need to get close enough to the target to counter the effects of active electronic jamming. The ability of an SM-2 missile in the model to destroy an aircraft is based on a number of factors. First, the aircraft must be detected by the ship's sensors. Detection can be accomplished either actively, with radar, or passively, with electronic support measures (ESM) designed to detect other sources of electronic emissions. Radar will provide a line of bearing and range to the target where ESM will only provide a line of bearing. The SAG will rely heavily on the capabilities of the SPY-1 radar, associated with the AEGIS combat system, for the detection of surface and air threats. The SPY-1 has the ability to simultaneously track several hundred targets at a time out to ranges on the order of 200 miles. The radar also has the ability to guide SM-2 missiles to their targets, about twenty of which can be engaged simultaneously. No other system comes close to this capability and the resultant ability to counter saturation attacks is a major reason why AEGIS equipped ships are considered capable of operating without carrier air support.

The sooner a target is detected, the sooner it can be engaged. The standard flight profile for an attack plane is to fly as low as possible so that any radar image it might produce is lost in the return created by the surface of the water. At the last possible moment, the aircraft climbs in altitude to obtain a good radar lock on its target and launches its missile. Because SPY-1 has the means to filter out most of the sea return, and multiple search radars will be on-line at the same time, the assumption is made in the model that all aircraft which enter the SM-2 engagement range (40 miles) will be detected.

An aircraft flying at over 500 mph will travel the length of the SM-2's engagement range in less than five minutes, thus the time available destroy to the aircraft is severely limited. Since the aircraft will launch its missile as far away as possible, especially if it perceives that it has been fired upon, that engagement time is further diminished. The number of SM-2 engagements per aircraft is limited by the time it takes an SM-2 to engage a target at maximum range, for AEGIS to make the determination if a kill was achieved, and to initiate another engagement prior to the detection of a cruise missile launch from the target aircraft. That number also takes into account that AEGIS equipped ships will provide area-wide air defense for the entire battlegroup, not just themselves. Even when operating together as a group, the SAG could be spread out over an area of ten miles or more.[19] As a result, the effective range of SM-2s when engaged in the defense of other ships in the SAG is decreased and fewer salvos can be launched. In conjunction with the fact that once a cruise missile is launched, the primary threat to the SAG becomes the cruise missile and the aircraft is no longer engaged, it is estimated for simulation purposes that the average number of SM-2 engagements per aircraft is two. The number of SM-2s fired per engagement, however, can be more than one.

There are several SM-2 engagement tactics that can be used, the first being "shoot-look-shoot". In this instance, an SM-2 is launched and a determination is made as to whether a kill has been made prior to launching a second missile. The second tactic is the "shoot-shoot-look-shoot", where a second SM-2 is launched in quick succession against a target before it is determined if the first SM-2 scored a kill. The advantage of this approach is that a second SM-2 is already in the air should the first one miss, with a better probability of destroying the target in the time period of the first engagement. The disadvantage is that the ship's supply of

SM-2s is expended at a quicker rate. The effectiveness of SM-2s against aircraft is determined in the model by what engagement tactic is used.

The third type of aircraft faced by the SAG is the one armed with conventional gravity bombs. These are tactical attack aircraft or fighter/bombers with one or two man crews capable of carrying four to eight tons of bombs of various sizes. Smart bomb technology has not proliferated to Third World countries to the point where their presence would be a factor in a conflict and are not considered in the model. Tactical bombers in the model will have the most difficulty in penetrating the SAG's defenses and releasing their ordnance as they are forced to come extremely close to their target during the course of their attack. As such, they will be subjected to the full spectrum of defenses available to the SAG. The tactical bomber will first have to evade the SM-2s fired at it. The flight profile of attack aircraft is similar to those that carry cruise missiles in that they will fly at sea level in order to minimize the SAG's detection and reaction time. Within the last few miles to the target, the aircraft gains altitude in order to set the fuzes on the bombs and then release them. This attack profile provides the maximum protection to the aircraft and is the most effective way dropping the bombs so that they hit the target. Those aircraft which do penetrate the SM-2 engagement zone, however, will then have to defeat the weapons which comprise the point defense engagement zone.

Continuing to track the inbound aircraft, AEGIS determines at what point the target has passed inside the SM-2's minimum engagement range. This equates to the boundary between area and point defense zones where secondary anti-air weapons are now used to engage the target. One of the more significant aspects of the AEGIS system is the ability to fully coordinate the ship's defensive weapon systems to provide the maximum protection for the ship. If AEGIS is in semi-automatic mode, it will prompt the appropriate personnel that the target must be engaged with point defense weapons. Ship's crew will then determine how and when these weapons will be employed. Otherwise, AEGIS will automatically control the point defense weapons itself, sending targeting information to the weapons and issuing fire commands. Probability of kill values assigned to SAG missile and gun systems in the model reflect the ability of AEGIS to optimize the use of these systems when engaging multiple simultaneous threats.

There are several different gun systems which make up the point defense weapons against aircraft, dual-purpose guns and 20mm gatling guns. All of the ships which comprise the SAG are equipped with either a 3" or 5" dual-purpose gun. The primary use of these guns is against surface and land targets, but they do possess some anti-air capabilities. The 3" gun is an automatic system able to fire 80 rounds per minute. The 5" gun is similar, but fires a larger projectile at a rate of 20 rounds per minute. The accuracy of these systems against aircraft is dependent on the speed and maneuverability of the target. Although tracking a target is not so much a problem for the gun's fire control radar, the gun itself is physically constrained in its ability to remain centered on the target due to limitations on how fast it can train and elevate. Guns are also limited in their effectiveness against aircraft in that once the projectile has been fired, it cannot be guided. Thus, an aircraft which still has the ability to maneuver can reduce the effectiveness of the gun.

Also onboard all these ships is the PHALANX close-in weapon system. A 20mm, six barrel, gatling gun capable of firing 3000 rounds per minute, it is specifically designed to engage and destroy aircraft and cruise missiles. With an effective range of one mile, it is the last weapon that can actively engage an air threat. Like dual-purpose guns, PHALANX can only engage one target at a time and is therefore susceptible to saturation attacks. This is reflected in the model by reducing the overall effectiveness of all guns systems as the number of aircraft and cruise missiles entering the point defense zone increases.

The bombers which are able to survive engagements with the gun systems are finally in a position to drop their weapons. Whether or not those bombs hit their target is subject to several factors accounted for in the model; the size and number of bombs per aircraft, the skill of the pilot, and the sophistication of the aircraft itself. Pilot skill can vary depending on whether the aircraft belongs to the air force or the navy. Navy pilots would train in the tactics of attacking naval targets, whereas air force pilots would be considerably less proficient in such tactics. Most, if not all, of the aircraft to be encountered would belong to that nation's air force, reducing the overall effectiveness of bombing attacks.[20] Damage inflicted is expressed in terms of fractions of ships destroyed and is a function of the number of bombs that hit and an associated damage factor. It represents the effectiveness of the bomb, the damage control capabilities of the ship, and an average assessment of were the bomb(s) would impact the ship.

TOMAHAWK Cruise Missile Module

An effective means of reducing the threat of aircraft and air-launched cruise missiles is to destroy the aircraft before it can sortie. Aircraft can also be rendered inoperable by destroying the maintenance facilities required to keep the aircraft combat ready or the runways used to launch the planes. This strategy can be accomplished through the employment of TOMAHAWK land-attack cruise missiles (Figures 3 and 4).

The TOMAHAWK Land Attack Missile (TLAM) is a long range (750 miles), sub-sonic missile capable of being fitted with a variety of different warheads. The greatest asset of the missile is its ability to fly a precise path to its target. The route that takes the missile to its target is determined by two means. Targets are actually selected by intelligence agencies in the US. The Navy then determines an overland flight path to the target based on geography and information on the location of enemy defenses. This, coupled with the low altitude at which the missile flies, maximizes the chance that the missile will arrive at the target. These mission profiles are stored electronically as software programs that are downloaded to the missile when that mission is to be conducted. The ship that launches the missile determines the route the missile will take to get to the point where the mission begins. Once the missile is in flight, it determines its location by taking a radar picture of the ground below it and matching it to a digital map stored in its memory. Course corrections are made as necessary to remain centered on its flight path. For more precise targeting, an optical sensor is used for navigation just prior to arriving at the target. New generation missiles are now able to communicate with Global

Positioning Satellites to obtain extremely accurate location updates while in flight. The ability of the TOMAHAWK to fly such a precise flight path to the target and to avoid defenses are reflected in the model by the high probability that a TOMAHAWK mission will be successful and the level of damage that is created.[21]

There are two major versions of this missile, each conceived for a specific purpose. The TLAM-C (TOMAHAWK Land Attack Missile - C variant) is equipped with a 1000 lb warhead and is designed to impact a stationary target and destroy it. The D variant missile (TLAM-D) carries a canister filled with hundreds of small bomblets designed to be dispersed over a runway. These bomblets explode on the airfield, creating potholes that make the airfield unusable for short periods of time and damaging any aircraft exposed there. TLAMs are used in the model to render an airfield unusable and prevent the sortie of aircraft from there. Both missile variants are used together to form coordinated and comprehensive attacks on the airfield designed to simultaneously destroy the aircraft themselves and the ability to launch them. The two factors which determine the size and composition of these strikes are the number of operational aircraft and physical status of the runways and the maintenance facilities. TLAMs will no longer be launched once 90% of hostile aircraft have been destroyed, otherwise, TLAMs will be launched so as to minimize an aircraft's ability to sortie. The ability of planes to sortie in the model is dependent upon the availability of a usable runway and the ability to maintain the aircraft so that it can perform combat missions. The ability of a TLAM to inflict damage is dependent primarily upon its own performance capabilities, many of which were defined in Operation Desert Storm. These include the missile's ability to successfully launch, fly its flight profile, locate and hit the target. The survivability of the missile is enhanced by the ability to program the route taken by the missile so that it avoids known anti-aircraft emplacements.[22] The amount of damage caused by an attack is randomized in the model to simulate the fact that a timely and accurate damage assessment cannot be made when air and satellite reconnaissance are unavailable or sporadic. The result is that more TOMAHAWKs may be launched than what would technically be required to neutralize the airfield to compensate for the uncertainty.

The damage done by TLAM-Cs against maintenance facilities represents the destruction aircraft hangers, test gear and spare parts, and fueling equipment. Because of the time lag in repairing damaged parts or obtaining replacements from other locations, the rate at which these facilities can be brought back to operational use is low. The damage done by TLAM-Ds against the airfield is not as long lasting. Modern high performance aircraft require long stretches of flat runway for take-offs and landings and relatively small holes in the runway can halt operations until those holes are repaired. TLAM-Ds create many such holes, but they are not catastrophic in nature and do not require extensive equipment to repair. Repair is delayed, but not stopped, due to bomblets containing delayed fuses, causing them to explode at random times and making airfield repair more hazardous. The rate at which the airfield can be repaired in the model is thus greater than for maintenance facilities.

The second means of reducing the number of aircraft which sortie in the model is to destroy the aircraft while they are still on the ground. Because TLAM-Ds possess multiple bomblets that disperse over a large area, they are more prone to damage aircraft out in the open than the TLAM-C. The TLAM-C, however, is much better able to destroy aircraft which are located in protected bunkers or hangers. The number of aircraft that are destroyed on the ground is dependent on the number of aircraft present at the time of attack and the number of TOMAHAWKS which comprise the attack.

Ground Launched Cruise Missile Threat Module

Ground launched cruise missiles (GLCM) represent anti-ship missile launchers that are mounted on vehicles (Figure 5). They are generally the same type of missiles that are launched from ships or aircraft and have the additional advantage of being extremely mobile, thereby reducing its vulnerability. Two such systems which have been employed are the French EXOCET and the Chinese SILKWORM.

The TOMAHAWK weapon system has received a new capability, called afloat planning, which allows a ship to target these launchers itself by being able to program a TOMAHAWK mission from scratch. This capability was developed so that ships could attack such targets of opportunity, however, it is subject to the availability of reconnaissance assets. Since the SAG has no air support, it must rely on reconnaissance satellites for accurate targeting data. Such satellites are few and are further constrained by orbital mechanics as to where and when they may be available. Detection of GLCM launchers is also dependent on whether it is operationally deployed. Being small and mobile allows the GLCM to remain hidden from surveillance until such time as it is ready to be employed. GLCM employment in the model is a value based on the probability that the SAG will enter the range at which a particular GLCM can launch and the ability to get it to an acceptable launch point and set up. For a GLCM launcher to be detected, then, requires that it be out in the open at the same time that a reconnaissance satellite is overhead. Built into the detection probability is whether the timeliness of the information allows a TOMAHAWK strike to be launched while the GLCM is still at the place it was located. Once a TOMAHAWK strike is launched, its success is based on the same factors that affect strikes on airfields, and the model assumes that if the TOMAHAWK arrives at the target, the GLCM launcher will be destroyed.

Surface Threat Module

The primary threat posed based by surface ships in the model is the ability to launch anti-ship cruise missiles. The SAG, equipped with HARPOON and TOMAHAWK anti-ship (TASM) cruise missiles (60 and 250 miles range respectively) and the AEGIS controlled SPY-1 radar, is extremely capable of detecting and engaging targets outside the range of naval guns. As a result, the probability of a surface ship coming within gunnery range (12 miles maximum) is considered insignificant and the effects of surface gunnery are not considered in the model. The danger presented by hostile cruise missiles, however, is very high and almost all surface ships are equipped with them. It is because most anti-ship missiles systems are extremely lethal and very easy to operate and to backfit on ships that Third World navies, no matter how small, must be considered dangerous.

Two types of hostile surface warships are considered in the model (Figure 6). The first are destroyer/frigate/

corvette size ships, hereafter referred to as destroyers. They displace 1500 to 5000 tons and are either older ships considered obsolete and sold off by a foreign navy or are newly built, medium capability ships bought from a foreign shipyard. Destroyers are not state of the art, but usually contain individual upgrades to certain electronic or weapons systems that makes the ship overall a potent threat. Almost all older ships not originally equipped with cruise missiles are backfitted with them.

The second type of ship is the missile armed patrol craft. They differ from destroyers in that they are smaller and considerably faster (50 knots to speed as opposed to 25 knots). The smaller patrol craft generally have fewer and less sophisticated electronic and defensive weapon systems, but are able to carry an equal number of cruise missiles. Because patrol craft can pack the offensive firepower of larger destroyers and are significantly cheaper to build and operate, these ships will be encountered most often.

The engagement sequences against destroyers and patrol craft in the model are identical, although values for certain variables are different to reflect the unique capabilities of the two types of ships. The first factor considered is the availability of hostile ships to conduct combat operations. These are ships which have already put to sea and have not yet expended their missiles and those which have been in port and are now ready to get underway. The ability of a ship to sortie is based upon the material readiness of the ship as well as the availability of port services necessary to assist a ship in getting underway. Material readiness represents the ability of the ship's crew to maintain the ship so that it capable of conducting combat operations. How well the crew is able to do this is based upon their technical proficiency and the availability of spare parts. Port services include maintenance facilities, tugs, fuel barges and other logistical services intrinsic to the port that impact on the ship's capacity to get underway.

Once a ship puts out to sea it is at an immediate disadvantage. The average range of the cruise missiles it carries is 50-75 miles. The SAG, however, is equipped with TOMAHAWK anti-ship missiles with a range of 250+ miles. If the SAG is able to detect and target a hostile ship at a range greater than 75 miles, the destroyer/patrol craft can be destroyed prior to launching its own weapons.

Detection is dependent on the range to the target, the size of the target, environmental conditions that affect the transmission of radar waves, and whether or not the target is radiating any electronic noise. The SPY-1 radar is the primary surface search radar and can track surface targets out to their maximum missile engagement range. Radar performance of the SPY-1 and other electronic systems, however, can be degraded by certain atmospheric conditions, such as heavy rain and temperature inversions. These factors are accounted for in the probability of detection for each unit.

The most effective means the destroyer/patrol craft has of remaining undetected is to limit, or prevent completely, the transmission of radar and communications signals. Radar signals can be detected with electronic support measures (ESM) at ranges far greater than they can themselves report a target. The model assumes hostile surface ships can rely on either land based radar or air reconnaissance to locate targets and pass that information to them, so that they can operate without utilizing their own electronic systems. This has the effect of limiting the effectiveness of SAG ESM and gives the ship a better probability of closing to within cruise missile range.

Ships that are initially detected outside the range of the SAG's HARPOON missiles will be engaged with TASMs. As a sea-skimming missile, flying just above the surface of the water, a TASM is difficult to detect until it enters the inner defense zone of its target and performs its terminal attack maneuvers. The TASM also possesses a highly sophisticated guidance system and the ability to recognize and avoid various decoy and jamming techniques. Armed with a 1000 lb warhead, a single TASM that strikes its target is capable of rendering it incapable of further fighting, if not sinking it outright.

The destroyer/patrol craft that detects an inbound cruise missile will attempt to decoy the missile away from the ship using chaff to confuse the missile's radar guidance system. The cruise missile will also be engaged by any air defense missile and gun systems that the ship possesses. The most potent defensive system, and one available on all ships, is one of several close-in gun systems. Similar to the PHALANX system onboard SAG ships, it is a rotary multi-barreled gatling gun able designed specifically to counter cruise missiles. Like PHALANX, it can be overwhelmed by a multi-missile attack.

To ensure a cruise missile strike is effective, multiple missiles are launched and timed to arrive at the target simultaneously in order overwhelm the target's defenses, primarily the point defense gun systems. Destroyers are larger, and thus able to support more defensive weapons and absorb more damage. However, being larger than patrol craft, they are more easily detected by the TASM's own guidance radar and thus more vulnerable to them. Patrol craft do not possess the same defense in depth capabilities afforded larger ships but can rely on their greater speed and smaller size for a greater level of protection. The number of TASMs per salvo will be varied in different simulation runs to account for the defensive capabilities of both types of ships and to ascertain the impact of salvo size on the number cruise missiles launched at the SAG.

The next layer of defense against surface ships consists of helicopters armed with anti-ship missiles. All ships in the SAG, except Arleigh Burke destroyers, are able to operate one or two multi-purpose SH-60 Seahawk helicopters. In the anti-ship configuration, the Seahawk is armed with two short-ranged PENGUIN anti-ship missiles. The Seahawk, in making an attack, flies at sea level to minimize the risk of detection. This is especially important as the 18 mile range of the PENGUIN requires the helicopter to fly within range of any hostile area air defense weapons. The availability of Seahawks to perform anti-ship missions, however, is dependent on the number of submarines still operating against the SAG. The Seahawk is the SAG's primary anti-submarine weapon and will not be given other tasks until such time that the threat from submarines has been eliminated.

The method used to determine the effects of PENGUIN attacks is different than that used for TOMAHAWKs. A maximum of two PENGUINs can be launched from a single helicopter at any given time. With the salvo size a known quantity, the engagement process between the PENGUIN and the target's defenses is clearly defined. The variable salvo size that makes up TOMAHAWK attacks demands that the effects of missile saturation on ship defenses be considered.

Ships that survive engagements with helicopters face the last of the SAG's anti-ship weapons; the HARPOON missile. It possesses a shorter (60 miles) range and a smaller (500 lb) warhead than the TOMAHAWK, but is similar in its capabilities. Like the TOMAHAWK, the HARPOON has several different attack profiles. Either the missile performs a pop-up maneuver in order to attack the target while in a steep dive, or it drops altitude to just above sea level in order to strike the target at the waterline. Pop-up maneuvers are effective because the missile ascends above the angle that the target's radar can scan at that distance from the ship. A HARPOON in sea skimming mode can hide from the target's radar in the electronic noise caused by radar waves reflected off the surface of the water. Both attack profiles minimize the chance that the HARPOON can be tracked and engaged.

Another capability of both HARPOON and TOMAHAWK is the ability to be programmed prior to launch to fly a given route to the target via a series of defined waypoints. By having missiles in the salvo fly different routes and attacking the target from multiple directions, the target's defenses are spread out, reducing reaction time and increasing the chance that a hit can be scored. These capabilities are reflected in the model by the missiles' probability of kill values.

Unlike SM-2s and TOMAHAWKs, HARPOONs cannot be launched from the VLS. Instead, they are usually stored and launched from deck mounted canisters, up to eight missiles per ship.

This means that there is a limited number of HARPOONs available to the SAG. This is accounted for in the model by placing an upper limit on the number of HARPOONs that can be fired at targets and is dependent upon the number of ships used to comprise the SAG.

The cruise missiles carried by enemy combatants have roughly the same range as that of the HARPOON. The assumption is made that any hostile ship which survives attacks by missile armed helicopters will be able to launch its own missiles prior to being hit by HARPOONs. The ships that survive TOMAHAWK and helicopter attacks, and are able to locate and target the SAG, will then launch their own missiles. Four missiles, the nominal loadout, are presumed to be launched per strike. This simulates that, if the SAG is detected, all of the units will be detected and multiple targets will be presented; and that the ship will fire all of its missiles at the first opportunity in order to disengage from the SAG and increase its own chances for survival.

Surface ships which get underway and survive the various attacks launched by the SAG, but did not target the SAG and still possess their weapons, remain at sea and are included in the number of ships that sortie during the next time iteration. At this point, they are subject to the same attack sequence from the SAG as ships just getting underway. Having penetrated into the SAG's inner defense zone, it is assumed that they would be the primary surface threat and all of the SAG's available resources would be dedicated to eliminating this more imminent threat.

Submarine Threat Module

Submarines are particularly dangerous to the SAG because of the stealth in which they can operate. Modern diesel submarines are very quiet, and depending on the environmental conditions of the water in which they operate, they can be next to impossible to detect.[23] Nuclear submarines are too complex and expensive to be maintained by the countries being evaluated and are not reflected in the model.

Diesel submarines can be armed with torpedoes and/or cruise missiles. Cruise missile equipped submarines can be considered the most dangerous of all threats to the SAG because of their armament and capability to remain undetected up to the point it launches its weapons. Torpedoes, however, are potentially more lethal than cruise missiles because the damage they can do is more likely to severely cripple, if not actually sink its target. There are also less countermeasures which can be taken by the target to defend itself against the torpedo.

The model evaluates two types of submarines (Figure 7). The first include submarines (SSG) armed with both cruise missiles and torpedoes. These submarines will attempt to launch their cruise missiles at maximum range before closing with the SAG in order to make torpedo attacks. The second type of submarine (SS) is armed only with torpedoes.

The engagement sequence against submarines in the model is similar to that used for hostile surface ships. The first factor to be considered being the ability of the submarine to get underway. This is dependent on the same material readiness and port services values that are used to determine the underway capability of surface ships.

Once underway, the goal of the submarine is to remain undetected until it can launch it weapons. Cruise missiles carried by SSGs are usually submarine launched versions of the types carried by surface ships and have comparable ranges, so SSGs must approach to within approximately 60 miles of the SAG. Submarines armed only with torpedoes, however, must come within several thousand yards of its target before they can launch their torpedoes.

The SAG has two primary submarine detection systems, sonars and helicopters. Each ship in the SAG has two separate sonar systems and, with the exception of DDG-51 class destroyers, can operate up to two helicopters. Hull mounted sonars have both an active and passive search capability. Active sonar search is the process of transmitting an acoustic signal to detect a target. Like transmitting radars, active sonar search potentially provides more information to hostile forces than it gathers and is used primarily only to obtain final targeting data. Passive search relies on the sonar's ability to detect sounds in the water whereupon computers are used to assist the operator in determining the nature of the sound. Depending on environmental conditions, passive search can detect targets at much greater ranges than active search and at the same time does not divulge any information that can be received by enemy units. The second sonar system available is an extremely capable passive search system. It consists of a 5000 ft cable containing an array of hydrophones that is towed behind the ship. Removed from the noise that is generated by the ship, the towed array can pick up weaker signals at longer ranges than hull mounted sonars. A primary reason why units in the SAG would be spread out over some miles, weakening the SAG's overall area air defense capability, is to provide maneuvering room and improve passive search performance for ships with a deployed towed array.

A ship's ability to detect and target a submarine is greatly enhanced by the presence of anti-submarine warfare (ASW) helicopters. The SH-60 Seahawk has a range of 150 miles, can carry two air-dropped torpedoes, sonobuoys, and has an electronic ability to process the information obtained by sonobuoys and transmit it back to the ship. After a contact is detected by ship sensors, a helicopter can be dispatched to the scene in order to assist in the determination on whether the contact is in fact a hostile submarine. Sonobuoys carried onboard the helicopter are dropped in the water and perform as miniature active and/or passive sonar systems. The information they gather is transmitted to the helicopter and then relayed to the ship. Should the new information indicate that a submarine has indeed been located, the helicopter is in a position to immediately execute an attack by dropping its torpedo. The helicopter thus extends the range in which submarines can be engaged, enough so that the SAG has the potential to strike against those submarines before they can launch their own weapons.

Both SS and SSG type submarines must therefore first penetrate the area patrolled by SAG helicopters. The ability to detect one of these submarines is dependent upon the number of SAG ships and helicopters still operational. Ships that have their helicopter available have a better probability of detecting a submarine than ships whose helicopter has been destroyed or damaged.

In the model, submarines which are detected are attacked first with helicopters. The number of helicopters available to perform ASW duties is determined by the number of surviving ships which can still operate helicopters and the number of helicopters which have not suffered a critical mechanical breakdown. Weapon hits on the SAG are the factor which impacts a ship's ability to carry on flight operations and takes into account the damage sustained by the helicopter itself, hanger facilities and flight deck, and ship's list due to flooding.

Under combat situations, SAG helicopters are expected to operate continuously with little or no access to spare parts other than what is normally carried onboard ship. The chance of mechanical failure occurring that would permanently ground the helicopter increases as a function of the amount of time the helicopter must fly at an increased tempo. A helicopter attrition function is included in the model to represent the effects of continuous operations on helicopter availability.

A helicopter will attack a sub by dropping a MK46 lightweight torpedo, which will then seek out and home in on the target. Because the MK46 torpedo is not an exceptionally powerful weapon, and newer submarines have stronger hulls, the damage inflicted by MK46 torpedoes may not be enough to render it incapacitated. The probability the submarine will survive a helicopter engagement thus depends on the probability of its being detected, the number of helicopters performing ASW duties, and the probability that the torpedo will hit and seriously damage the submarine.

Cruise missile submarines are now in a position to make a missile attack. The submarine must have detected the SAG prior to an attack, at which time it can launch its full complement of missiles. Probability of detection is based on the sophistication of the submarine's sensors, crew competence, and the ability of the submarine to obtain targeting data from other sources afloat or ashore. Submarine launched missiles are treated like all other cruise missiles and are detected and engaged by the SAG in the same manor.

SSGs which do not obtain targeting information during the first time iteration are available the next iteration and are added to those submarines which just got underway. Those which did launch their missiles are still armed with torpedoes and are treated as available SS during the next time interval.

Submarines attempting to conduct torpedo attacks must first survive engagements with the SAG's primary shipboard ASW weapon, the Vertical Launched ASROC (VLA). Essentially a MK46 torpedo with an attached rocket booster, it can be launched at a target out to a distance of 5 miles, farther than the range of most submarine launched torpedoes. This gives the SAG a first strike capability against any SS which penetrate the helicopter's defensive barrier, given the SAG can maintain contact with the submarine. The means in which an SS is detected and attacked is the same as for an SSG. The loss of helicopters to search for submarines at nearer distances is compensated by the increased detection capability of shipboard sonars at closer range. VLA attacks are conducted as are MK46 because only the method of delivery has changed.

Submarines which survive VLA attacks are now able to launch their own torpedoes. The number of torpedoes which are fired during a time iteration is dependent on the number of SS which obtained enough information to target at least one unit in the SAG, and the number of torpedoes per salvo. Submarines which did not acquire sufficient targeting data to make an attack are available to attempt one in the next time period.

A ship in the SAG attacked with torpedoes has only one countermeasure, the use of a towed noisemaker called Nixie. The purpose of this system is to make a large enough acoustic signal so that the torpedo homes in on the noisemaker instead of the ship. The major drawback to Nixie is the time it takes to deploy it. Should the noisemaker work and manage to decoy a torpedo, thereby being destroying also, time must be expended in preparing another to be deployed.

Torpedoes that actually hit the SAG are the product of the number of torpedoes launched and the probability that the torpedo is not decoyed or is not a dud. A torpedo damage factor is calculated which determines the actual impact of a torpedo hit on ship availability.

The last factor involved in the submarine engagement process are Urgent VLA attacks. Because of the distinctive noise caused by the launching of torpedoes underwater, ships in the SAG may be able to localize on the sound and launch a

VLA almost immediately. The submarine torpedo launch and VLA launch are considered simultaneous.

SAG Availability Module

The goal of this model is to determine whether or not the SAG can survive in a given threat environment, where survivability in the model is measured in terms of the number of ships in the SAG that are still available to operate effectively (Figure 8). All weapons that penetrate the SAG's defenses reduce that level of availability. Each type of weapon; torpedo, bomb, and cruise missile, is evaluated for its reliability and lethality. This is reflected in the probability of the weapon actually impacting the target and by assigning it damage factor modifier. The damage that each weapon can cause is dependent on such factors as the size of the warhead, what part of the ship is likely to be hit by a particular type of weapon, and the relative ability of the ship's crew to conduct damage control repairs. Damage caused by a torpedo hit, which would include massive flooding of large spaces, fuel oil fires, and loss of maneuvering capability, is different from that caused by cruise missiles. Here, the main threat is damage to the ship's command and control functions, weapon and sensor systems, and damage control facilities.

During each time iteration, the number of weapon hits is calculated and the impact on the number of ships to be combat effective is determined. Because the SAG will be comprised of between three to five combatants, a loss of one or more ships would have a critical impact on the ability of the SAG to carry out its mission. Losses impact the number of ships still available for combat, search and detection capabilities, and helicopter operations.

SECTION 5

SIMULATION RESULTS

The Scenarios

After the computer model was constructed and debugged (Appendix A), several scenarios were drafted intended to test both the SAG's suitability as a feasible solution and the validity of the model itself. Three different scenarios were ultimately tested. The first scenario, ARGENTINA 1982, simulated a Falkland Islands War campaign in which the SAG was substituted in place of the original British Royal Navy. The threats faced by the SAG in this scenario consisted of a large number of conventional bombers, a respectable number of surface launched cruise missiles, and a small number of submarines. The scenario assumed that the Argentine surface fleet would actively seek out combat, a fact that did not occur historically.

This scenario was also used to validate the model because of the amount of historical data which existed for this conflict. Royal Navy capabilities and tactics were directly mapped and compared to the same attributes possessed by the proposed SAG. By evaluating the relative strengths and weaknesses of the two forces made evident by the comparison, the actual results experienced by the Royal Navy and the simulated results experienced by the SAG in the model could be compared and used to determine the credibility of the model.

The second scenario, IRAQ 1990, simulated the presence of a SAG operating in the Persian Gulf on the eve of the Iraqi invasion of Kuwait in 1990. The scenario assumed that the SAG would come to the immediate aid of Kuwait and that hostilities between United States and Iraq forces would then result. The threats faced by the SAG in this scenario consisted of a large number of aircraft armed with both gravity bombs and cruise missiles, and a substantial number of surface and ground launched cruise missiles.

The third scenario, COMPREHENSIVE THREAT, matches the SAG against a well balanced threat. The comprehensive threat possesses a medium size and well rounded air force, with comparable surface and submarine forces. Although no specific nation fields such capabilities, it is a useful scenario for determining in what warfare area the SAG is particularly weak and what actions might be taken to make the SAG more survivable.

Identifying Variable and Baseline Values

There are approximately thirty variables associated with the numbers and capabilities of hostile forces which must be accounted for in the model. These values remained constant for all simulation runs executed for that particular scenario. Table 2 provides a list of these values for all three scenarios. A description of each variable is provided in Appendix B. Numerous sources were available to provide an accurate order of battle for both Argentine and Iraqi forces. Values representing the capabilities of these units and associated weapons were derived where possible from actual combat results documented in such unclassified sources as historical references and trade journals. Where values could not be obtained from historical sources, they were often derived from one of several wargames dealing with modern tactical naval warfare. Of particular usefulness was the HARPOON game system developed by Lawrence Bond. A wealth of technical data was also obtained from the various military reference books published by the Janes Information Group.

In order to measure the relative effectiveness of various SAG configurations, baseline values were assigned to all SAG decision variables (Table 3). Having four ships comprise the baseline SAG is based on the minimum number assumed necessary to provide unit cohesiveness and that also provides sufficient magazine space for the required missile loadout. The four ships which comprise the baseline SAG include one CG-47 cruiser, one DDG-51 destroyer, one DD-963 destroyer, and one FFG-7 frigate (Table 1). The baseline configuration also assumed that these ships would deploy with their normal compliment of helicopters, each ship carrying one with the exception of the DDG-51 which has no onboard helicopter capability. Baseline salvo sizes for the various missile types represent the assumed minimum needed to obtain noticeable results.

Results from Running the Simulation

Numerous iterations were run for each of the three scenarios and the results from each were combined in order to obtain a comprehensive assessment on the feasibility of the SAG concept. Each scenario was first run against the baseline SAG configuration. After the results of this initial run were studied, SAG decision variables were altered as means to find configurations that would provide a better solution. Because the three scenarios impacted the baseline SAG in different ways, different approaches were taken to counter the various discovered deficiencies. As a result, a configuration that may have been tried as a feasible alternative for one scenario may not have been tried at all in a second scenario if previous results indicated that line of reasoning would produce worse results than had already been established. The configurations that provided either the most desired outcomes or the most important insights into the dynamics of the model are identified in Tables 4,5, and 6. From these simulation runs certain lessons learned about SAG performance in the various warfighting categories can be stated.

The first lesson learned from the results was that the SAG cannot survive the determined onslaught of 150+ warplanes. Although 85% of attacking aircraft were shot down, enough ordnance got through the SM2 and point defense zones so that multiple ships were taken out of action. This outcome was most readily apparent in the IRAQ 1990 scenario where the number of aircraft encountered was simply more than a full load of anti-aircraft missiles and point defense weapons could handle. Attempts to compensate by adding an extra ship to the SAG and increasing the number of SM2s per salvo were insufficient and the SAG was still destroyed. Two points should be noted, however, that would influence these results in the real world. The first point is that the model does not take into account the political ramifications inherent in the total annihilation of a large part of a nation's military. While the model does test a worst case situation where all available military hardware is thrown into the battle, in reality a political/military decision would probably be made to terminate attacks that result in such massive casualties.[24]

The second point also encompasses the second lesson learned. The use of TLAM strikes on airfields had a minimal effect on the number of aircraft that were able to launch ordnance. This was a result of the policy that allowed the hostile nation to conduct the first strike as a significant amount of damage to the SAG was caused by aircraft that sortied on the first day. Since SAG defenses destroyed the vast majority of aircraft in the air, the number of surviving aircraft destroyed or unable to sortie due to subsequent TLAM strikes was therefore quite small. The use of TLAMs against aircraft, then, would be effective only if TLAMs were themselves used as a first strike weapon. Otherwise, they would best be used against other strategic targets not related to the naval campaign.

Of the three types of weapons launched at the SAG the one that proved to be the most dangerous in terms of damage caused per weapon platform was the torpedo. Whereas large numbers of aircraft or cruise missiles had to be launched so that some were able to penetrate the SAG's defenses, the relatively few submarines in the COMPREHENSIVE THREAT and ARGENTINE 1982 scenarios inflicted a high percentage of the damage sustained by the SAG. A comparison of the relative effectiveness of the different weapon types based on the number of weapon platforms necessary to achieve hits is examined in Table 7. Cruise missiles were dangerous if launched but lost their impact as the number units that carried them were destroyed. Surface ships, the largest potential source of cruise missiles, were easily countered by TOMAHAWK missiles and helicopters so that most were destroyed before they could launch their own missiles. Bombers were completely wiped out in their effort to drop their bombs and were the least efficient form inflicting damage on the SAG. However, as explained above, shear numbers were sufficient to inflict an unacceptable amount of damage.

Conclusions

Previous experiences in naval combat modeling indicate that many conflicts entail low numbers of involved units and that final engagements are quick, intense, and decisive.[25] Results obtained from multiple SAGDEM simulation runs also exhibited this type of behavior. The premise that the opposing force would commence hostilities with an all out first strike led to both sides incurring what would probably be considered unacceptable losses. While it is doubtful that such levels of attrition would be acceptable in any real world situation, the assumption is still valid for modeling purposes in order to determine the maximum amount of damage that would be sustained by the SAG in a given threat environment. It is also difficult to accurately predict to what limits a political leader will in the end push his armed forces, so that the worse case situation is desireable for that reason alone.

The model demonstrated that the SAG suffered too many

TABLE 2

VALUES FOR SPECIFIC VARIABLES

	ARGENTINA 1982	IRAQ 1990	COMPREHENSIVE THREAT
AC	6	20	24
CM_AC	1	2	2
LRCMBMB	0	0	12
LRCM_AC	0	0	1
CM_LOCK	0.95	0.90	0.90
BOMBER	134	202	48
BOMBDAMFACT	0.3	0.3	0.3
BOMBPAC	2	2	2
BOMBACCURACY	0.2	0.2	0.2
AFREPRATE	0.15	0.15	0.15
MNTREPRATE	0.05	0.05	0.05
NUMBERLNCHR	2	10	10
DDGAVAIL	9	0	5
SURFPORT	1.0	1.0	1.0
SURFMAINT	0.8	0.7	1.0
DETTGT	0.7	0.8	0.7
CMPERDDG	4	0	4
PCAVAIL	0	8	10
CMPERPC	0	4	4
DEFCM	0.25	0.25	0.25
SSGAVAIL	0	0	3
SSAVAIL	3	0	6
SUBMAINT	1.0	0	1.0
SUBPORT	1.0	0	1.0
SSGDETTGT	0	0	0.7
SLCM_SSG	0	0	8
SSDETTGT	0.9	0	0.9
TORPSALVO	2	0	2
TORPDAMFACT	0.3	0	0.3
SSTORPHIT	0.6	0	0.6
CMDAMFACT	0.3	0.3	0.3
PROBLAU	0.2	0.4	0.4
SSSOPHIST	0.2	0	0.3

TABLE 3

SAG BASELINE DECISION VARIABLES

Number of ships which comprise the SAG (SHIPSAVAIL)	4
Number of helicopters available (HELOSAVAIL)	3
Number of SM2s launched per aircraft (SMPERAC)	1
Number of SM2s launched per cruise missile (SMPCM)	1
Number of TASMs launched per destroyer (TASMPERDDG)	2
Number of TASMs launched per patrol craft (TASMPERPC)	2
Number of HARPOONs launched per destroyer (HARPPDDG)	2
Number of HARPOONs launched per patrol craft (HARPPPC)	2

TABLE 4

SIMULATION RESULTS
SAG VS ARGENTINA 1982

SAG POLICY	SAG LOSSES AFTER 5 DAYS COMBAT	MISSILES AVAILABLE	MISSILES EXPENDED
Baseline with minimum SM2 inventory	2.3	315	SM2 163 TLAM 42 TASM 19 VLA 4 HARPOON 4 232
Increase available ships/helicopters SHIPSAVAIL = 5 HELOSAVAIL = 4 Increase SM2 salvo per aircraft SM2PERAC = 2	0.8	400	SM2 296 TLAM 42 TASM 19 VLA 2 HARPOON 4 361
Decrease available ships/helicopters SHIPSAVAIL = 3 HELOSAVAIL = 2	3.0	275	SM2 163 TLAM 42 TASM 19 VLA 9 HARPOON 5 238
Double available helicopters HELOSAVAIL = 6	1.9	315	SM2 163 TLAM 42 TASM 18 VLA 1 HARPOON 4 228
TASM salvo against ships increased TASMPERDDG(PC) = 3	2.2	315	SM2 161 TLAM 42 TASM 27 VLA 4 HARPOON 2 236

TABLE 4
(cont)

SIMULATION RESULTS
SAG VS ARGENTINA 1982

SAG POLICY	SAG LOSSES AFTER 5 DAYS COMBAT	MISSILES AVAILABLE	MISSILES EXPENDED
Baseline with minimum SM2 inventory No TLAM strikes against airfields	2.3	315	SM2 168 TLAM 0 TASM 19 VLA 4 HARPOON 4 193

TABLE 5

SIMULATION RESULTS
SAG VS IRAQ 1990

SAG POLICY	SAG LOSSES AFTER 5 DAYS COMBAT	MISSILES AVAILABLE	MISSILES EXPENDED
Baseline with minimum SM2 inventory	3.7	315	SM2 250+ TLAM 51 TASM 16 VLA 0 HARPOON 1 315+
Increase available ships/helicopters SHIPSAVAIL = 5 HELOSAVAIL = 4	3.0	400	SM2 275 TLAM 51 TASM 16 VLA 0 HARPOON 0 341
Increase available ships/helicopters SHIPSAVAIL = 5 HELOSAVAIL = 4 Increase SM2 salvo per aircraft SM2PERAC = 2	4.6	400	SM2 350+ TLAM 51 TASM 0 VLA 0 HARPOON 3 400+
Double available helicopters HELOSAVAIL = 6	3.7	315	SM2 250+ TLAM 51 TASM 16 VLA 0 HARPOON 0 315+

TABLE 5
(cont)

SIMULATION RESULTS
SAG VS IRAQ 1990

SAG POLICY	SAG LOSSES AFTER 5 DAYS COMBAT	MISSILES AVAILABLE	MISSILES EXPENDED
Increase available ships/helicopters SHIPSAVAIL = 5 HELOSAVAIL = 4 Increase SM2 salvo per aircraft SM2PERAC = 2 No TLAM strikes against airfields No TASMs against surface ships	4.6	400	SM2 400+ TLAM 0 TASM 0 VLA 0 HARPOON 5 400+

TABLE 6

SIMULATION RESULTS
SAG VS COMPREHENSIVE THREAT

SAG POLICY	SAG LOSSES AFTER 5 DAYS COMBAT	MISSILES AVAILABLE	MISSILES EXPENDED
Baseline with minimum SM2 inventory	4.0	315	SM2 179 TLAM 51 TASM 31 VLA 29 HARPOON 10 300
Double available helicopters HELOSAVAIL = 6	4.0	315	SM2 173 TLAM 51 TASM 31 VLA 17 HARPOON 10 282
Increase available ships/helicopters SHIPSAVAIL = 5 HELOSAVAIL = 8	3.5	400	SM2 169 TLAM 51 TASM 31 VLA 7 HARPOON 10 268
Increase available ships/helicopters SHIPSAVAIL = 5 HELOSAVAIL = 8 TASM/HARPOON salvo increased TASMPERDDG(PC) = 3 HARPPDDG(PC) = 3	3.3	400	SM2 162 TLAM 51 TASM 46 VLA 7 HARPOON 8 274

TABLE 6
(cont)

SIMULATION RESULTS
SAG VS COMPREHENSIVE THREAT

SAG POLICY	SAG LOSSES AFTER 5 DAYS COMBAT	MISSILES AVAILABLE	MISSILES EXPENDED
Increase available ships/helicopters SHIPSAVAIL = 5 HELOSAVAIL = 8 TASM/HARPOON salvo increased TASMPERDDG(PC) = 3 HARPPDDG(PC) = 3 Increase SM2 salvo per aircraft SM2PERAC = 2	2.7	400	SM2 226 TLAM 45 TASM 46 VLA 7 HARPOON 8 332
Increase available ships/helicopters SHIPSAVAIL = 5 HELOSAVAIL = 8 TASM/HARPOON salvo increased TASMPERDDG(PC) = 3 HARPPDDG(PC) = 3	3.3	400	SM2 162 TLAM 51 TASM 46 VLA 7 HARPOON 8 274
Increase available ships/helicopters SHIPSAVAIL = 5 HELOSAVAIL = 8 TASM/HARPOON salvo increased TASMPERDDG(PC) = 3 HARPPDDG(PC) = 3 Increase SM2 salvo per aircraft SM2PERAC = 2	2.7	400	SM2 226 TLAM 45 TASM 46 VLA 7 HARPOON 8 332

TABLE 6
(cont)

SIMULATION RESULTS
SAG VS COMPREHENSIVE THREAT

SAG POLICY	SAG LOSSES AFTER 5 DAYS COMBAT	MISSILES AVAILABLE	MISSILES EXPENDED
Increase available ships/helicopters SHIPSAVAIL = 5 HELOSAVAIL = 8 TASM/HARPOON salvo increased TASMPERDDG(PC) = 3 HARPPDDG(PC) = 3 No TLAM strikes agaianst airfields	4.1	400	SM2 208 TLAM 0 TASM 46 VLA 7 HARPOON 8 269

Table 7

DAMAGE INFLICTED ON SAG BY WEAPON TYPE
BASED ON NUMBER OF WEAPON PLATFORMS

Scenario	Torpedoes (Submarines)	Bombs (Aircraft)	Cruise Missiles (All Sources)
ARGENTINA 1982	0.127	0.010	0.013
IRAQ 1990	N/A	0.010	0.012
COMPREHENSIVE THREAT	0.175	0.008	0.024

Note: Numbers refer to the reduction in SAG Availability in the baseline configuration per weapon platform capable of launching the appropriate weapon.

losses to be a survivable force in the threat environments in which it was placed. With the exception of the ARGENTINA 1982 scenario, SAG configurations could not be found that would produce a viable force for that scenario. In the cases where the SAG was overwhelmed by the number of aircraft it encountered, the only solutions would be to increase the size of the SAG to that of a full carrier battlegroup, not economically viable, or send a carrier battlegroup itself. The SAG in the model was forced to dedicate too much of its magazine space for air defense missiles, leaving too little capability to strike targets ashore, one of the system requirements. Against such a large air threat the carrier battlegroup would be a better solution because of the extra layer of protection provided by carrier fighters performing combat air patrol.

While submarines were the most lethal weapon platforms and took their toll on the SAG when encountered, their relatively few numbers reduced their overall effectiveness and the SAG was able eliminate this threat over time. One possible refinement that would improve SAG survivability in this warfare area would be the inclusion of a friendly submarine in the SAG when hostile submarines are known to be present. Submarines are the best means of countering other submarines and lessons learned from their use in the newly formed Maritime Action Groups would prove beneficial.

SAGDEM demonstrated that there are obvious limits to the situations where the SAG is an effective fighting force capable of sustained operations. Results showed that while the SAG could be overwhelmed by numbers, the number of weapons that could be countered and the number of weapon platforms that could be engaged and destroyed was extremely high. High enough that it is likely that the level of attrition would cause the hostile nation to cease combat before the SAG would itself suffer too greatly. Additionally, the number of nations which posses the cababilities of those in the three scenarios is extremely small.

Although the SAG did not perform as desired in two of the three scripted scenarios, the SAG clearly demonstrated the ability to engage and destroy the vast majority of weapons it encountered. Because few nations will have both a large air force and a large submarine force, and because attrition to hostile forces will probably cause hostilities to cease before SAG losses become unacceptable, it is recommended that the SAG concept be considered a feasible alternative for the carrier battlegroup for certain situations. The SAG concept met system requirements in that in most configurations sufficient VLS magazine space was available for TLAMs to be used against strategic targets. Requirements were also met as existing weapon and electronic systems proved to be very capable of detecting and targeting all types of threats so that no new such systems would be required for the sole purpose of enhancing the SAG concept. Both the AEGIS weapon system and the Vertical Launching System proved to be valuable resources. Since the SAG suffered an undesirable number of losses in the COMPREHENSIVE THREAT scenario, it is also recommended that further simulations be performed to ascertain exactly what level of threat constitutes the maximum that the SAG would be considered a suitable force for.

SECTION 6

PROJECT SUMMARY

This project grew out of the desire to create a computer model that would utilize dynamic modeling techniques as a means of simulating modern naval warfare. A major goal of the project was to integrate the knowledge obtained in the Systems Engineering program with the author's professional and personal interests in the United States Navy. The design of the model was based primarily on the author's experience in and understanding of both tactical naval warfare and dynamic modeling techniques. The model thus represents his own interpretation of how naval combat at the tactical level can be modeled.

The Systems Engineering approach of identifying a problem and establishing system requirements was utilized and defined the process leading to the construction the model. Specifying the nature of the problem, that of finding a carrier battlegroup replacement, was relatively straight forward and much of the information used to define the statement of need and subsequent system requirements was obtained from the Navy white paper, "From the Sea..."

Only one feasible solution to the stated problem, that being the creation of the Surface Action Group, was evaluated in this project. The purpose of the project being more to examine dynamic modeling techniques than provide a detailed analysis of the early stages of the Systems Engineering process.

Once the SAG concept was developed, evaluation criteria were established to determine the eventual feasibility of the concept. It would not be time or cost effective to initially evaluate the SAG concept via at-sea testing and naval exercises. Modeling would thus be the most appropriate means of evaluating the concept and so a causal diagram representing the relationship between the SAG and the anticipated threat environment was developed. From the diagram a computer model was generated and input data was gathered from existing sources or from predictions and allocated to the appropriate variables. Results from the model are highly dependent on the source of the data and may be in error as most of the values assigned to various warfighting capabilities were extrapolated from unclassified sources. Scenarios were developed and a baseline SAG configuration chosen from which to compare the relative performance of different simulation runs. Data resulting from multiple simulation runs against different scenarios were then matched against the evaluation criteria to determine the feasibility of the SAG concept. A decision was then made as whether the SAG concept should be pursued farther.

Dynamic modeling and the Systems Engineering process proved to be valuable tools in organizing information so that the finished model was able to answer specific questions and provide useful feedback. The author feels that it would be highly beneficial to utilize these techniques in solving many of the problems concerning the allocation of limited resources faced by the military today. Such topics could include determining the size of ground forces that are still needed to be maintained in countries like Germany and South Korea and determining the necessary procurement amount and rate for new combat weapon systems.

ENDNOTES

1. "Clinton's Pledges," The Washington Post, 20 January 1993, The Federal Page, p.A19, col.1.

2. Benjamin S. Blanchard and Wolter Frabycky, Systems Engineering and Analysis, 2nd ed., (Englewood Cliffs, NJ: Prentice Hall, 1990), p.35.

3. The Honorable Sean O'Keefe, ADM Frank B. Kelso, GEN Carl E. Mundy, Jr., "...From the Sea," Proceedings, November 1992, pp. 93-96.

4. Sean O'Keefe, "Be Careful of What You Ask For...," Proceedings, January, 1993, p.74.

5. Robert Crawshaw, "What is a Maritime Action Group?," Proceedings, January, 1993, p.30.

6. Norman Polmar, "Going Downtown the Safe Way," Proceedings, August, 1992, p.105.

7. Norman Polmar, "Going Downtown the Safe Way," pp.105-106.

8. Averall M. Law and W. David Kelton, Simulation Modeling and Analysis, 2nd ed., (New York: McGraw-Hill, 1991), p.1.

9. Law and Kelton, Simulation Modeling and Analysis, p.7.

10. Wayne P. Hughes, Jr., ed, Military Modeling, Military Operations Research Society, 1984), pp.176-177.

11. Hughes, Military Modeling, pp.170-172.

12. Hughes, Military Modeling, p.175.

13. Hughes, Military Modeling, p.178.

14. Wayne p. Hughes, Jr., Fleet Tactics, (Annapolis, MD: Naval Institute Press, 1986), p.275.

15. Hughes, Fleet Tactics, p.253.

16. Hughes, Fleet Tactics, p.232.

17. Hughes Fleet Tactics, p.252.

18. Hughes, Fleet Tactics, p.196.

19. This is done to present a less dense target for cruise missiles and torpedoes, allowing ships to maneuver freely when under attack. It also provides better conditions in which to search for submarines as the noise produced by nearby ships degrades the performance of passive sonar systems.

20. David Brown, The Royal Navy and the Falklands War, (Annapolis, MD: Naval Institute Press), 1987.

Many of the variables used to simulate the relationship of tactical bombers against surface ships were derived from the combat experiences of the Falkland Island War in 1982 between British and Argentine forces. Argentine bombers would fly at sea level and pop up in altitude at the last moment in order to arm and launch their bombs. Tactical discipline was lax in that the first ship they encountered usually became the target, when the pilots should have been seeking the high value units. Since the British had no effective airborne early warning (AEW) system and limited air defense capabilities, many of the Argentine attack sorties were able to reach the point defense engagement zone before being engaged and were able to drop their bombs on the target. Still, the attrition rate was for these aircraft was extremely high and their effectiveness was reduced as the number of planes available to sortie diminished. Damage done by bombs hitting British ships was random and varied greatly. Some bombs failed to explode and merely fell through the ship creating a hole. Others struck magazines, started fires, or destroyed damage control facilities to the point where the ship had to be abandoned. Almost all of the Argentine aircraft used in the Falkland's War belonged to the air force. Of the aircraft which penetrated the target's defenses and were able to drop their bombs, only 25% scored hits. Of the bombs that hit, only 50% detonated.

21. Steve Froggett, "Tomahawk in the Desert," Proceedings, January 1992, p. 72.

Approximately 85% of the 288 TOMAHAWKS launched during the Persian Gulf War hit their target. This number is consistent with the number of TOMAHAWKS which hit their target during the retaliatory raid conducted in January, 1993.

22. It is known that some TOMAHAWKS were destroyed in the Persian Gulf War because the Iraqis had discovered that most missiles were entering Iraqi airspace from the same place. The need to quickly create pre-planned TOMAHAWK missions back in the US resulted in the same landfall point being used for the majority of missions created. As the war progressed, the Iraqis identified this point and were thus able to destroy some of the missiles as soon as they made landfall. Also several TOMAHAWKS got lost and did not reach

their targets because some landmarks used to navigate had been previously destroyed and were no longer identifiable.

23. The British Navy in the Falkland Island War expended over 150 anti-submarine weapons against mostly false targets during the course of the conflict. Only one Argentine diesel submarine was operating in the vicinity of British forces during that time.

24. Brown, The Royal Naval and the Falklands War.
A 20% attrition rate forced the Argentine Air Force to halt bombing attacks on the British task force.

25. Hughes, Fleet Tactics, p.7.

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APPENDIX A

SURFACE ACTION GROUP DEFENSE MODEL (SAGDEM)

COMPUTER PROGRAM

COMPREHENSIVE THREAT SCENARIO

```
* ****************************************************
* *  SURFACE ACTION GROUP DEFENSE MODEL  (SAGDEM)  *
* ****************************************************

* ******************************************
* *  CRUISE MISSILES LAUNCHED BY AIRCRAFT  *
* ******************************************

L AC.K=AC.J+DT*(-AC_KILLRATE.JK-TVSAC.JK)
*    cm carrying aircraft

N AC=24


R AC_KILLRATE.KL=ACLAUNCHED.K-ACLAUPT.KL
*    rate cm ac destroyed by sm2

A ACLAUNCHED.K=SORTIE.K*AC.K
*    cm aircraft launched/day

R ACLAUPT.KL=ACLAUNCHED.K-(ISTKILL.K*ACLAUNCHED.K/ACESM2R.K)
*    cm aircraft reach cm launch pt/day

A CMLAU.K=(ACLAUPT.Kl*CM_AC)+(LRCMLPT.Kl*LRCM_AC)
*    cruise missiles launched/day

A TOTALCM.K=CMLAU.K+LRCMLAU.K
*    combined cm & lrcm launched/day

A LRCMLAU.K=ACWLRCM.K*LRCM_AC*(1-SLQ32_LRCM)
*    long range cm launced/day

A ACWLRCM.K=LRCMBMB.K*SORTIE.K
*    lrcm ac launched/day

L LRCMBMB.K=LRCMBMB.J+DT*(-TVSLRCMBMB.JK-LRCMKILRTE.JK)
*    long range cm carrying aircraft

N LRCMBMB=12

A LRCMNOWCM.K=SLQ32_LRCM*ACWLRCM.K
*    long range cm carrying aircraft that enter sm2 range

R LRCMLPT.KL=(ISTKILL.K*LRCMNOWCM.K/ACESM2R.K)
*    long range cm carrying aircraft that survive sm2

R LRCMKILRTE.KL=LRCMNOWCM.K-LRCMLPT.KL
*    long range cm carrying aircraft shot down by sm2
```

```
c SLQ32_LRCM=0.1
*    ability of ew jamming to force lrcm aircraft to enter sm2
*    range

C CM_AC=2
*    cruise missiles/aircraft

C LRCM_AC=1
*    long range cm/aircraft

A SM2PK.K=TABLE(SM2EFF,SM2PERAC.K,1,3,1)
*    sm2 aaw msl probability of kill

T SM2EFF=0.70,0.90,0.97
*    sm2 effectiveness/salvo size

A SM2PERAC.K=1
*    sm2 salvo size

R SM2LAU1ST.KL=MIN(SM2PERAC.K*ACESM2R.K,SM2REMAIN.K)
*    sm2 launch vs ac

A ISTKILL.K=MIN(ACESM2R.K*SM2PK.K,SM2PK.K*^
           SM2REMAIN.K/SM2PERAC.K)
     number of ac enter sm2 range and destroyed

L SM2REMAIN.K=SM2REMAIN.J+DT*(-SM2LAU1ST.JK-SM2LAUCM.JK)
*    total sm2 launch

N SM2REMAIN=200

A ACESM2R.K=ACLAUNCHD.K+BOMBLAU.K+LRCMNOWCM.K
     number of all ac types enter sm2 range

* ****************************************************
* *  CRUISE MISSILES ENTERING SM2 ENGAGEMENT RANGE  *
* ****************************************************

L CM_KIA.K=CM_KIA.J+DT*(CMKILLRATE.JK)
*    cm destroyed by sm2

N CM_KIA=0

R CMKILLRATE.KL=MIN(CMESM2R.K*SM2PKCM.K,SM2LAUCM.KL*^
                    SM2PERCM.K)
*    sm2 prob of kill vs cm

A CMESM2R.K=TOTALCM.K+TOTGLCM.K+TOTSLCM.K+TOTSURFCM.K
*    total cm enter sm2 engage rng
```

```
A CMSURVSM2.K=CMESM2R.K-CMKILLRATE.KL
*    cm survive sm2 engagement

A SM2PKCM.K=TABLE(SM2EFCM,SM2PERCM.K,1,3,1)
*    sm2 prob of kill vs cm

T SM2EFCM=0.5,0.75,0.85
*    sm2 effectiveness/salvo size

A SM2PERCM.K=1
*    salvo size

R SM2LAUCM.KL=MIN(CMESM2R.K*SM2PERCM.K,SM2REMAIN.K^
                -SM2LAU1ST.KL)
*    #sm2 launched vs cruise missiles

A CMAQTGT.K=CMSURVSM2.K*CMLOCK
*    cm that aquire ship

C CMLOCK=0.95
*    cm guidance set lock on prob

A CMSURVPDEF.K=CMAQTGT.K*(1-PDEFPKCM.K)
*    cm survive point defense wpns

A PDEFPKCM.K=1-(1-CIWS_CM.K)(1-GUNS_CM.K)(1-SLQ32_CM.K)
*    point defense prob of kill

A CIWS_CM.K=TABLE(CIWSEFCM,CMAQTGT.K,0,100,50)
*    probability close-in weapon system kill cruise missile

T CIWSEFCM=.70,.60,.50
*    CIWS kill probability based on # cruise missiles inbound

A GUNS_CM.K=TABLE(GUNSEFCM,CMAQTGT.K,0,100,50)
*    probability guns kill cruise missile

T GUNSEFCM=.20,.15,.10
*    gun kill probability based on # cruise missiles inbound

A SLQ32_CM.K=TABLE(SLQ32CM,CMAQTGT.K,0,100,50)
*    probability electronic warfare kill cruise missile

T SLQ32CM=.40,.30,.20
*    elctronic warfare kill probability based on # cruise
*    missiles inbound

A CMHITS.K=CMSURVPDEF.K*CMDAMFACT
*    cm hits on ship
```

```
C CMDAMFACT=0.30
*    amount cm hit affects ship availability


* **************************************************
* *  BOMBERS CARRYING CONVENTIONAL GRAVITY BOMBS   *
* **************************************************

LBOMBER.K=BOMBER.J+DT*(-BSHOTDOWN.JK-BKILLPDEF.JK-TVSBMB.JK)
*    bomb carrying aircraft

N BOMBER=48

R BKILLPDEF.KL=BSURVSM2.Kl*PDEFPKAC.K
*    bmb kill by point def/day

R BSHOTDOWN.KL=BOMBLAU.K-BSURVSM2.KL
*    bmb kill inbound by sm2/day

A BOMBLAU.K=BOMBER.K*SORTIE.K
*    bombers launched/day

R BSURVSM2.KL=BOMBLAU.K-(ISTKILL.K*BOMBLAU.K/ACESM2R.K)

*    inbound bombers survive sm2

A BSURVPDEF.K=BSURVSM2.KL*(1-PDEFPKAC.K)
*    bombers survive point defense

A PDEFPKAC.K=1-(1-CIWS_AC.K)(1-GUNS_AC.K)
*    point defense prob of kill

A CIWS_AC.K=TABLE(CIWSEFAC,BSURVSM2.KL,0,100,50)
*    probability close-in weapon system kill aircraft

T CIWSEFAC=.70,.60,.50
*    CIWS kill probability based on # aircraft inbound

A GUNS_AC.K=TABLE(GUNSEFAC,BSURVSM2.KL,0,100,50)
*    probability guns kill aircraft

T GUNSEFAC=.30,.20,.10
*    gun kill probability based on # aircraft inbound

A BMBHITS.K=(BSURVPDEF.K*BOMBPAC*BMBRACCURACY)*BMBDAMFACT
*    The number of bombs that strike target

c BMBDAMFACT=0.30
*    amount bomb hit affects ship availability
```

```
C BOMBPAC=2
*    bombs per aircraft

C BMBRACCURACY=0.20
*    probability a released bomb will strike target

* ****************************************
* *  AIRCRAFT SORTIE CAPABILITY BASED ON  *
* *      DAMAGE CAUSED BY TOMAHAWKS       *
* ****************************************

A SORTIE.K=(AFAVAIL.K+MAINTAVAIL.K)/2
*    no. of times ac can launch/day

A AFAVAIL.K=1-AFDAMAGE.K
*    airfield avail to launch ac

L AFDAMAGE.K=AFDAMAGE.J+DT*(TLMDDAMRTE.JK-AFREPRATE.JK)
*    total damage to airfield

N AFDAMAGE=0

R TLMDDAMRTE.KL=TLMDLAU.K*TLMSUCC*DPERD.K
*    tlam-d damage rate to airfield

C TLMSUCC=0.85
*    tlam prob of hitting target

A DPERD.K=NORMRN(0.04,0.02)
*    airfield damage/cm

R AFREPRATE.KL=CLIP(.15,(AFDAMAGE.K),AFDAMAGE.K,.15)
*    airfield repair rate

A MAINTAVAIL.K=1-MAINTDAMAGE.K
*    ac maintenance capability

L MAINTDAMAGE.K=MAINTDAMAGE.J+DT*(TLMCDAMRTE.JK-MNTREPRATE.JK)

N MAINTDAMAGE=0
*    damage to maint capability

R TLMCDAMRTE.KL=TLMCLAU.K*DPERC.K*TLMSUCC
*    tlam-c damage rate to maint

A DPERC.K=NORMRN(0.04,0.02)
*    maint facility damage/cm

R MNTREPRATE.KL=CLIP(.05,(MAINTDAMAGE.K),MAINTDAMAGE.K,.05)
```

```
*    maint fac repair rate

A
TLMDLAU.K=CLIP(MAX(0,(1-AFDAMAGE.K)/DPROBDEST),0,TOTALAC.K,1)
*    no. tlam-d launched/day

C DPROBDEST=0.04
*    prob destruction per TLAM-D

A TLMCLAU.K=CLIP(MAX(0,(1-MAINTDAMAGE.K)/CPROBDEST),0,^
                 TOTALAC.K,1)
*     -no. tlam-c launched/day

C CPROBDEST=0.06
*    prob destruction per TLAM-C

* *******************************************************
* *  TOMAHAWK LAUNCHES AND PLANES KILLED ON THE GROUND  *
* *******************************************************

A TLMCKILRATE.K=TLMCLAU.K*TLMCPK.K
*    tlam-c rate ac kill on ground

A TLMDKILRATE.K=TLMDLAU.K*TLMDPK.K
*    tlam-d rate ac kill on ground

ATLMCPK.K=TABLE(C_ACDENSITY,TOTALAC.K*(1-SORTIE.K),0,240,40)
*    prob #ac killed/tlam-c

T C_ACDENSITY=0,.33,.36,.40,.45,.50,.60
*    prob ac destroyed based on # present

ATLMDPK.K=TABLE(D_ACDENSITY,TOTALAC.K*(1-SORTIE.K),0,240,40)
*    prob #ac killed/tlam-d

T D_ACDENSITY=0,.40,.45,.50,.55,.60,.65
*    prob ac destroyed based on # present

A CMBKILLS.K=TLMDKILRATE.K+TLMCKILRATE.K
*    combined ac kill by tlam

A TOTALAC.K=AC.K+LRCMBMB.K+BOMBER.K
*    total enemy aircraft

A FRACLRCMBMB.K=LRCMBMB.K/TOTALAC.K
*    fraction that carry lrcm

A FRACAC.K=AC.K/TOTALAC.K
*    fraction that carry cm
```

```
A FRACBOMBER.K=BOMBER.K/TOTALAC.K
*    fraction that carry grav bombs

R TVSLRCMBMB.KL=MIN(FRACLRCMBMB.K*CMBKILLS.K,LRCMBMB.K*^
                    (1-SORTIE.K))
*    lrcm bombers destroyed by TOMAHAWKS

R TVSAC.KL=MIN(FRACAC.K*CMBKILLS.K,AC.K*(1-SORTIE.K))
*    cm bombers destroyed by TOMAHAWKS

R TVSBMB.KL=MIN(FRACBOMBER.K*CMBKILLS.K,BOMBER.K*(1-SORTIE.K))
*    bombers destroyed by TOMAHAWKS

R TLMLAURATE.KL=TLMDLAU.K+TLMCLAU.K+LNCHRLOC.K
*    land-attack TOMAHAWKS launched per day

L TOTTLAM.K=TOTTLAM.J+DT*(TLMLAURATE.JK)
*    total land-attack TOMAHAWKS launched

N TOTTLAM=0

* ********************************************
* *  GROUND LAUNCHED CRUISE MISSILE LAUNCHES   *
* ********************************************

A TOTGLCM.K=LNCHRFIRED.KL*MSL_LNCHR
*    ground launched cruise missiles launched

C MSL_LNCHR=4
*    glcms/launcher

R LNCHRFIRED.KL=PROBLAU*MAX(0,NUMBERLNCHR.K)
*    rate at which glcm launchers are expended

C PROBLAU=0.30
*    prob glcm launcher will launch missiles

LNUMBERLNCHR.K=NUMBERLNCHR.J+DT*(-TLAMDEST.JK-LNCHRFIRED.JK)
*    number of launchers available

N NUMBERLNCHR=10

R TLAMDEST.KL=LNCHRLOC.K*TLMSUCC
*    rate glcm launchers are destroyed by TOMAHAWKS

A LNCHRLOC.K=PROBLAU*NUMBERLNCHR.K*SATDET
*    prob of locating a glcm launcher
```

```
C SATDET=0.50
*    prob deployed glcm launcher detected by satellite


* ********************************************************
* *  SURFACE LAUNCHED CRUISE MISSILES (DDG/PC)         *
* *  TASM,HARPOON,AND HELECOPTER ENGAGEMENTS           *
* ********************************************************

L DDGAVAIL.K=DDGAVAIL.J+DT*(-DDGUW.JK+DDGDAY2.JK)
*    number destroyer sized ships avail

N DDGAVAIL=5

A SURFSORTIE.K=(SURFMAINT+SURFPORT)/2
*    number surface ships that sortie

C SURFPORT=1.0
*    percent port facilities avail

C SURFMAINT=0.90
*    percent ship maintenance fac avail

R DDGUW.KL=(SURFSORTIE.K*DDGAVAIL.K)
*    rate destroyers get underway

A DDSURVTASM.K=DDGUW.KL*(1-TASMDMSNPK.K)*PROBSURFDET.K
*    destroyers survive anti-ship TOMAHAWKS

A TASMDMSNPK.K=TABLE(TASMDEFF,TASMPDDG.K,1,4,1)
*    prob TOMAHAWKS incapacitate destroyers

T TASMDEFF=.50,.75,.85,.90
*    prob incapacitate destroyer per salvo size

R TASMLAU.KL=DDGUW.KL*TASMPDDG.K
*    rate at which anti-ship TOMAHAWKS launched at destroyers

A TASMPDDG.K=2
*    TOMAHAWK salvo size per destroyer

L TOTTASM.K=TOTTASM.J+DT*(TASMLAU.JK+PCTASMLAU.JK)
*    total anti-ship TOMAHAWKS launched

N TOTTASM=0

A DDGSURFCMLAU.K=DDSURVHELO.K*DETTGT*CMPERDDG
*    destroyers which launch cruise missiles
```

```
C DETTGT=0.7
*    Prob destroyer detects target

C CMPERDDG=4
*    cruise missiles per destroyer

A DDSRVHARPOON.K=DDSURVHELO.K*(1-HARPDMSNPK.K)
*    destroyers that survive HARPOON attacks

A HARPDMSNPK.K=TABLE(HARPDEFF,HARPPDDG.K,1,4,1)
*    prob HARPOON incapacitate destroyer

T HARPDEFF=.40,.65,.80,.90
*    prob incapacitate destroyer per salvo size

R DDGHARPLAU.KL=MIN(DDSURVHELO.K*HARPPDDG.K,HARPREMAIN.K)
*    rate HARPOON launched against destroyers

A HARPPDDG.K=2
*    HARPOON salvo size per destroyer

L TOTHARP.K=TOTHARP.J+DT*(DDGHARPLAU.JK+PCHARPLAU.JK)
*    total HARPOONS launched

N TOTHARP=0

R DDGDAY2.KL=DDSRVHARPOON.K*(1-DETTGT)
*    rate destroyers survive to fight next day

A TOTSURFCM.K=DDGSURFCMLAU.K+PCSURFCMLAU.K
*    total surface launched cruise missiles launched

L PCAVAIL.K=PCAVAIL.J+DT*(-PCUW.JK+PCDAY2.JK)
*    number patrol craft sized ships avail

N PCAVAIL=10

R PCUW.KL=(SURFSORTIE.K*PCAVAIL.K)
*    rate patrol craft get underway

A PCSURVTASM.K=PCUW.KL*(1-TASMPMSNPK.K)*PROBSURFDET.K
*    patrol craft survive anti-ship TOMAHAWKS

A TASMPMSNPK.K=TABLE(TASMPEFF,TASMPPC.K,1,4,1)
*    prob TOMAHAWKS incapacitate patrol craft

T TASMPEFF=.40,.65,.80,.90
*    prob incapacitate patrol craft per salvo size
```

```
R PCTASMLAU.KL=PCUW.KL*TASMPPC.K
*    rate at which anti-ship TOMAHAWKS launched per patrol
*    craft

A TASMPPC.K=2
*    TOMAHAWK salvo size per patrol craft

A PCSURFCMLAU.K=PCSURVHELO.K*DETTGT*CMPERPC
*    patrol craft which launch cruise missiles

C CMPERPC=0
*    cruise missiles per patrol craft

A PCSRVHARPOON.K=PCSURVHELO.K*(1-HARPPMSNPK.K)
*    patrol craft that survive HARPOON attacks

A HARPPMSNPK.K=TABLE(HARPPEFF,HARPPPC.K,1,4,1)
*    prob HARPOON incapacitate patrol craft

T HARPPEFF=.30,.50,.65,.75
*    prob incapacitate patrol craft per salvo size

R PCHARPLAU.KL=MIN(PCSURVHELO.K*HARPPPC.K,HARPREMAIN.K)
*    rate HARPOON launched against patrol craft

A HARPPPC.K=2
*    HARPOON salvo size per patrol craft

R PCDAY2.KL=PCSRVHARPOON.K*(1-DETTGT)
*    rate patrol craft survive to fight next day

A SH60PEN.K=CLIP(HELOSAVAIL.K,0,1,TOTALSUB.K)
*       helicopters avail for anti-surface warfare

A DDSURVHELO.K=MAX(0,DDSURVTASM.K-(SH60VSSURF.K*FRACDDG.K))
*       destroyers survive helo attacks

A SH60VSSURF.K=PROBSURFDET.K*SH60PEN.K*NUMPENG*PENGHIT*^
               (1-DEFCM)*PENGKIL
*       helo effectiveness against surface ships

C NUMPENG=2
*       number PENGUIN cruise missiles per helo

C PENGHIT=0.90
*       prob penguin acquires target

C DEFCM=0.25
*       defensive countermeasures against PENGUINS
```

```
C PENGKIL=0.50
*       prob PENGUIN destroys target if it hits

A PROBSURFDET.K=1-(1-SPYDET)**SHIPSAVAIL.K
*       prob detecting enemy surface ship

C SPYDET=0.90
*       prob SPY-1 radar detect target

A FRACDDG.K=DDGAVAIL.K/TOTDDPC.K
*       percent ships which are destroyers

A FRACPC.K=PCAVAIL.K/TOTDDPC.K
*       percent ships which are patrol craft

A TOTDDPC.K=MAX(0.0001,DDGAVAIL.K+PCAVAIL.K)
*       total surface ships avail

A PCSURVHELO.K=MAX(0,PCSURVTASM.K-(SH60VSSURF.K*FRACPC.K))
*       patrol craft survive helo attacks

L HARPREMAIN.K=HARPREMAIN.J+DT*(-DDGHARPLAU.JK-PCHARPLAU.JK)
*       harpoon missiles available

N HARPREMAIN=32


* *******************************************************
* *  SUBMARINE LAUNCHED CRUISE MISSILES AND TORPEDOES;  *
* *  HELECOPTER AND VLA ENGAGEMENTS                     *
* *******************************************************

L SSGAVAIL.K=SSGAVAIL.J+DT*(-SSGUW.JK+SSGDAY2.JK)
*       number of cruise missile equipped submarines (SSG)

N SSGAVAIL=3

R SSGUW.KL=SSGAVAIL.K*SUBSORTIE.K
*       rate SSG get underway

R SSGDAY2.KL=SSGSURVHELO.K*(1-SSGDETTGT)
*       rate SSG survive to fight next day

R SSGNOWSS.KL=SSGSURVHELO.K*SSGDETTGT
*    rate SSG expend missiles and are avail to launch
*   torpedoes

A SUBSORTIE.K=(SUBMAINT+SUBPORT)/2
*       prob subs sortie
```

```
C SUBMAINT=0.90
*       percent maintenance facilities avail

C SUBPORT=1
*       percent sub port facilities avail

A SSGSURVHELO.K=MAX(0,SSGUW.KL-(HELOVSSUB.K*FRACSSG.K))
*       SSG survive helo attacks

A HELOVSSUB.K=PROBSUBDET.K*HELOSAVAIL.K*MK46HIT*MK46KIL
*       helo effectiveness against submarines

C MK46HIT=0.60
*       prob MK46 torpedo hits sub

C MK46KIL=0.70
*       prob torpedo incapacitates sub if hit

A PROBSUBDET.K=1-((((1-SHIPHELODET)**SHIPWHELO.K)^
                ((1-SHIPDET)**SHIPNOHELO.K))*(1-SSSOPHIST)
*       prob detecting submarine

C SSSOPHIST=0.1
*           sophistication & technological level of enemy
submarines

C SHIPHELODET=0.50
*       prob ship w/helo detects sub

C SHIPDET=0.40
*       prob ship w/no helo detects sub

A SHIPWHELO.K=MIN(SHIPSAVAIL.K,HELOSAVAIL.K)
*       number of ships w/helo avail

A SHIPNOHELO.K=SHIPSAVAIL.K-SHIPWHELO.K
*       number ships w/no helo avail

L SHIPSAVAIL.K=SHIPSAVAIL.J+DT*(-TOTHITS.JK)
*       current number friendly ships avail

N SHIPSAVAIL=4

R TOTHITS.KL=MIN(CMHITS.K+TORPHITS.K+BMBHITS.K,SHIPSAVAIL.K)
    number of weapon hits inflicted on sag per day

R HELOLOST.KL=MIN(CMHITS.K+TORPHITS.K+BMBHITS.K+HELOATTRIT.K,^
                HELOSAVAIL.K)
    rate at which sag helicopters become unavailable
```

```
L HELOSAVAIL.K=HELOSAVAIL.J+DT*(-HELOLOST.JK)
*       number of helicopters avail

N HELOSAVAIL=3

A HELOATTRIT.K=HELOSAVAIL.K*HELOCASREP.K
*       rate helos are destroyed or damaged

A HELOCASREP.K=TABLE(HELOBREAK,TIME.K,0,30,10)
*       helo maintenance break down

T HELOBREAK=0,.05,.10,.15
*       helo break down as function of time

A TOTSLCM.K=SSGSURVHELO.K*SSGDETTGT*SLCM_SSG
*       number sub launched cruise missiles launched

C SSGDETTGT=0
*       prob sub detects target

C SLCM_SSG=0
*       number cruise missiles per sub

L
SSAVAIL.K=SSAVAIL.J+DT*(-SSUW.JK+SSGNOWSS.JK+SSSURVURGVLA.JK)
*       number of torpedo equipped submarines (SS)

N SSAVAIL=6

R SSUW.KL=SSAVAIL.K*SUBSORTIE.K
*       rate SS get underway

R SSSURVHELO.Kl=MAX(0,(SSUW.KL-(HELOVSSUB.K*FRACSS.K)))
*       SS survive helo attacks

A TOTALSUB.K=MAX(0.0001,SSGAVAIL.K+SSAVAIL.K)
*       number of subs avail

A FRACSSG.K=SSGAVAIL.K/TOTALSUB.K
*       percent subs carry cruise missiles

A FRACSS.K=SSAVAIL.K/TOTALSUB.K
*       percent subs carry only torpedoes

R SSSURVVLA.Kl=SSSURVHELO.Kl*(1-VLAVSSS.K)
*       SS survive vertical launched ASROC torpedoes

A VLAVSSS.K=MK46HIT*MK46KIL*PROBSUBDET.K
*       VLA effectiveness against subs
```

```
A TORPLAU.K=SSSURVVLA.Kl*SSDETTGT*TORPSALVO
*       number torpedoes launched against friendly ships

C SSDETTGT=0.90
*       prob SS detects target

C TORPSALVO=2
*       torpedoes per salvo

A TORPHITS.K=TORPLAU.K*SSTORPHIT*TORPDAMFACT
*       rate torpedoes hit friendly ships

C TORPDAMFACT=0.30
*       amount torphit affects ship availability

C SSTORPHIT=0.60
*       prob torpedo hits ship

R SSSURVURGVLA.KL=SSSURVVLA.KL*SSDETTGT*(1-VLAURG.K)+^
                  SSSURVVLA.KL*(1-SSDETTGT)
*       rate SS survives urgent VLA attack

A VLAURG.K=MK46HIT*MK46KIL*SSLOCAL
*       probability of successful urgent VLA attack

C SSLOCAL=0.50
*       prob of localization of sub after torp launch

L TOTVLA.K=TOTVLA.J+DT*(SSSURVHELO.JK+SSSURVVLA.JK)
*       total mumber VLA weapons expended

N TOTVLA=0


*    auxillaries
save    acesm2r,aclaunched,aclaupt,acwlrcm,afavail,bmbhits,^
bomblau,bsurvpdef,ciws_ac,ciws_cm,cmaqtgt,cmesm2r,cmhits,^
cmbkills,cmlau,cmsurvpdef,cmsurvsm2,ddgsurfcmlau,^
ddsurvharpoon,ddsurvhelo,ddsurvtasm,dperc,dperd,fracac,^
fracbomber,fracddg,fraclrcmbmb,fracpc,fracss,fracssg,^
guns_ac,guns_cm,harpdmsnpk,harppmsnpk,harppddg,harpppc,^
heloattrit,helocasrep,helovssub,istkill,lrcmlau,lrcmnowcm,^
lnchrloc,maintavail,pcsrvharpoon,pcsurfcmlau,pcsurvhelo,^
pcsurvtasm,pdefpkac,pdefpkcm,probsubset,probsurfdet,^
shipnohelo,shipwhelo,sh60pen,sh60vssurf,slq32_cm,sm2perac,^
sm2percm,sm2pk,sm2pkcm,sortie,ssgsurvhelo,subsortie,^
surfsortie,tasmdmsnpk,tasmpddg,tasmppc,tasmpmsnpk,^
tlmckilrate,tlmclau,tlmcpk,tlmdkilrate,tlmdlau,tlmdpk,^
torphits,torplau,totalac,totalcm,totalsub,totglcm,totddpc,^
```

```
totslcm,totsurfcm,vlaurg,vlavsss

*    rates
save    ac_killrate,afreprate,bkillpdef,bshotdown,bsurvsm2,^
cmkillrate,ddgday2,ddgharplau,ddguw,helolost,lrcmkilrte,^
lrcmlpt,lnchrfired,mntreprate,pcday2,pcharplau,pctasmlau,^
pcuw,sm2laucm,sm2lau1st,ssgday2,ssgnowss,ssguw,sssurvhelo,^
sssurvurgvla,sssurvvla,ssuw,tasmlau,tlamdest,tlmcdamrte,^
tlmddamrate,tlmlaurate,tothits,tvsac,tvsbmb,tvslrcmbmb

*    levels
save         ac,afdamage,bomber,cm_kia,ddgavail,harpremain,^
helosavail,lrcmbmb,maintdamage,numberlnchr,pcavail,^
shipsavail,sm2remain,ssavail,ssgavail,totharp,tottasm,^
tottlam,totvla

*    constants
* save    bmbdamfact,bmbraccuracy,bombpac,cm_ac,cmdamfact,^
cmlock,cmperddg,cmperpc,cprobdest,defcm,dettgt,dprobdest,^
lrcm_ac,mk46hit,mk46kil,msl_lnchr,numpeng,penghit,pengkil,^
problau,satdet,shipdet,shiphelodet,slcm_ssg,slq32_lrcm,^
spydet,ssdettgt,ssgdettgt,sslocal,sssophist,sstorphit,^
subport,submaint,surfport,surfmaint,tlmsucc,torpdamfact,^
torpsalvo

*    tables
* save    c_acdensity,ciwsefac,ciwsefcm,d_acdensity,^
gunsefcm,harpdeff,harppeff,helobreak,gunsefac,slq32cm,sm2eff,^
sm2efcm,tasmdeff,tasmpeff



SPEC DT=1/LENGTH=5/SAVPER=1
```

APPENDIX B

DEFINITION OF MODEL VARIABLES

AC - level - The current number of hostile, cruise missile carrying aircraft available. The number of aircraft is reduced by the number shot down by SM2 AAW missiles and by the number destroyed on the ground by TOMAHAWK cruise missiles. These aircraft must launch their cruise missiles inside the SM2 engagement range.

ACESM2R - aux - The number of aircraft that enter SM2 range per day. It includes all aircraft that launch less those that launch long-range cruise missiles.

AC_KILLRATE - rate - The number of cruise missile carrying aircraft that are shot down by SM2's per day. It is the product of the number of aircraft that launched and were engaged by SM2's that day and the probability that it was shot down.

ACLAUNCHED - aux - The number of cruise missile carrying aircraft that can be launched from the airfield and launch an attack. It is the product of the number of aircraft available and the probability that the aircraft can sortie from the airfield. The ability to sortie is affected by the damage the airfield receives due to TOMAHAWK attacks.

ACLAUPT - aux - The number of cruise missile carrying aircraft that survive SM2 engagements, reach the cruise missile launch point, and launch their cruise missiles.

ACWLRCM - aux - The number of long range cruise missile carrying aircraft that can be launched from the airfield and launch an attack. It is the product of the number of aircraft available and the probability that the aircraft can sortie from the airfield. The ability to sortie is affected by the damage the airfield receives due to TOMAHAWK attacks. Long range cruise missiles are defined as those that can be launched outside the ship's anti-aircraft missile range. This permits the aircraft to release its weapon without fear of attack.

AFAVAIL - aux - The availability of an airfield to be used for flight operations. It is a function of the amount of damage the airfield currently possesses.

AFDAMAGE - level - The current amount of damage that exists to the airfield. The damage is affected by the amount of damage incurred by TOMAHAWK strikes less the repairs carried out to make the airfield operational.

AFREPRATE - rate - The amount of airfield damage per day that can be repaired.

BKILLPDEF - rate - The number of bombers per day that are destroyed by point defense weapons. It is the product of the number of bombers which survive SM2 engagements and the probability of being destroyed by point defense weapons.

BMBDAMFACT - constant - Value that represents the amount of bomb damage that can be delivered to the SAG in terms of ship availability.

BMBHITS - aux - The damage inflicted by bombs per day. It is the product of the number of bombers which survive point defense weapons, the number of bombs per aircraft, the accuracy at which the bomb(s) is released, and the bomb damage factor.

BMBRACCURACY - constant - The probability that once a bomb is released that it will hit its target.

BOMBER - level - The current number of conventional gravity bomb carrying aircraft. Bombers are destroyed in flight by SM2's and shipboard point defense weapons, and on the ground by TOMAHAWK cruise missiles.

BOMBLAU - aux - The number of bombers per day that launch from their airbase. It is the product of the number of bombers available and the ability of airfield and maintenance facilities to launch the aircraft.

BOMBPAC - constant - The number of bombs carried by a bomber.

BSHOTDOWN - rate - The number of bombers per day that are shot down while still inbound of their target by SM2's. It is the product of the number of bombers that sortie and the probability of an SM2 destroying the bomber.

BSURVPDEF - aux - The number of bombers per day that survive engagements with point defense weapons. It is the product of the number of bombers which survive SM2 engagements and the probability of surviving point defense weapons.

BSURVSM2 - rate - The number of bombers per day that survive engagements with SM2's. It is the product of the number of bombers that sortie and the probability of surviving an SM2 engagement.

C_ACDENSITY - table - The table that describes the amount of damage caused by a C variant TOMAHAWK in relationship to the number of aircraft present at the time of the attack.

CIWS_AC - aux - The probability that point defense rotary cannon weapons (PHALANX) can destroy an inbound aircraft. Because of rapid ammunition expenditures and the difficulty in reloading, its effectiveness is severely degraded when forced to contend against multiple simultaneous threats.

CIWS_CM - aux - The probability that point defense rotary cannon weapons (PHALANX) can destroy a missile. Because of rapid ammunition expenditures and the difficulty in reloading, its effectiveness is severely degraded when forced to contend against multiple simultaneous threats.

CIWSEFAC - table - The table function that relates the effectiveness of point defense rotary gatling guns against incoming aircraft to the number of aircraft that must be countered at one time.

CIWSEFCM - table - The table function that relates the effectiveness of point defense rotary gatling guns against incoming missiles to the number of missiles that must be countered at one time.

CM_AC -constant - The number of cruise missiles that can be carried per aircraft.

CMAQTGT - aux - The number of cruise missiles per day that acquire friendly units. It is the product of the number of cruise missiles which survive SM2 engagements, the probability of the missile to find its target and the ability of friendly electronic countermeasures to deflect the missile away from the ship.

CMDAMFACT - constant - Value that represents the amount of cruise missile damage that can be delivered to the SAG in terms of ship availability.

CMESM2R - aux - The number of cruise missiles which enter SM2 engagement range per day. It is the sum of the number of cruise missiles launched from the air, land, or from submarines and surface ships.

CMHITS - aux - The damage per day caused by cruise missile hits. It is a function of the number of cruise missiles that penetrate the ship's defenses and the crise missile damage factor.

CMBKILLS - aux - The total number of aircraft destroyed on the ground per day by TOMAHAWK missiles. It is the sum of the number of aircraft destroyed by C and D variant TOMAHAWK missiles.

CM_KIA - level - The current number of enemy cruise missiles which have been destroyed by SM2's.

CMKILLRATE - rate - The number of cruise missiles destroyed by SM2 missiles per day. It is the product of the number of cruise missiles which enter SM2 engagement range and the probability that an SM2 salvo will destroy its target.

CMLAU - aux - The number of cruise missile that are launched per day. It is the product of the number of aircraft that reach the launch point and the number of cruise missiles that can be carried per aircraft.

CMLOCK - constant - The probability that a cruise missile can acquire its target after it is launched.

CMPERDDG - constant - The number of anti-ship cruise missiles carried by destroyer/frigates.

CMPERPC - constant - The number of anti-ship cruise missiles carried by patrol craft.

CMSURVPDEF - aux - The number of cruise missile per day that survive ship point defense weapons. It is the function of the number of cruise missiles which acquire the target and the probability that survive attacks from point defense weapons.

CMSURVSM2 - aux - The daily number of cruise missiles which survive engagements with SM2's. It is the product of the number of cruise missiles entering SM2 engagement range and the probability that they are not destroyed by SM2's.

CPROBDEST - constant - The pre-launch prediction of the amount of damage a C variant missile is expected to produce to the target maintenance facilities. It is used to determine the number of missiles that should be launched at a target but is different from the randomized number that represents the true damage actually inflicted by that particular salvo.

D_ACDENSITY - table - The table that describes the amount of damage caused by a D variant TOMAHAWK in relationship to the number of aircraft present at the time of the attack.

DDGAVAIL - level - The current number of hostile frigate/destroyer size ships available to sortie and in a position fire anti-ship missiles. It is affected by the number of ships already underway and whether or not they have launched their anti-ship missiles.

DDGDAY2 - rate - The number of destroyer/frigates that have survived all attacks, did not launch their weapons (did not detect a target), and are therefore available for use on the next day.

DDGHARPLAU - rate - The number of HARPOON missiles that are launched per day against destroyer/frigates. It is the product of the number of ships that survive helo engagements and the number of HARPOONs per salvo.

DDGSURFCMLAU - aux - The number of surface launched cruise missiles launched per day by destroyer/frigates. It is the product of the number of ships which survive engagements with missile equipped helicopters, the ability of the ship to detect its target, and the number of cruise missiles onboard.

DDGUW - rate - The number of destroyer/frigate size ships that are underway per day. It is the product of the number of ships available and the ability of those ships to get underway.

DDSRVHARPOON - aux - The number of destroyer/frigates that survive HARPOON anti-ship missiles engagements. It is the product of the number of ships that have previously survived engagements with helicopters and the probability that they survive the HARPOON salvos.

DDSURVHELO - aux - The number of destroyer/frigates that survive helo engagements. It is determined by the effectiveness of anti-ship missile equipped helicopters against surface ships and the relative number helos that engage destroyer/frigates.

DDSURVTASM - aux - The number of destroyer/frigates that survive TOMAHAWK anti-ship cruise missile (TASM) attacks. It is the product of the number of destroyer/frigates underway and the probability that they survive TASM attacks.

DEFCM - constant - The probability that an enemy surface ship will shoot down an inbound cruise missile.

DETTGT - constant - The ability of a surface ship to detect a target at the range that it can launch missiles.

DPERC - aux - A randomized number that represents the amount of damage a salvo of TOMAHAWKS (C variants) will inflict on maintenance facilities.

DPERD - aux - A randomized number that represents the amount of damage a salvo of TOMAHAWKS (D variants) will inflict on the airfield.

DPROBDEST - constant - The pre-launch prediction of the amount of damage a D variant missile is expected to produce to the target airfield. It is used to determine the number of missiles that should be launched at a target but is different from the randomized number that represents the true damage actually inflicted by that particular salvo.

FRACAC - aux - The fraction of the total number of aircraft that carry cruise missiles.

FRACBOMBER - aux - The fraction of the total number of aircraft that carry gravity bombs.

FRACDDG - aux - The percentage of ships available (at sea) that are destroyer/frigates.

FRACLRCMBMB - aux - The fraction of the total number of aircraft that carry long-range cruise missiles.

FRACPC - aux - The percentage of ships available (at sea) that are patrol craft.

FRACSS - aux - The percentage of submarines available (at sea) that possess only torpedoes.

FRACSSG - aux - The percentage of submarines available (at sea) that possess cruise missiles.

GUNS_AC - aux - The probability that ownship dual purpose guns (3" and 5") can destroy an aircraft. Ammunition expenditure is not an issue, but the guns effectiveness is constrained by a relatively slow engagement reaction time.

GUNS_CM - aux - The probability that ownship dual purpose guns

(3" and 5") can destroy a missile. Ammunition expenditure is not an issue, but the guns effectiveness is constrained by a relatively slow engagement reaction time.

GUNSEFAC - table - The table function that relates the effectiveness of dual-purpose guns against incoming aircraft to the number of aircraft that must be countered at one time.

GUNSEFCM - table - The table function that relates the effectiveness of dual-purpose guns against incoming missiles to the number of missiles that must be countered at one time.

HARPDEFF - table - The table function that relates the probability of a successful HARPOON strike against a destroyer/frigate to the number of HARPOONs in the salvo.

HARPDMSNPK - aux - The probability that a salvo of HARPOON missiles will prevent a destroyer/frigate ship from carrying out its mission and is a function of the number of HARPOONs launched at the ship.

HARPPMSNPK - aux - The probability that a salvo of HARPOON missiles will prevent a patrol craft ship from carrying out its mission and is a function of the number of HARPOONs launched at the ship.

HARPPDDG - aux - A decision variable that defines the number of HARPOONs that are assumed to be needed against a destroyer/frigate in order to incapacitate the target.

HARPPEFF - table - The table function that relates the probability of a successful HARPOON strike against a patrol craft to the number of HARPOONs in the salvo.

HARPPPC - aux - A decision variable that defines the number of HARPOONs that are assumed to be needed against a patrol craft in order to incapacitate the target.

HARPREMAIN - level - The current number of HARPOONs that are available to the SAG.

HELOATTRIT - aux - The number of helicopters that are no longer available for use due to mechanical breakdowns. it is the product of the number of helos available and rate at which they break down.

HELOBREAK - table - The table that relates the rate at which helicopters break down as a function of time in operation.

HELOCASREP - aux - The rate at which a helicopter breaks down as a function of time. Limited repair capabilities onboard ship keep helos from operating indefinitely.

HELOLOST - rate - The rate at which helicopters are lost for combat use. Losses are due to mechanical breakdowns as well as from damage suffered from weapons hits to itself and the ship it is assigned.

HELOSAVAIL - level - The current number of helicopters available. Initially one helo is assigned per ownship. The number of helos is reduced as a function of the number of missile, torpedo, and bombs that strike their parent ship and the helo attrition rate.

HELOVSSUB - aux - The expected number of submarines that can be engaged and destroyed with helicopters per day. It is the product of the helo's ability to detect a target, the overall effectiveness of the torpedo (MK46) that it carries, and the number of helos available and the probability of detecting those submarines.

ISTKILL - aux - The number of aircraft that enter SM2 range that are shot down by SM2's. It is the product of the number of aircraft which enter SM2 range and the SM2 probability of kill, constrained by the number of SM2s in the inventory.

LRCM_AC - constant - The number of long range cruise missiles that can be carried per aircraft.

LRCMBMB - level - The current number of long range cruise missile carrying aircraft. This value is affected by the number of aircraft destroyed on the ground as a result of TOMAHAWK strikes.

LRCMKILRTE - rate - The number of aircraft carrying long range cruise missiles that are shot down by SM-2's.

LRCMLAU - aux - The number of long range cruise missiles that are launched outside of the SM-2 engagement range per day. It is the product of the number of aircraft that carry long range cruise missiles, the number of missiles that can be carried per aircraft, and the number of aircraft unaffected by electronic jamming.

LRCMLPT - rate - The number of aircraft carrying long range cruise missiles that survive SM-2 engagements.

LRCMNOWCM - aux - The number of long range cruise missile aircraft that enter SM-2 range.

LNCHRFIRED - rate - The number of launchers per day that fire their missiles. It is the product of the number of launchers with missiles available and the probability that the launcher is in a position to detect and fire at a target.

LNCHRLOC - aux - The number of GLCM launchers located per day. It is a function of the number of GLCM's that are deployed and the probability that they will be detected via reconnaissance satellites.

MAINTAVAIL - aux - The availability of aircraft maintenance facilities to be used to keep aircraft operational. Aircraft that do not receive maintenance break down and are thus not able to sortie. It is a function of the amount of damage maintenance facilities currently possesses.

MAINTDAMAGE - level - The current amount of damage that exists to the aircraft maintenance facilities. The damage is affected by the amount of damage incurred by TOMAHAWK strikes less repairs made.

MK46HIT - constant - The probability that a MK46 torpedo will acquire its target after launch.

MK46KIL - constant - The probability that a MK46 torpedo that strikes its target will critically damage it in such a way as to render it combat ineffective.

MNTREPRATE - rate - The amount of maintenance facilities damage per day that can be repaired.

MSL_LNCHR - constant - The number of ground launched cruise missiles (GLCM) per launcher.

NUMBERLNCHR - level - The current number of GLCM launchers which have not yet fired their missiles. It is a function of the initial number of GLCM launchers available minus those which have expended their missiles and have been destroyed by TOMAHAWK strikes.

NUMPENG - constant - The number of PENGUIN anti-ship missiles carried by an SH-60 multi-purpose helicopter.

PCAVAIL - level - The current number of hostile patrol craft size ships available to sortie and in a position fire anti-ship missiles. It is affected by the number of ships already underway and whether or not they have launched their anti-ship missiles.

PCDAY2 - rate - The number of patrol craft that have survived all attacks, did not launch their weapons (did not detect a target), and are therefore available for use on the next day.

PCHARPLAU - rate - The number of HARPOON missiles that are launched per day against patrol craft. It is the product of the number of ships that survive helo engagements and the number of HARPOONs per salvo.

PCSRVHARPOON - aux - The number of patrol craft that survive HARPOON anti-ship missiles engagements. It is the product of the number of ships that have previously survived engagements with helicopters and the probability that they survive the HARPOON salvos.

PCSURFCMLAU - aux - The number of surface launched cruise missiles launched per day by patrol craft. It is the product of the number of ships which survive engagements with missile equipped helicopters, the ability of the ship to detect its target, and the number of cruise missiles onboard.

PCSURVHELO - aux - The number of patrol craft that survive helo engagements. It is determined by the effectiveness of anti-ship missile equipped helicopters against surface ships and the relative number helos that engage patrol craft.

PCSURVTASM - aux - The number of patrol craft that survive TOMAHAWK anti-ship cruise missile (TASM) attacks. It is the product of the number of patrol craft underway and the probability that they survive TASM attacks.

PCTASMLAU - rate - The number of TASMs launched against patrol craft per day. It is the product of the number of ships that get underway and the number of TASMs launched against each.

PCUW - rate - The number of patrol craft size ships that are underway per day. It is the product of the number of ships available and the ability of those ships to get underway.

PDEFPKAC - aux - The probability that shipboard point defense weapons (guns, point defense missiles) will destroy an inbound bomber.

PDEFPKCM - aux - The probability that ownship point defense weapons (guns, point defense missiles, chaff, jamming) can destroy cruise missiles or cause them to miss their target.

PENGHIT - constant - The probability that a PENGUIN anti-ship missile will acquire its target after launch.

PENGKIL - constant - The probability that a PENGUIN missile that strikes its target will critically damage it in such a way as to render it combat ineffective.

PROBLAU - constant - The probability that a GLCM launcher will launch its missiles on a given day.

PROBSUBDET - aux - The probability that an enemy submarine will be detected while underway. Detection is primarily based upon the active and passive sonars available onboard ownship and helicopter, and the number which are available.

PROBSURFDET - aux - The probability that an enemy ship will be detected while underway. Detection is primarily based upon the capabilities of the AEGIS SPY-1 radar and integrated electronic support measures, and the number which are available.

SATDET - constant - The probability that reconnaissance satellites will detect an exposed GLCM launcher.

SHIPDET - constant - The probability that a ship not operating with its helicopter can detect and track a submarine.

SHIPHELODET - constant - The probability that a ship operating in conjunction with its helicopter can detect and track a submarine.

SHIPNOHELO - aux - The number of ownships that no longer have operational helicopters. It is the result of the total number of ships available less the ones with helicopters.

SHIPSAVAIL - level - The current number of ownships available.

The number is reduced as a function of the number of missiles, torpedoes, and bombs that strike friendly ships. Damage is assumed to be evenly distributed between existing ships.

SHIPWHELO - aux - The number of ownships that are operating helicopters. It is the lesser value of the number of ships available and the number of helicopters available.

SH60PEN - aux - the number of helicopters (SH-60) available per day for use against enemy surface ships. it is a function of the number of helos present and whether or not the submarine threat has been eliminated. A primary anti-submarine warfare asset, it will not be available against surface ships until the total number of enemy subs has been reduced to almost zero.

SH60VSSURF - aux - The expected number of surface ships that can be engaged and destroyed with helicopters per day. It is the product of the helos ability to detect a target, the overall effectiveness of the anti-ship missile (PENGUIN) that it carries, and the effectiveness of the target's defensive capabilities.

SLCM_SSG - constant - The number of cruise missiles per submarine.

SLQ32CM - table - The table function that relates the effectiveness of electronic jamming/chaff against incoming missiles to the number of missiles that must be countered at one time.

SLQ32_CM - aux - The probability that ownship electronic countermeasures can cause a missile to miss its target.

SLQ32_LRCM - constant - The ability of electronic jamming to force long range cruise missile aircraft to enter SM-2 range.

SM2EFCM - table - The table function that relates the probability of a cruise missile being destroyed by SM2's based on the number of SM2's fired at it.

SM2EFF - table - The table function that defines the probability that an SM2 will hit its target based on the number of SM2s launched at the target.

SM2LAUCM - rate - The number of SM2's launched at all types of cruise missiles per day. It is the product of the number of targets fired at and the number of SM2's launched per target.

SM2LAU1ST - rate - The rate at which SM2s are launched per day. It is the product of the number of aircraft entering SM2 range and the number of SM2s per salvo, constrained by the existing number of SM2s in the inventory.

SM2PERAC - aux - Used in table SMEFF as the number of SM2s launched per aircraft. This is a decision variable based on defined rules of engagement.

SM2PERCM - aux - Used in table SM2EFCM as the number of SM2s launched per cruise missile. This is a decision variable based on defined rules of engagement.

SM2PK -aux - The probability that an SM2 air defense missile will destroy or damage an aircraft so that it is no longer a threat to the ship. It is a function of the number of SM2s that are allocated and launched against a particular target and is defined via a table function.

SM2PKCM - aux - The probability of an SM2 salvo destroying a cruise missile. The probability of kill is a function of the number of SM2's launched against the cruise missile.

SORTIE - aux - The ability of an aircraft to launch and perform a mission. It is a function of the damage incurred by the airfield and aircraft maintenance facilities due to TOMAHAWK strikes.

SPYDET - constant - The probability that the SPY-1 radar will detect a surface target at or beyond the range that the target can launch anti-ship missiles.

SSAVAIL - level - The current number of hostile submarines equipped with torpedoes available to sortie and in a position to launch their torpedoes. It is affected by the number of subs already underway and whether or not they have launched their torpedoes.

SSDETTGT - constant - The probability that a submarine operating at torpedo launch range can detect a target.

SSGAVAIL - level - The current number of hostile submarines equipped with anti-ship cruise missiles and torpedoes available to sortie and in a position fire anti-ship missiles. It is affected by the number of subs already underway and whether or not they have launched their cruise missiles.

SSGDAY2 - rate - The number of cruise missile submarines that have survived all attacks, did not launch their weapons (did not detect a target), and are therefore available for use on the next day.

SSGDETTGT - constant - The probability that a submarine operating at optimum cruise missile launch range can detect a target.

SSGNOWSS - rate - The number of cruise missile submarines that have survived all attacks, launched all their missiles, and are now in position to use their torpedoes. Because cruise missiles have a much greater range than torpedoes, missiles are the first weapon of choice.

SSGSURVHELO - aux - The number of cruise missile submarines that survive helo engagements. It is determined by the effectiveness of torpedo equipped helicopters against submarines and the relative number helos that engage cruise missile equipped ones.

SSGUW - rate - The number of cruise missile equipped subs that are underway per day. It is the product of the number of subs available and the ability of those subs to get underway.

SSLOCAL - constant - The ability of the SAG to detect a submarine which has just launched a torpedo attack against it so that an urgent VLA counter-attack can be made.

SSSOPHIST - constant - Value that represents the technological level of the submarine and impacts the ability to detect that type of submarine.

SSSURVHELO - rate - The number of torpedo only submarines that survive helo engagements. It is determined by the effectiveness of torpedo equipped helicopters against submarines and the relative number helos that engage torpedo equipped ones.

SSTORPHIT - constant - The probability that a torpedo will strike and significantly damage its target.

SSSURVURVLA - rate - The number of cruise missile submarines that have survived all attacks, including urgent VLA attacks, did not launch their weapons (did not detect a target), and are therefore available for use on the next day.

SSSURVVLA - rate - The number of torpedo equipped submarines that survive vertically launched ASROC (anti-submarine rocket) attacks. It is the product of the number of subs that survive helo attacks and the probability that they can survive ASROC attacks.

SSUW - rate - The number of torpedo equipped subs that are underway per day. It is the product of the number of subs available and the ability of those subs to get underway.

SUBMAINT - constant - The material readiness of a submarine and its impact on the ability to sortie and be combat effective.

SUBPORT - constant - The relative capability of a port to provide services to the submarines present, to includes maintenance and fueling support.

SUBSORTIE - aux - The fraction of submarines that can sortie from port. It is a function of the availability of port services and the material readiness of the subs themselves.

SURFMAINT - constant - The material readiness of a surface ship and its impact on the ability to sortie and be combat effective.

SURFPORT - constant - The relative capability of a port to provide services to the ships present, to includes maintenance and fueling support.

SURFSORTIE - aux - The fraction of surface ships that can sortie from port. It is a function of the availability of port services and the material readiness of the ships themselves.

TASMDEFF - table - The table function that describes the effectiveness of a TASM salvo against a destroyer/frigate as a function of the number of missiles in the salvo.

TASMLAU - rate - The number of TASMs launched against destroyer/frigates per day. It is the product of the number of ships that get underway and the number of TASMs launched against each.

TASMDMSNPK - aux - The function that defines the ability of a TASM salvo to prevent a destroyer/frigate from carrying out its mission based on the number of missiles in the salvo.

TASMPDDG - aux - A decision variable that defines the number of TASMs that are assumed to be needed against a destroyer/frigate in order to incapacitate the target.

TASMPPC - aux - A decision variable that defines the number of TASMs that are assumed to be needed against a patrol craft in order to incapacitate the target.

TASMPEFF - table - The table function that describes the effectiveness of a TASM salvo against a patrol craft as a function of the number of missiles in the salvo.

TASMPMSNPK - aux - The function that defines the ability of a TASM salvo to prevent a patrol craft from carrying out its mission based on the number of missiles in the salvo.

TLAMDEST - rate - The number of GLCM launchers destroyed per day by TOMAHAWK strikes. It is the product of the number of launchers that have been detected and the probability that they will be destroyed by a TOMAHAWK strike.

TLMCDAMRATE - rate - The amount of damage per day inflicted on maintenance facilities by TOMAHAWK (C variant) missiles. It is the product of the number of C variant missiles launched, the probability of the missile hitting its target, and the mount of damage to facilities per each TOMAHAWK.

TLMCKILRATE - aux - The number of aircraft per day that are destroyed on the ground by C variant TOMAHAWKS. It is the product of the number of C variant TOMAHAWKS launched and the average number of aircraft that could be expected to destroyed by the missile's warhead.

TLMCLAU - aux - The number of TOMAHAWK (C variant missiles launched per day. C variant missiles contain a single large warhead and are designed to destroy a single target; i.e. a building or aircraft hanger. No C variant missile will be launched if the number of available enemy aircraft assigned to the airfield is less than one. Otherwise the number of missiles launched is determined by the amount of existing damage to maintenance facilities and the expected number of missiles required to make those facilities completely inoperable. If they are completely destroyed, then no missiles are launched.

TLMCPK - aux - The number of aircraft that could be expected to be destroyed on the ground by a C variant TOMAHAWK. It is defined in a table as a function of the number of aircraft on the airfield and in hangers at the time of the attack. The more aircraft on the ground, the greater the amount of damage that can be done by a single TOMAHAWK.

TLMDDAMRATE - rate - The amount of damage per day inflicted upon an airfield by TOMAHAWK (D variant) missiles. It is the product of the number of D variant missiles launched, the probability of the missile hitting its target, and the amount of damage to the airfield per each TOMAHAWK.

TLMDKILRATE - aux - The number of aircraft per day that are destroyed on the ground by D variant TOMAHAWKS. It is the product of the number of D variant TOMAHAWKS launched and the average number of aircraft that could be expected to destroyed by the missile's warhead.

TLMDLAU - aux - The number of TOMAHAWK (D variant missiles launched per day. D variant warheads contain hundreds of smaller bomblets designed to make potholes in runways and disable exposed aircraft. No D variant missile will be launched if the number of available enemy aircraft assigned to the airfield is less than one. Otherwise the number of missiles launched is determined by the amount of existing damage to the airfield and the expected number of missiles required to make the airfield completely inoperable. If the airfield is currently inoperable, then no missiles are launched.

TLMDPK - aux - The number of aircraft that could be expected to be destroyed on the ground by a D variant TOMAHAWK. It is defined in a table as a function of the number of aircraft on the airfield and in hangers at the time of the attack. The more aircraft on the ground, the greater the amount of damage that can be done by a single TOMAHAWK.

TLMLAURATE - rate - The number of land attack variant TOMAHAWKS launched per day. it is the sum of all C and D variant missiles launched against airbases and mobile missile launchers.

TLMSUCC - constant - The probability that a TOMAHAWK cruise missile will reach its target following launch.

TORPDAMFACT - constant - Value that represents the amount of torpedo damage that can be delivered to the SAG in terms of ship availability.

TORPHITS - aux - The number of torpedoes per day that strike ownships. it is the product of the number of torpedoes launched and the probability the torpedo will strike and damage its target.

TORPLAU - aux - The number of torpedoes launched by submarines per day. It is the product of the number of surviving subs, the ability to detect a target, and the number of torpedoes launched per salvo.

TORPSALVO - constant - The number of torpedoes normally launched per salvo.

TOTALAC - aux - The total number of enemy aircraft available per day. It is the sum of the available number of cruise missile carrying aircraft, long-range cruise missile aircraft, and bombers.

TOTALCM - aux - The total number of air launched cruise missiles launched per day. It is the combination of the number of cruise missiles and long range cruise missiles.

TOTALSUB - aux - The total number of submarines available per day. It is the sum of the number of cruise missile equipped and torpedo equipped subs available.

TOTGLCM - aux - The number of ground launched cruise missiles that launch per day. It the product of the number of launchers that fire their missiles and the number of missiles per launcher.

TOTDDPC - aux - The total number of surface ships available per day. It is the sum of the number of destroyer/frigates and patrol craft available.

TOTHARP - level - The current number of HARPOONs that have launched against all surface ships, destroyers/frigates and patrol craft.

TOTHITS - rate - The amount of damage inflicted on the SAG per day in terms of ship availability. It includes the hits from bombs, cruise missiles, and torpedoes.

TOTSLCM - aux - The number of submarine launched cruise missiles launched per day. It is the product of the number of subs that survive all attacks, the probability of detecting a target, and the number of missiles per sub.

TOTSM2LAU - level - The current number of SM2's that have been launched against both aircraft and cruise missile targets.

TOTSURFCM - aux - The number of anti-ship cruise missiles launched per day by all surface ships (destroyer/frigates and patrol craft).

TOTTASM - level - The current number of TASMs that have launched against all surface ships, destroyers/frigates and patrol craft.

TOTTLAM - level - The total number of land attack TOMAHAWKS launched. It is a function of the rate of missiles launched per day.

TVSAC - rate - The number of cruise missile carrying aircraft that are destroyed on the ground by both TOMAHAWK variants per day. It is the product of the total number of aircraft that are expected to be destroyed and the fraction of those aircraft on the ground which carry cruise missiles. This value cannot exceed the number of cruise missile carrying aircraft currently on the ground.

TVSBMB - rate - The number of bombers that are destroyed on the ground by both TOMAHAWK variants per day. It is the product of the total number of aircraft that are expected to be destroyed and the fraction of those aircraft on the ground which are bombers. This value cannot exceed the number of bombers currently on the ground.

TVSLRCMBMB - rate - The number of long-range cruise missile carrying aircraft that are destroyed on the ground by both TOMAHAWK variants per day. It is the product of the total number of aircraft that are expected to be destroyed and the fraction of those aircraft on the ground which carry long-range cruise missiles. This value cannot exceed the number of long-range cruise missile carrying aircraft currently on the ground.

VLAURG - aux - The ability of the SAG to launch an attack against a submarine which has just launched a torpedo attack. It is the product of the ability to detect that submarine and the probability of destroying it with a VLA.

VLAVSSS - aux - The probability that a vertical launched ASROC (VLA) attack will prevent a submarine from carrying out its mission. It is the product of the ability to detect the submarine and the overall effectiveness of the VLA in destroying or crippling the sub.