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A JOINT CAMPAIGN ANALYSIS APPROACH TO ANTISUBMARINE WARFARE USING A CIRCULATION MODEL TEMPLATE

by

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September, 1996

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A JOINT CAMPAIGN ANALYSIS APPROACH TO ANTISUBMARINE WARFARE USING A CIRCULATION MODEL TEMPLATE

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- The members of the CFC-Korea, J3-PL-OA staff whose continuous support made this project possible, especially LCDR Jeffrey Cares.
- My parents and my wife's parents for their continued encouragement throughout my studies at the Naval Postgraduate School.
- My sons whose curiosity and smiles remind me of what is really important.

Most importantly I would like to express my sincerest thanks to my wife Sonia, whose help and support go far beyond mere patience and understanding. This thesis could not have been accomplished without her untiring assistance and unconditional love. I dedicate this thesis to her.

EXECUTIVE SUMMARY

The complex changes in the world over the last decade have caused a shift in the thinking of the antisubmarine warfare (ASW) community. The Soviet submarine threat in years past has been massive, yet relatively easy to define. Knowing the systems confronting the ASW forces and the country that would be operating them, standard ASW deployment plans were developed and these employment plans worked extremely well. For the ASW community, the shift is from a nuclear submarine threat in blue water (>300 NM from land) to a diesel submarine threat along the littoral.

Our primary ASW goals must now be:

- ensure free logistical flow of military goods and resupply,
- protection of merchant shipping, and
- control of the operating areas to include the protection of high value units.

Achieving these ASW goals will be more difficult along the littoral than the high seas. This is especially true against the rapid mobilization of submarines from a disgruntled third world country who chooses to disrupt shipping of a nearby nation. The invading nation can attack in a relatively short period of time due to the short transit required. Unprotected ships will be essentially defenseless against the invading submarines. Antisubmarine *defense* takes significant resources and time.

A dramatic change in mind set must occur to fully utilize all available assets for this "traditional-navy-mission" – ASW. It must become clear to the Air Force, Army and Marine Corps that they no longer can ignore the consequences of an enemy's

submarine blockade. Just as a tactical air campaign precedes the primary ground offensive, so too must the sea lanes be secured to an uninterrupted flow of war material before even the air campaign can begin This realization is the first step in the "jointization" of antisubmarine warfare.

With the de-emphasizing of ASW training and equipment procurement, there will be fewer and fewer naval forces available. Yet, third world submarine acquisition is not seeing the same de-emphasis. A strong ASW force must come from the available assets or be made available from joint and combined forces. The task then becomes the development of an effective antisubmarine warfare campaign plan against any country possessing a viable submarine threat. The flexibility and robustness of this model allows it to be applied to any scenario that poses a submarine threat.

To rapidly respond there must be a plan for such a campaign. The aim of this thesis is to provide a tool to the military decision-maker, a large-scale, aggregated, highly flexible model of the ASW campaign that is not limited by force mix or tactics. The user friendly campaign decision aid developed in this thesis provides an integrated look at all the ASW forces' effects in concert, and the total threat of a submarine fleet to shipping (or warships) over their operating lifetime. The deliverable graphical interface developed in this thesis will function as the analytical tool for flexible and robust ASW campaign analysis.

The generality and simplicity of the model allows for "jointization" of an ASW campaign by allowing the user to utilize any available resources to define the force mix. The model is designed, first and foremost, to examine the change in the marginal effectiveness of friendly ASW forces due to changes in force level, mix, effectiveness, and employment strategies. The model is keyed to the interaction of a threat submarine with friendly ASW forces and merchant or military shipping. Specific features of the model provide for four unique attack regimes. The in port and operational regimes control friendly attacks on a daily basis while the outbound and inbound regimes control barriers by events. The campaign model is a deliverable product programmed using Borland® Delphi™ for use in Microsoft® Windows®.

I. INTRODUCTION

A. BACKGROUND

The complex changes in the world over the last decade have caused a shift in the thinking of the antisubmarine warfare (ASW) community. The Soviet submarine threat in years past has been massive, yet relatively easy to define. Knowing the systems confronting the ASW forces and the country that would be operating them, standard ASW deployment plans were developed and these employment plans worked extremely well. For the ASW community, the shift is from a nuclear submarine threat in blue water (>300 NM from land) to a diesel submarine threat along the littoral.

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Achieving these ASW goals will be more difficult along the littoral than the high seas. This is especially true against the rapid mobilization of submarines from a disgruntled third world country who chooses to disrupt shipping of a nearby nation. The invading nation can attack in a relatively short period of time due to the short transit required. Unprotected ships will be essentially defenseless against the invading submarines. Antisubmarine *defense* takes significant resources and time.

The ASW campaign required in such a <u>littoral situation</u> must include both an **offense and a defense**. An offensive portion of the ASW campaign must attack the enemy submarine before they can strike or resupply. This may be equated to the tactic of "attacking the archer instead of the arrow." This will be difficult if the submarine mobilization is to be extremely rapid due to the short transit distance required by the invading nation. Also, the attacks on shipping and resupply in the littoral will be swift and unopposed due to the nature of the submarine (nuclear or non-nuclear). Therefore, a defensive campaign must be equally as swift as the offensive campaign. The question is then, how can these ASW goals be attained in the earliest stages of the war to provide the most expedient transition to the counter invasion and destruction phase of the war? The answer lies in ***full utilization of available assets*** and ***a timely response.*** The model developed in this thesis provides for both of these factors.

B. PURPOSE

1. Joint ASW - Trade-Offs Of Various ASW Assets

In order for a military organization to survive in modern times, it must know the limits of its combat and economic potential. Combat potential is more than what an army can do in the ground war or an air force can do in an aerial bombardment. It is the optimal use of all available forces to accomplish the mission, regardless of their traditional role. A country's economic potential forms the limits of "all available forces."

No traditional mission is seen as less joint or more service-unique than antisubmarine warfare (ASW) (Linder, 1995). The following summary of a fictitious, yet reasonable and viable scenario exemplifies Joint ASW. Traditionally thought of as a naval mission, this article presents convincing reasons why ASW must become a joint mission requiring full utilization of all available assets.

(Partial summary of the article entitled *The Future of Joint ASW*, Linder, 1995.)

The year is 1999, North Korean forces invaded South Korea (ROK). South Korean and American resistance evaporated in the face of both a North Korean blitzkrieg and a surprisingly effective use of battlefield chemical weapons. North Korean theater ballistic missiles rained down on distant airfields. The smoking remnants of our proud tactical air forces resembled those at Clark Air Field in the Philippines in 1941. Within a week, Seoul had fallen, and North Korean forces were 50 miles south of the 38th Parallel.

It was thought to be another Kuwait. We would demand a return of captured land, threaten consequences, build up a response force, and then roll them back. Everyone thought the North Koreans would wilt. No one was prepared for such an effective use of diesel submarines. No credible regional submarine threat had been mounted in more than 50 years, and most thought the US Navy could easily squash a force of antiquated diesel submarines.

At the start of the war, the US lost four ships from a maritime prepositioning squadron within sight of Pusan harbor. Resupply and reinforcement by sealift froze. Without a guarantee of the arrival of their heavy-lift equipment by sealift, Army troops began piling up at their transshipment airheads in the United States. To add to the mass disruption, the Navy ordered three aircraft carrier battle groups out of the Sea of Japan until safety could be assured; Air Force tactical aircraft stayed at distant rear bases in Japan and Okinawa until sufficient aviation fuel and ordnance at their Korean air bases could be stockpiled.

The Navy said it could not guarantee sealift resupply until D-Day +30. But North Koreans were pouring south in corps strength. The Navy needed to flush the subs, organize escort, and sanitize the approach routes. The Army insisted it did not have 30 days to sit on their hands waiting for the Navy to scare away a few clunky old subs.

Two divisions had already been airlifted from the States. The troops had to have their equipment, they could not wait 30 days. Everything depended on resupply but unlike Desert Storm the luxury of a slow and unopposed buildup was not available. It was the Navy role in a major regional conflict to assist the buildup of Army power. But the US Navy had few forces to commit. Meager ASW assets in theater were immediately deployed: A few nuclear submarines deployed to patrol areas off the Korean coast; land-based aircraft launched from Japanese bases; and precious escort ships sailed to barrier patrols and with convoys.

U. S. Navy forces began to score submarine kills, but Coalition shipping losses continued to mount. Two Army Prepositioning Afloat (APA) ships, three chartered tankers, and two scarce amphibious transports fell victim to enemy torpedoes or submarine-laid mines within a week's time.

To increase enemy submarine attrition even more Navy ASW forces were demanded — but there were none to tap. Naval surface combatants were stretched to the *limit, filling other missions of the Coalition plan that competed with ASW assignments: traditional gunfire support, Tomahawk cruise missile strikes, or the new task of protecting against enemy theater ballistic missiles.*

The answer to this dilemma "was": Antisubmarine warfare must be analyzed from a **joint warfighting perspective**.

A nation with a submarine force can quickly become a threat to any country's commerce and logistics lifeline. Even vintage diesel submarines can cripple a supply line for weeks.

> *"No other single weapon available to the world's regional powers today can derail a modern military campaign so totally and rapidly as a submarine."*
> *(Linder, 1995)*

2. The Need For A Flexible ASW Model

A dramatic change in mind set must occur to fully utilize all available assets for a "traditional-navy-mission" -- ASW. It must become clear to the Air Force, Army and Marine Corps that they no longer can ignore the consequences of an enemy's submarine blockade. Just as a tactical air campaign precedes the primary ground offensive, so too must the sea lanes be secured to an uninterrupted flow of war material before even the air campaign can begin This realization is the first step in the "jointization" of antisubmarine warfare.

> To provide historical backing: Analysis of RAF data from World War II shows where British bombers were integrated into the anti-U-boat patrols in the Atlantic. Long range RAF Sutherland, Liberator, and Catalina aircraft and shorter-range Willington, Whitley, Maruader, and Hudson aircraft accounted for 247 of the reported 781 U-boat losses in the Atlantic. Ships and aircraft working in tandem destroyed another 32 submarines.
>
> (MacMillan, 1950)

The "traditional-navy" ASW platforms are submarines, maritime patrol aircraft (MPAs), and surface ASW ships and their aerial complement. Non-traditional ASW platforms could be Air Force F-117s, B-52s and tankers, Marine Harriers and helicopters, and SOCOM special forces. Joint ASW tactics could include submarine port bombing, radar flooding, satellite system targeting, and harbor mining.

To rapidly respond there must be a plan for such a campaign. This aim of this thesis is to provide a tool to the military decision-maker, a large-scale, aggregated, highly flexible model of the ASW campaign that is not limited by force mix or tactics. The user friendly campaign decision aid developed in this thesis provides an integrated look at all the ASW forces' effects in concert, and the total threat of a submarine fleet to shipping (or warships) over their operating lifetime. The deliverable graphical user interface developed in this thesis will function as the analytical tool for flexible and robust ASW campaign analysis.

3. The Needs Of Combined Forces Command - Korea

Much like nuclear weapons, the submarine was and is a weapon that can frighten even the largest of powers, and proliferation is continuing. If old submarines can be viewed as such a threat, consider the fact that diesel submarines like the Russian Kilo and the German Type 209 are being made available to almost any country with the money. Is it any wonder that the North Korean submarine force, the third largest in the world, is considered the greatest obstacle to rapid resupply and the timely destruction of a North Korean invasion of Republic of Korea?

The tense nature of the region, the unstable state of the armistice and close proximity to North Korea's powerful submarine force deems the Republic of Korea as a nation in need of a joint ASW campaign model. The Combined Forces Command - Analysis Branch, Republic of Korea is the sponsor of the original intent of this model. It was their desire that the North Korean submarine threat be analyzed by Naval Postgraduate School students and faculty.

The Korean War scenario in Chapter I presents realistic expectations that a North Korean invasion will be rapid and possibly unorthodox. Resupply from the sea will probably be interrupted by submarines, North Korean and/or some other nation. If only limited assets are available, the ROK will need to quickly develop a Joint and Combined ASW plan. The model presented in this thesis is the **analytical tool** that is **flexible and robust** enough to develop such a timely campaign.

C. MODEL APPLICABILITY

The model is not limited to the Korean MRC (major regional conflict) but could be used for any scenario that involves a submarine fleet, that of Red China for example. With the de-emphasizing of ASW training and equipment procurement, there will be fewer and fewer naval forces available. Yet, third world submarine acquisition is not seeing the same de-emphasis. A strong ASW force must come from the available assets or be made available from joint and combined forces. The task then becomes the development of an effective antisubmarine warfare campaign plan against any country possessing a viable submarine threat. The flexibility and robustness of this model allows it to be applied to any scenario that poses a submarine threat.

The model can be applied to scenarios where:

- pre-war or post-war analyses are required,
- on-going war analysis is required,
- single patrol or single submarine campaign is desired,
- multiple patrol or multiple op area campaign is desired,
- force allocation is desired,
- littoral and open water analysis are desired,
- any specific starting or stopping point is desired,
- the submarine platform varies,
- the number of submarines varies,
- submarine tactics vary,
- deployment schedules vary,
- ASW tactics vary,
- campaign aggregation is desired,
- varying coalition forces will be employed.

(Throughout this thesis and when using the model, the term red submarine can be thought as a single enemy submarine or an entire enemy submarine pack or force.)

II. THE MODEL

A. DESCRIPTION

The primary modeling effort of this thesis focuses on the construction of an ASW campaign template that is easy to understand and use. The Jack Hall (1969) circulation model was the initial basis for the campaign template. A circulation model with multiple barriers is necessary to incorporate all possible traditional naval ASW assets along with as many joint elements that can be made available to the ASW mission. In template form, these will be nothing more than simple aggregated probability of kill inputs.

In order to use the Joint-ASW Model GUI, various survival probabilities of an enemy (red) submarine must be known based on the friendly (blue) ASW combat effectiveness in four different regimes. The regimes for attack are:

- In port (prior to departure),
- Outbound (enroute to the op area),
- Op areas, and
- Inbound (enroute to the red submarine port).

The ASW forces can range from none to a large aggregation of subsurface, surface, air, and space resources. A single ASW "barrier" can include naval as well as joint and combined service components which contribute to the ASW campaign. The objective of the ASW barrier must be to kill the red submarine during its transit. This equates to increased survivability of friendly ships. It is important to note that shipping protection can be accomplished in many ways, to include delaying the red submarine, knowing where the red sub is located to avoid it and of course localizing and killing it. The delays which may be accomplished by repair facility bombing or delays while overt mines are swept are not directly accounted for in the model. These tactics may be indirectly accounted for in the number of days or events endured by the red submarine in a particular regime.

The equations presented in this section are derived from a simple circulation model. ASW resources can be used alone or as a coordinated barrier. The probability of survival through any single "barrier attack" must be determined by separate tactical analysis prior to execution of the model. This requires:

1. A **pre-determination of the forces available to the ASW barrier** and
2. A **knowledge of how the aggregation of forces defines the probability of survival** of the red submarine through the barrier.

Along with this determination, it is important that the user have a variety of barrier packages defined as survival probabilities. This will allow the user to best determine how the available ASW assets can be mixed and their performance enhanced.

The model depicts one red submarine's single operational cycle. The cycle is then used as the skeleton for the blue ASW campaign. The equations used follow classical circulation models like those developed by Philip Morse and George Kimball (1946), Jack Hall (1969), and Brian McCue (1990). For simplicity, the time steps in the model are one day in both the submarine port and the operational areas while the outbound and inbound regime time steps are one "*event.*" For instance, two "similar" air attacks is equal to two events for an enroute air attack barrier.

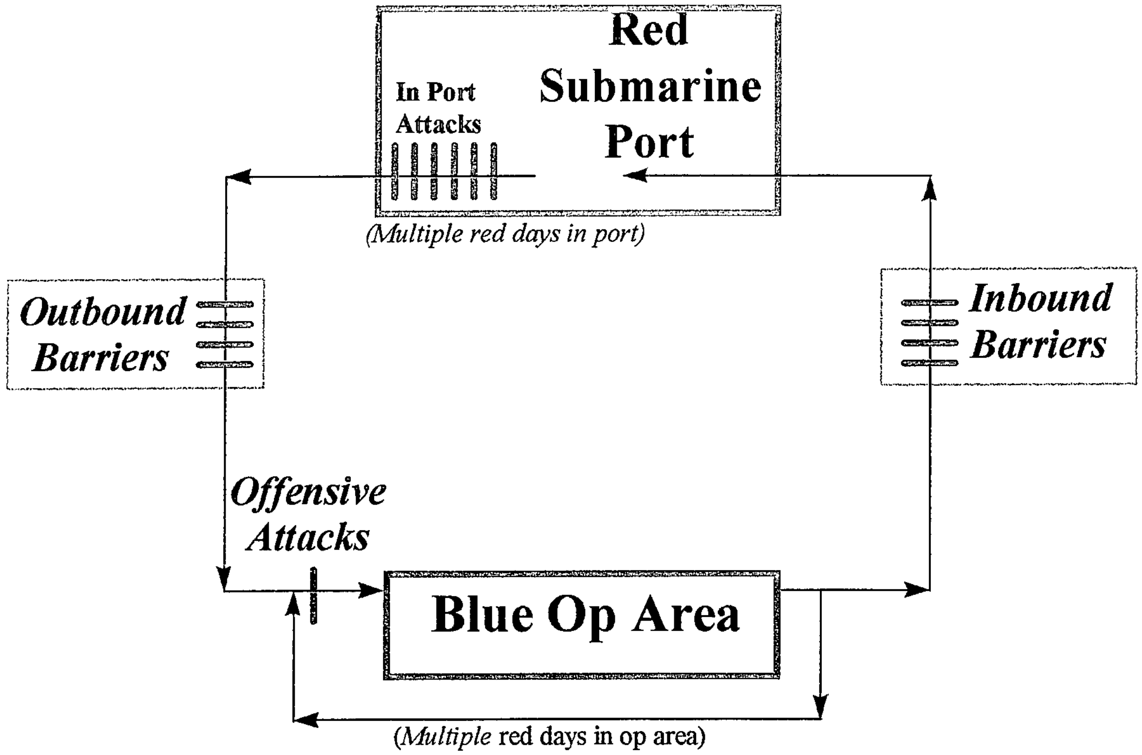


Figure 1. Basic circulation model for an ASW campaign. Note: The number of attacks presented serves to illustrate that multiple attacks are possible.

Figure 1 illustrates a red submarine operation cycle and the blue ASW campaign to combat it. For instance, a red submarine spends a number of days in port (6 days are depicted in the Figure 1). While in port, it is subject to daily in port attacks. The probability that it survives is a function of the number of days spent in port and daily survival rate, which is affected by the magnitude of the blue offensive. Surviving the in port attacks, the red submarine begins to transit toward its operational area. Along the way, the blue forces have assembled various ASW barriers. (Four barriers are depicted in the Figure 1.) The outbound barrier's effectiveness is a function of the capabilities of the barrier, the ASW attacks during the sub transit of the barrier, and the number of barriers. These barriers will be explained in more detail in a later section.

When the red submarine arrives in its operational area, it is subject to attrition by ASW forces in the op area each day it remains there. In addition to the daily effectiveness of blue offensive ASW forces, the probability of red survival in the op area is a function of the engagement rate of the submarine and the blue screen's capability. The screen must detect and then prosecute based on the detection. Once the red submarine leaves the op area it is again subject to ASW barriers during its return transit to port. The cycle is complete when the red submarine reaches port. The expected number of attacks it makes and the probability of kill for the cycle is recorded.

B. REGIMES - DEFINITIONS AND EQUATIONS

The equations are broken down into the four regimes (shown in gray): in port attacks, outbound barriers, operational areas, and inbound barriers. Figure 2 shows an example of the user's data form. It is used for data input, viewing a record of output and accessing other forms such as help files and the data set being created.

The input regimes depicted in Figure 2 in the dark gray boxes are described in detail below. ***Each regime description below is encapsulated in a light gray box like this to provide continuity and clarity.*** The equations for each regime are presented to provide an understanding of how the results are determined. The final section of this chapter provides the equations for the calculated Results (shown in the green box). The term record refers to a data set entry consisting of inputs and results an entire patrol calculation. Each time the "Calculate" button is clicked a new record is created that can be added to the data set. (See the Appendix A for data base navigation.)

(The numbers presented in the following descriptions of input and output are just an example and do not represent a real world campaign.)

The reader is reminded that this is an ***expected value model*** *and* ***the compounded results are expected (mean) values.***

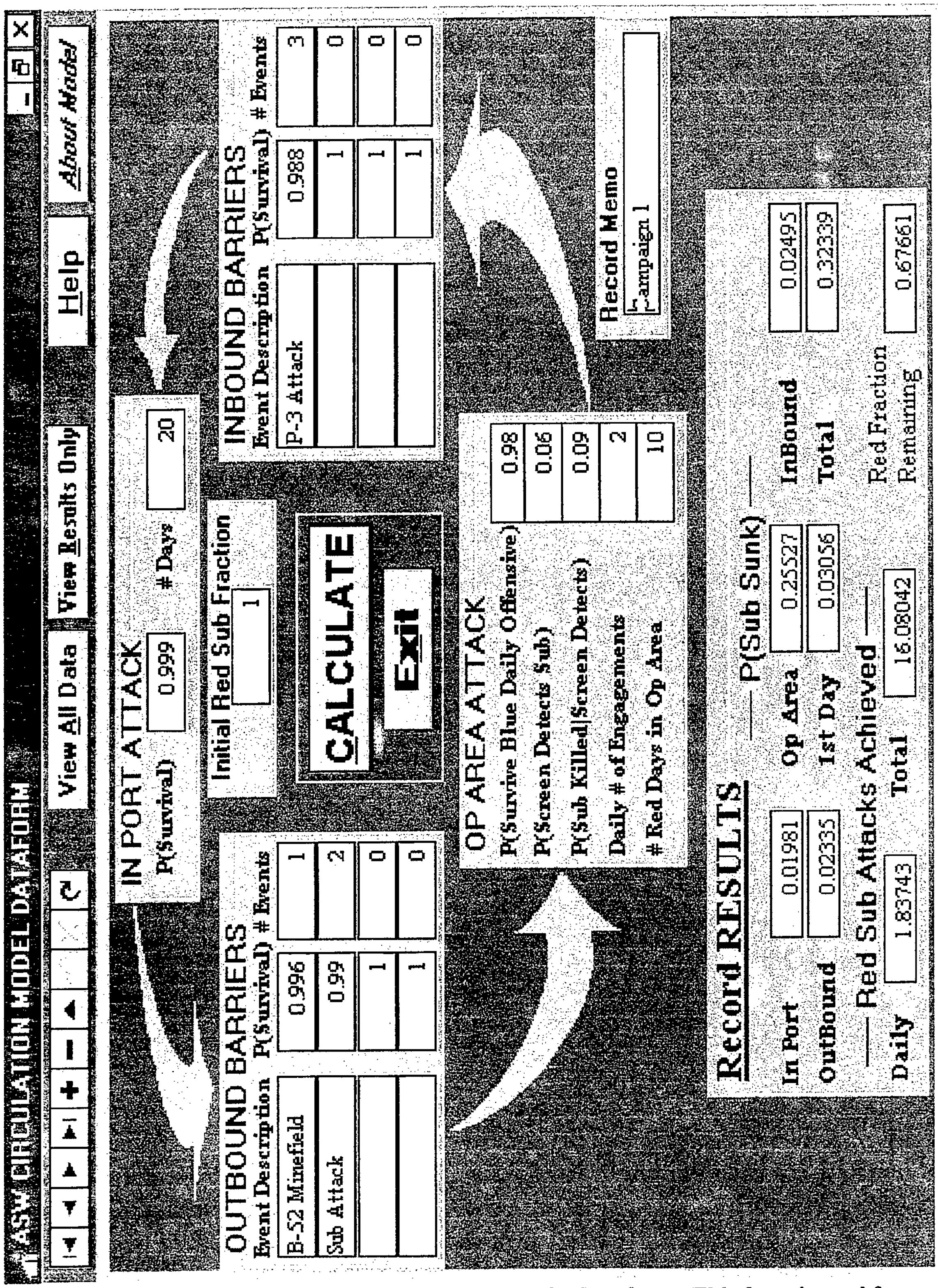


Figure 2. Example of ASW circulation model main data form. This form is used for inputting parameters, calculations, viewing a single record and accessing other features such as viewing datasets and getting help.

1. Initial Red Sub Fraction

The nature of the model provides for multiple runs of the model or aggregated campaigns. For a typical first run or patrol of a red submarine force the *initial red sub fraction* is one.

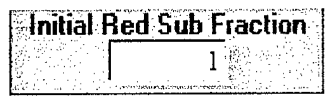


Figure 3. Example of user input for the initial red submarine fraction box

When the red submarine force has been attrited by one or more previous patrols, then the *initial red sub fraction* becomes the expected *"red fraction remaining"* from the previous run. The *"red fraction remaining"* is given in the green results box.

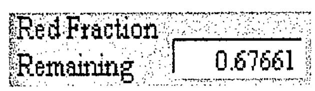


Figure 4. Example of output for the fraction of red submarine force remaining

2. In Port Regime

For simplicity of the model, only attacks against the red submarine are of interest. As mentioned previously only direct attacks are accounted for in the model calculations. Examples of direct attacks on a submarine are bombing, missile attack, and hull mining. Less direct and effective attacks must be accounted for by increased in port time due to bombing of submarine piers, repair facilities, weapon storage facilities, communication sites, harbor mining, and jamming of submarine communications.

IN PORT ATTACK

User entries:
P(Survival) := qPort = Probability of survival of the red submarine in port
 # Days := Dport = Number of Days the red submarine spends in port

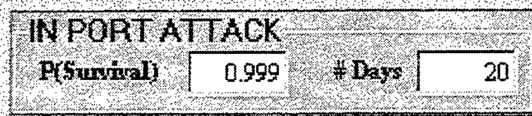


Figure 5. Example of user input for the in port attack box

The in port survival formulation is: $qInPort = qPort^{Dport}$ (1)

The model formulation to this point is:

$$PSubSunkInPort = (1 - RedInit \bullet qInPort) \quad (2)$$

3. Outbound Regime

The outbound barriers can take the form of any anti-submarine tactic that hinders the red submarine's progress to its op area. Examples include harbor and sea lane mining, traditional Naval ASW consisting of submarines, P-3s, destroyers, and others, and various assets used for C4ISR such as aircraft and satellites for communication interception and reconnaissance. Any of these assets can be used alone or as an aggregated barrier. The probability of survival through any barrier must be determined by the user prior to execution of the model. This will require a prior determination of the assets to be assigned to the ASW barrier which in turn determines the probability of survival of the red submarine passing through the barrier. Along with this determination it is important that the user have a variety of barrier survival probabilities for various

ASW asset mixes. This allows the user to determine how the available ASW assets can best be allocated.

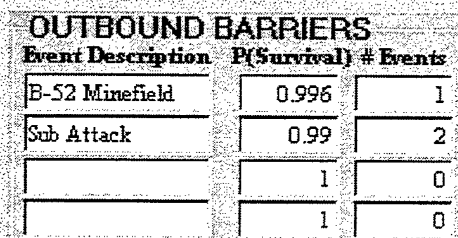
OUTBOUND BARRIERS

User entries:
Event Description := Text description of barrier
P(Survival) := $qOut_i$ = Probability of red sub surviving one blue attack event in barrier i
 # Events := NOut = Number or type of events of the outbound barrier

An example of the outbound formulation for 4 barriers is:

$$qOut_1^2 \bullet qOut_2 \bullet qOut_3^5 \bullet qOut_4$$

where the first barrier has 2 events, the second and fourth have 1 event, and the third has 5 events.



OUTBOUND BARRIERS

Event Description	P(Survival)	# Events
B-52 Minefield	0.996	1
Sub Attack	0.99	2
	1	0
	1	0

Figure 6. Example of user input for the outbound barrier box

The Outbound survival formulation is:

$$qOutbound = \prod_{i=1}^{N_{Out}} qOut_i^{n_i} \qquad (3)$$

where $qOut_i^{n_i}$ *is the probability of survival for barrier i,* n_i *is the number of days in barrier i and* N_{Out} *is the number or type of Outbound barriers.*

The model formulation to this point is:

$$PSubSunkOutbound = RedInit \bullet qInPort \bullet (1 - qOutbound) \qquad (4)$$

4. Operational Area Regime

The operational area of the blue forces is defined as the area where the blue ships will operate, loiter and seek targets to attack. It is the objective destination of the red submarine. The blue ASW campaign objective is to successfully operate in this area while minimizing ship loss to red submarines.

Merchant or cargo vessels are generally thought of as **defenseless** against a submarine. They can travel independently or in convoys, with protective escort or without. **High value units** (HVU) such as aircraft carriers, while somewhat defenseless without their complement of aircraft, have ASW assets available and will always travel with an escort.

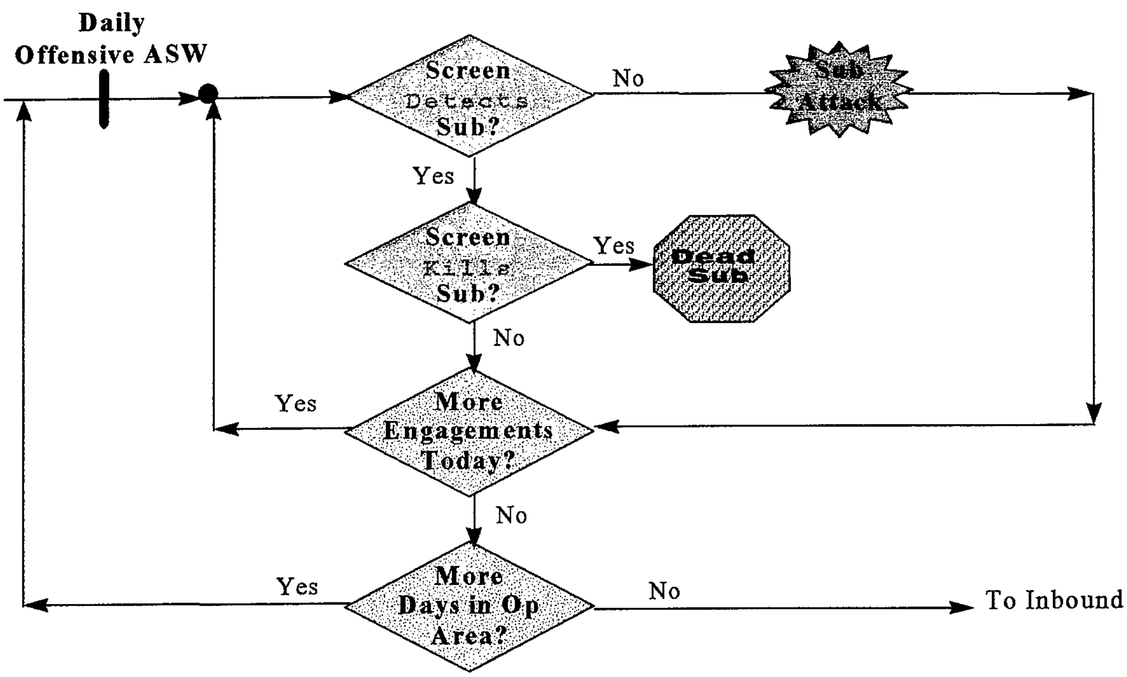


Figure 7. Wire diagram of red submarines' transit through a blue Operational Area.

OP AREA ATTACK

User entries:
P(Survive Offensive) := qOff = Probability of red sub surviving daily offensive ASW
P(Screen Detects Sub) := Pd = Probability blue screen detects the red sub that attempts to attack a target
P(Red Killed | Blue Detects) := Pk|d = Probability blue kills red given red is detected

Daily # of Engagements := Engage = Number of red attacks plus blue detections based on a daily rate or number of attempted attacks by red sub per day
 # Red Days in Op Area := Dop = Number of days the red sub spends in operational area (model assumes sub does not exhaust its torpedoes)

OP AREA ATTACK	
P(Survive Blue Daily Offensive)	0.98
P(Screen Detects Sub)	0.06
P(Sub Killed|Screen Detects)	0.09
Daily # of Engagements	2
# Red Days in Op Area	10

Figure 8. Example of user input for the operational area attack box

Useful relations:
$(1 - qOff)$ = Probability of red sub being killed by (daily) offensive ASW
$Pd \bullet Pk|d$ = Probability of red sub being killed by a screen attack
$(1 - Pd \bullet Pdk|d)$ = Probability of red sub surviving a screen attack

Daily Probability of Red Sub Being Sunk in the Op Area

$$PSubSunkOn1stDay = (1 - qOff) + qOff \bullet Pd \bullet Pk|d \bullet \sum_{i=0}^{Engage-1} (1 - Pd \bullet Pk|d)^i \qquad (5)$$

let qDailyOpArea = 1 - PSubSunkOn1stDay

Probability of Red Sub Being Sunk in the Op Area

$$RedInit \bullet qInPort \bullet qOutbound \bullet PSubSunkOn1stDay \bullet \sum_{j=0}^{Dop-1} (qDailyOpArea)^j \qquad (6a)$$

If $0 < Engage < 1$ then the daily probability of the red sub being sunk is handled in a special way explained below. If the number of days in the op area is less than one, then these probabilities are zero. If *Engage =0 but Dop >= 1* then the red submarine is being killed only by the screen and the probability of the red sub being sunk is:

$$RedInit \bullet qInPort \bullet qOutbound \bullet \sum_{j=0}^{Dop-1} (1 - qOff)^j \qquad (6b)$$

--------- **Equation 6a or 6b is the equation to this point.** -----------

Attacks Achieved:

Daily Op Area Attacks Achieved by the Red Sub

$$DailyAttacksAchieved = qOff \bullet (1 - Pd) \bullet \sum_{k=0}^{Engage-1} (1 - Pd \bullet Pk|d)^k \qquad (7)$$

Total Op Area Attacks Achieved by the Red Sub:

$$RedInit \bullet qInPort \bullet qOutbound \bullet DailyAttacksAchieved \bullet \sum_{m=0}^{Dop-1} qOff^m \qquad (8)$$

Fractional Number of Engagements:

The model allows for the case where the number of engagements is between 0.0 and 1.0 since a fractional number in this range seems realistic for a daily engagement rate. Fractional values greater than one are not allowed but whole attacks per day (2, 3, 4, ...) are permitted. The fractional case is handled by adjusting the daily offensive ASW and the number of days the red sub spends in the op area. This allows the number of engagements *(Engage)* to take on the integer value 1 which is necessary for the software programming. The new values become:

Engage is a fraction so Engage* ⇒ 1,
qOff* = qOff / Engage,
Dop* = Dop / Engage.

This summation assumes that the number of engagements is greater than zero. If the number of engagements is zero then the model accounts for this by ignoring the engagement term.

5. Inbound Regime

The inbound barriers can take the form of any anti-submarine tactic that hinders the red submarine's progress. The inbound regime is similar to the outbound regime.

INBOUND BARRIERS

User entries:
Event Description := Text description of barrier
P(Survival) := qIn_i = Probability of red sub surviving one blue attack event in barrier *i*
 # Events := NIn = Number of events of the Inbound barrier

INBOUND BARRIERS

Event Description	P(Survival)	# Events
P-3 Attack	0.988	3
	1	0
	1	0
	1	0

Figure 9. Example of user input for the Inbound barrier box

The Inbound survival formulation is:

$$qInbound = \prod_{i=1}^{N_{In}} qIn_i^{n_i} \quad (9)$$

where $qIn_i^{n_i}$ is the probability of survival for barrier i, n_i is the number of days in barrier i and N_{In} is the number or types of Inbound barriers.

Letting:

- qInPort = 1 - PSubSunkInPort,
- qOutbound = 1 - pSubSunkOutbound,
- qOpArea = 1 - PSubSunkInOpArea

the equation to this point becomes:

$$PSubSunkInbound = RedInit \bullet qInport \bullet qOutbound \bullet qOpArea \bullet (1 - qInbound) \quad (10)$$

6. Output Results

The probability results can be interpreted as the fraction, on the average, of the red submarine force remaining after one patrol or cycle. The user must decide if the submarine threat has been sufficiently reduced in this one patrol based on the desires and capabilities of the campaign plan. Also considered must be the number of attacks the red submarine is able to achieve keeping in mind the simplifying assumption that the red submarine has a sufficient arsenal to conduct the calculated number of attacks achieved.

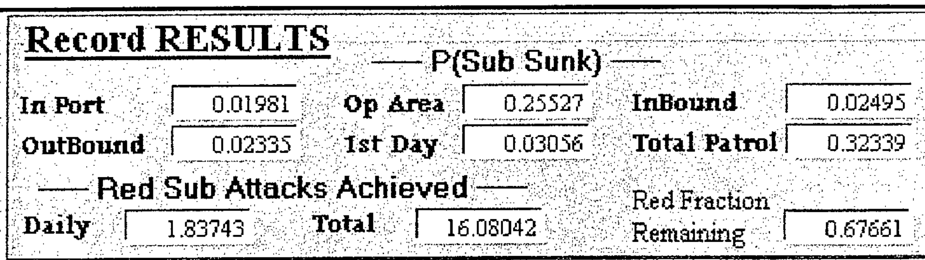


Figure 10. Example of user output for the record results box

P(Sub Sunk):

In Port := Probability the sub is sunk in port after *Nport* days in port

$$PSubSunkInPort = 1 - RedInit \bullet qPort^{Nport} \tag{11}$$

Outbound = Probability the sub is sunk in an outbound barrier

$$PSubSunkOutbound = RedInit \bullet qInPort \bullet (1 - qOutbound) \tag{12}$$

Op Area - First Day := Probability sub is sunk the first day in the operational area

$$PSubSunkOn1stDay = (1 - qOff) + qOff \bullet Pd \bullet Pk|d \bullet \sum_{i=0}^{Engage-1} (1 - Pd \bullet Pk|d)^i \tag{13}$$

Op Area := Probability sub is sunk in the operational area
PSubSunkInOpArea =

$$RedInit \bullet qInPort \bullet qOutbound \bullet PSubSunkOn1stDay \bullet \sum_{j=0}^{Dop-1} (1 - qDailyOpArea)^j \tag{14}$$

Inbound := Probability sub is sunk in an inbound barrier

$$PSubSunkInbound = RedInit \bullet qInport \bullet qOutbound \bullet qOpArea \bullet (1 - qInbound) \tag{15}$$

Total := Total probability sub is sunk {entire patrol}

$$TotalPSubSunk = 1 - RedInit \bullet qInport \bullet qOutbound \bullet qOpArea \bullet qInbound \tag{16}$$

Attacks Achieved:

Daily := Number of daily attacks achieved

$$DailyAttacksAchieved = qOff \bullet (1 - Pd) \bullet \sum_{k=0}^{Engage-1} (1 - Pd \bullet Pk|d)^k \tag{17}$$

Total := Total number of attacks achieved

$$\text{Re}dInit \bullet qInPort \bullet qOutbound \bullet DailyAttacksAchieved \bullet \sum_{m=0}^{Dop-1} qOff^{m} \quad (18)$$

C. SOFTWARE AND CODING

The Joint Anti-Submarine Warfare Model uses a graphical user interface (GUI) created in Borland® Delphi™ for Microsoft® Windows®. It requires Windows® 3.x or later to run the executable file, 16-bit and 32-bit versions are available.

This model is written to evaluate an ASW campaign utilizing various assets in ASW roles. The model provides the user an interface to enter the survival probabilities along with other related campaign parameters based on available ASW resources. The user is then provided as output the survival probabilities in three regimes, an overall survival prediction of the red submarine as well as the number of daily and total attacks the red submarine can achieve. Finally, the input and output are stored as a data base for further evaluation. This information can aide in determining force mix while providing an idea of how much of a submarine attack the blue forces are willing to endure.

Once the model was structured it was made interactive using the low level computer programming language PASCAL in Delphi. Other programming languages, analysis tools or graphical interfaces could have been used in a similar fashion. The ability of the model to be dynamic and interactive allows the user to easily tailor his ASW campaign forces to the model regimes. Along with applying traditional and joint

ASW assets, new ASW employment and tactics specifically designed for the areas along the littoral could easily be analyzed.

The user's manual (Appendix B) provides instructions of how the model can be applied to a campaign. The instructions inform the user of the flexibility of the input parameters allowing use of all available assets as well as the ability to easily incorporate new technologies as they become available. A working knowledge of how various probabilities of kills and ASW barrier strategies is assumed and necessary for valid data input and interpretation of the results. (A description of a circulation model and survival probabilities is presented in McCue, 1990.) Along with the application of assets, the varying of the asset mix to achieve the best possible ASW strategy without drawing too many assets from other areas of the campaign is explained. This critical mixing is the key to the joint applicability of the model. All available assets must be "fully" utilized. If some assets are over utilized by one facet of the war then the attempt at full utilization is wrong. For example, if B-52s are allocated to the ground campaign for large area bombing when the ground war is actually being delayed because enemy submarines are slowing the resupply effort then B-52s are not being properly utilized. Using the B-52s for a few days of submarine port bombing or harbor mining may be a better way to fully utilize available assets. The same is true if B-52s are performing ASW missions when the ground campaign is the primary focus of attack. This is the mind-set the model user must achieve to begin to tap the benefits of a joint ASW model.

D. SHORTCOMINGS OF THE MODEL INTERFACE

Due to a number of factors, including time and inexperience with the software, certain shortcomings of the usable model exist which must be known. These shortcomings are simply issues that the user should be aware of when using this analytical tool.

1. Limited Input Value Ranges

Abnormal values such as probabilities less than zero are not allowed by the model. The model will only accept values in the allowed ranges. The user will receive an error message and be prompted for another input if a value is outside the allowed range.

The ranges of allowed values are:

- **All probabilities and "Initial Red Sub Fraction" = {0.0, 1.0},**
- **Number of days and events = {0, 999} (this must be an integer value),**
- **Number of engagements = {0.0, 1.0} and {1, 99} (integer values $\geq$ 1)**
- **Event descriptions = 20 characters or less**
- **Memo Record = 50 characters or less**

The default parameters are such that not all of the input parameters need to be entered. The data is entered in a screen which is defined as the main form of the model. All other screens or forms can be accessed from the main form. In order to input data, the user simply clickc on the desired input box and types a value. It may be necessary to that is already in the box by backspacing or highlighting and deleting the value. It is possible to tab through the input boxes and enter values without having to delete old values.

2. Number Of Days And Engagements Per Day

Some values such as the number of days must be an integer value since these values are part of a summation or product index which is handled by program looping. The same is true of the number of engagements for values greater that or equal to one. The special case where the number of engagements is a fraction in the range of {0.0, 1.0} is coded by number manipulation and then rounding the value of the number of engagements to one. This number manipulation explained in detail in the section on *"Op Area Attack."* This fractional range from 0.0 to 1.0 was deemed important and easily codable for the model, but whole numbers greater than one are allowed.

3. Limited Number Of Barriers

Only four outbound and inbound barriers are allowed for a single patrol due size limitations of the input screen. This has, thus far, not been a problem for any verification campaigns.

4. Simple Help Files

The graphical interface does not allow the use of pull down menus like some software products because of time and the complexity of the coding required to accomplish these tasks. The help available to the user during the running of the model consists of a number of scrollable text files. If this is insufficient then the user's manual

(Appendix A) or this thesis can be used.

5. Rounding Output

Values had to be rounded to five decimal places to fit on the main form screen. This should not be a problem given the accuracy of most probability information.

6. Time Steps

The selection of daily and event time steps is based on convenience and is supported by previous models (Eagle, 1987) and (Washburn, 1980). The time step need not be one 24 hour day but simply a convenient unit of time that is consistent for all regimes. For example, a time step of one hour can be used provided that each regime uses the same time step. This can be done by adjusting the value for the number *"days" in port, "days" in the op area,* and the *"daily" number of engagements* to hours. The number of barrier events must also be adjusted accordingly. This may be another way to account for a fractional engagement rate.

7. What The Model Does Not Know In The Op Area

The model is not able to know if the red submarine has sufficient weapons to continue attacking for the inputted number of days in the operational area. Along these lines, the model cannot know if the red submarine would interrupt its attack cycle due to damage or some other reason. The damage in hits achieved by a red submarine attack is not a part of the model. Instead, just the number of attacks are tallied and the user must decide how many merchant ships or warships were put out of action or sunk in each attack. Also, the time required for *individual* engagements cannot be easily inputted into the model. Only a single daily engagement rate can be handled by the model.

III. MODEL VERIFICATION AND VALIDATION

Verification was achieved by trying each regime in isolation and comparing results with hand calculations. The entire model was then exercised and compared with hand calculations of aggregated model inputs. The verification numbers used were deemed reasonable to ASW trained personnel. The intent of verification was to simply test that the model produced results that correspond to the equations and event flows in the model. Validation consisted of inputting reasonable values to see that reasonable results ensued.

Presented in the subsections of this chapter are two campaigns. The testing is presented here as a series of tests. First, the in port regime was tested by itself. Second, the model was tested by adding the outbound regime to the in port regime. Third, the model was tested for an entire patrol and finally, the model was tested for multiple campaigns patrols or an aggregated campaign. Each time the model was tested, the legitimacy of the results was verified by hand calculations.

A. ISOLATED REGIME

Assuming a direct attack against a submarine in port would not be very effective the probability of survival, *qPort*, would be quite large, for example $qPort = 0.999$. For the simple case of a submarine spending one day in port, the total probability of the submarine surviving is just:

$$qPort^1 = qPort = 0.999.$$

If the submarine spends 20 days the total probability of the submarine surviving is:

$$qInPort = qPort^{20} = 0.999^{20}$$

$$= 0.980.$$

In words, 98 percent of the submarine force will be leaving the red submarine port to conduct the rest of the patrol. In terms of the probability that the submarine is sunk,

$$PSubSunkInPort = 1 - 0.98 = 0.02$$

or 2 percent of the submarine force was destroyed by in port attacks.

B. MULTIPLE REGIMES

Continuing with this 98 percent of a red submarine force, various blue barriers are staged to weaken the submarine threat along the outbound transit to the objective destination, the operational area. The outbound regime time steps are "events." Along the outbound transit, B-52s have laid a minefield which has a 0.4 percent chance of kill and is defined to be one event. Another outbound barrier encountered is a blue fast attack submarine which has a one percent chance of kill for each of its two attacks it conducts. Summarizing these two outbound barriers:

Minefield: qOut1 = 1 - 0.004 = 0.996, 1 event

Attack Sub: qOut2 = 1 - 0.010 = 0.99, 2 events

Outbound Survival Probability: $qOutbound = qOut^{1} \bullet qout2^{2}$

$$= 0.996 \bullet 0.99^{2}$$

$$= 0.976$$

The probability the sub is sunk during the outbound transit is:

$$qInPort \bullet (1 - qOutbound) = 0.98 \bullet (1 - 0.976) = 0.023$$

In words, 97.7 percent of the red submarine force will continue to the operational area regime to attack the blue forces. If the patrol did not continue to the operational area the blue force achieved a total probability of kill, *PSubSunkTotal = 1 - 0.977 = 0.023* or 2.3 percent attrition of the red submarine force.

C. FULL PATROL / SINGLE CAMPAIGN

Continuing with the example, next 97.7 percent of the red submarine force enters the operational area, blue ASW forces launch daily offensive attacks using MPA, Harrier reconnaissance, and coalition ASW submarines. The probability that the red submarine survives each daily offensive attack is *qOff = 0.98.* If the blue force does not have a screen, which will be the case for independently sailing merchant ships, then the probability that the submarine, is detected during an attack is zero. However, for this campaign we use a screen consisting of a cruiser, a destroyer and an S-3 yielding a probability of detecting the red submarine force, *Pd = 0.06*, and a probability of kill given detection, *Pk|d = 0.09.* For such a weak screen, *2 engagements per day by the red sub (Engage)* seem possible. We further estimate that the red submarine force will remain in the operational area for *10 days (Dop).* Summarizing the daily operational area results:

$$PSubSunkOn1stDay = (1 - qOff) + qOff \bullet Pd \bullet Pk|d \bullet \sum_{i=0}^{Engage-1}(1 - Pd \bullet Pk|d)^i$$

$$= (1 - 0.98) + 0.98 \bullet 0.06 \bullet 0.09 \bullet \sum_{i=0}^{2-1}(1 - 0.06 \bullet 0.09)^i$$

$$= 0.031$$

The probability that the sub is sunk in the operational area (ignoring previous attrition) over its entire 10 day patrol is:

$$PSubSunkInOpAreaAlone = PSubSunkOn1stDay \bullet \sum_{j=0}^{Dop-1}(1 - PSubSunkOn1stDay)^j$$

$$= 0.031 \bullet \sum_{j=0}^{10-1}(1 - 0.031)^j$$

$$= 0.267$$

Therefore, the probability that the red submarine force survives op area attacks is:

$$qOpArea = 1 - PSubSunkInOpAreaAlone$$

$$= 1 - 0.267 = 0.733$$

Including the previous attrition:

$$PSubSunkInOpArea = qInPort \bullet qOutbound \bullet (1 - qOpArea)$$

$$= 0.98 \bullet 0.976 \bullet (1 - 0.733)$$

$$= 0.255$$

Leaving the operational area, the red submarine force must transit through one inbound barrier of P-3s. A *1.2 percent chance of kill* exists for each of its *3 events* conducted. Summarizing this inbound barrier:

P-3 barrier: $qIn1 = 1 - 0.012 = 0.988$, *3 events*

Inbound Survival Probability: $qInbound = qIn1^3$

$$= 0.988^3$$

$$= 0.964$$

After accounting for the fact that some subs have already been sunk the probability that the submarine is sunk by the inbound barrier is:

$$PSubSunkInbound = qInPort \bullet qOutbound \bullet qOpArea \bullet (1 - qInbound)$$

$$= 0.98 \bullet 0.976 \bullet 0.733 \bullet (1 - 0.964)$$

$$= 0.025$$

The total patrol survival probability after the four regimes is:

$$qInPort \bullet qOutbound \bullet qOpArea \bullet qInbound$$

$$= 0.98 \bullet 0.976 \bullet 0.733 \bullet 0.964$$

$$= 0.676$$

In words, 67.6 percent of the red submarine force will complete the entire patrol. The total probability of kill achieved on the port-to-port cycle is:

$$PSubSunkTotal = 1 - 0.676 = 0.324$$

or 32.4 percent attrition of the red submarine force for its first round trip.

Also of importance is the number of attacks the red submarine force is able to achieve. These attacks are conducted in the blue operational area when an engaging red submarine is not detected by the screen. The calculations are dependent on how much of the red submarine force is available daily in the operational area to conduct attacks. Since we have specified that two attacks per submarine are possible, the number of red submarine attacks achieved on the first day are:

$$DailyAttacksAchieved = qOff \bullet (1 - Pd) \bullet \sum_{k=0}^{Engage-1} (1 - Pd \bullet Pk|d)^k$$

$$= 0.98 \bullet (1 - 0.06) \bullet \sum_{k=0}^{2-1} (1 - 0.06 \bullet 0.09)^k$$

$$= 1.84$$

The total number of attacks per sub achieved during its 10 days in the op area is:

$$TotalAttacksAchieved = qInPort \bullet qOutbound \bullet DailyAttacksAchieved \bullet \sum_{m=0}^{Dop-1} qOff^{m}$$

$$= 0.980 \bullet 0.976 \bullet 1.84 \bullet \sum_{m=0}^{10-1} 0.98^{m}$$

$$= 16.1$$

Simple Patrol Campaign Summary: The ASW campaign killed approximately 32 percent of the submarine force during its round trip, and each sub achieved approximately 16 attacks. We do not say how many ships in a convoy may be torpedoed on the average by each sub attack. For instance, it may fire a salvo of 6 torpedoes and hit 2.5 merchant ships for a total of 40 ships torpedoed. Achieving most (26.7%) of the attrition in the blue operational area where the red submarine force spends most of its time makes sense for the inputs in the example. However, the user would challengein his own mind whether the sub capable of making 16 attacks and hitting 40 ships would actually do so. If he fires 6 torpedoes per attack he would have to carry 96 torpedoes to sea!

D. MULTIPLE PATROL / AGGREGATED CAMPAIGN

A multiple patrol campaign test is next demonstrated to analyze how various forces can best be used. Achieving the proper force mix based on the available assets is a fundamental goal of running the model. Using the above example as the base campaign, various changes are described below and the results summarized in the table which follows.

Campaign 1 (Attrition) : Using the base campaign described in the previous sections, 67.7 percent of the red submarine force remain, a campaign of continuing attrition is conducted.

Campaign 1a: (Remaining red submarine force = 0.677)

1. Reduced bombing of the submarine port coupled with only a short in port period.

2. B-52 minefield is replenished but is not as effective because of enemy intelligence.

3. P-3 attack becomes an outbound vice an inbound barrier.

4. Op Area offensive becomes slightly more efficient at killing the red submarines.

5. JSTARS intelligence is added to the screen effectiveness.

6. The number of engagements per day decreases because of the increased complexity of the forces in the op area.

Campaign 1b: (Remaining red submarine force = 0.464)

1. Ten day in port period.

2. B-52 minefield is not replenished and therefore is less effective.

3. Op Area offensive is enhanced by a cruiser.

4. SSN is added to the screen.

5. P-3 attack and a coalition SS barriers are added to the inbound regime.

At the end of *campaign 1b* only 20.7 percent of the red submarine force remains.

Campaign 2: Using the base campaign described in previous sections, a campaign involving a submarine assault against a second and third operational area is conducted. Only the in port, outbound, and operational regimes from the original example will be used. Since the red submarine force is not returning to port after the first and second operational areas the inbound regime will be ignored. The outbound regime will be used for enroute barriers between the operational area regimes. The red submarine force will pass through the inbound barrier after the final operational area. The op area of Campaign 2a is for merchants while the op area for 2b is for an aircraft carrier.

Campaign 2a: (Remaining red submarine force = 0.702)

1. SSN attacks the red submarine in the outbound (enroute) regime.

2. No offensive ASW because this op area is for merchants.

3. Screen is limited to a FF and one helicopter.

4. The number of engagements is high because of the small ASW force in the op area.

Campaign 2b: (Remaining red submarine force = 0. 671)

1. P-3 attacks the red submarine force in the outbound (enroute) regime.

2. Air Force F-15 intelligence improves the P-3's ability to find the red submarine and thus decrease the probability of its survival in the outbound regime.

3. Offensive ASW consists of a cruiser and diesel submarine.

4. Screen consists of a cruiser, two destroyers, one SSN, one FFG and two S-3s freed form refueling duty by reallocation of assets.

5. The number of engagements per day is small (0.5). To allow the software to handle a fractional value, the number of days in the op area and the probability of surviving daily offensive attacks *(qOff)* must be altered. For 0.5 engagements/day the number of days is doubled (Dop/fractional number of engagements) and *qOff* halved (qOff/fractional number of engagements). This allows the number of engagements/day to take on an integer value of one.

6. A P-3 laid minefield is the sole barrier for the inbound regime.

At the end of campaign 2b only 0.47 percent of the red submarine force remains.

Table 1 contains the specific inputs and results for the extended campaigns.

	Attrition Campaign			Multiple Op Areas Campaign		
Inputs	**1**	**1a**	**1b**	**2**	**2a**	**2b**
Initial Red Sub Fraction	1	0.677	0.464	1	0.702	0.671
qPort	0.999	0.9999	0.9999	0.999	1	1
Dport	20	5	10	20	0	0
qOut1	0.996	0.998	0.999	0.996	0.985	0.9
# of Events	1	1	1	1	2	3
qOut2	0.99	0.99	0.99	0.99	1	1
# of Events	2	1	2	2	0	0
qOut3	1	0.988	1	1	1	1
# of Events	0	1	0	0	0	0
qOff	0.98	0.985	0.9	0.98	1	0.99
Pd	0.06	0.1	0.15	0.06	0.02	0.4
Pk|d	0.09	0.2	0.3	0.09	0.05	0.5
Engagements	2	1	1	2	3	0.5
Dop	10	10	5	10	5	10
qIn1	0.988	1	0.988	1	1	0.995
# of Events	3	0	2	0	0	1
qIn2	1	1	0.999	1	1	1
# of Events	0	0	1	0	0	0
Results						
P(Sub Sunk)						
In Port	0.02	0.324	0.537	0.02	0.298	0.329
Outbound	0.023	0.016	0.010	0.023	0.021	0.182
Op Area	0.255	0.196	0.241	0.255	0.010	0.484
1st Day	0.031	0.035	0.141	0.031	0.003	0.604
Inbound	0.025	0	0.005	0	0	0.000
Total	0.324	0.536	0.793	0.298	0.329	0.995
Attacks Achieved						
Daily	1.84	0.60	0.36	1.84	2.060	0.199
Total	16.1	5.47	1.42	16.1	10	0.279
Red Force Remaining	0.677	0.464	0.207	0.702	0.671	0.005

Table 1. Model verification input and output for two different campaigns

These scenarios provide verification to the model along with examples of how the model can be used. Other examples of campaign scenarios include:

- Pre-deployed red submarines. (Entering the model at any regime is possible by using the default values for the undesired regimes. The default values are such that the survival probability inputs are one, the probability of detection and kill given detection are zero, and number of days or events are zero.)
- Single regime or tactic analyses.
- One red submarine or many red submarines.

The model is considered verified. No real world validation of an entire campaign is possible, however, because of the complexity of the campaign. The best that can be hoped for is to use fleet exercises and tactical models to assemble the best possible inputs for in port, enroute and operational area effectiveness of the ASW force and of the red submarines in detecting, closing and attacking blue shipping or naval forces.

IV. SUMMARY AND RECOMMENDATIONS

A. SUMMARY

"No other single weapon available to the world's regional powers today can derail a modern military campaign so totally and rapidly as a submarine." *(Linder, 1995)*

The change in the world situation has prompted the emergence of an old problem that was never completely solved. The diesel threat was virtually disregarded during the development of nuclear power for submarines and the subsequent build up of the Soviet submarine force. ASW resources throughout the 1970s and 1980s were centered on the nuclear threat (SSNs/SSGNs) but the in the 1990s the threat has shifted to the significantly less expensive but prevalent diesel. Better use of available assets coupled with new tactics are required to deal with the diesel submarine.

The circulation model adapted for use in this thesis provides a flexible, robust approach to ASW campaign analysis. To rapidly respond there must be a plan for such a campaign. The aim of this thesis was to provide a tool to the military decision-maker, a large-scale, aggregated, highly flexible model of the ASW campaign that is not limited by force mix or tactics. The user friendly campaign decision aid developed in this thesis provides an integrated look at all the ASW forces' effects in concert, and the total threat of a submarine fleet to shipping (or warships) over their operating lifetime. The deliverable graphical user interface is the analytical tool for flexible and robust ASW campaign analysis.

More specifically, the model allows for changing threats, unlimited tactics, unlimited force mix, and varying campaign lengths. It uses fixed time steps of days and number of events for the various regimes which seem to characterize ASW campaign analyses. In fact, the unit of time for an entire patrol can be altered by the user if the desired.

This thesis develops a model distributable as a graphical user interface (GUI) for an antisubmarine warfare campaign. The use of the GUI as an analytical tool can aid in the planning and analysis of naval and joint force mix to combat an ASW threat. The GUI is based on the circulation model developed by Jack Hall (Hall, 1969). Instead of limiting the user to uniquely naval assets and specific blue water tactics, this model allows the user the flexibility to utilize all available ASW assets in any manner or tactic desired.

The model was developed in *Borland® Delphi™* for use in *Microsoft® Windows.®* It is distributable with a nearly empty database and the necessary configuration software (Borland Database Engine® and Reportsmith®) to set up and run the executable file. The file can be run from a file manager or a File|Run command window.

Some problems encountered with the model and its coding are discussed in the previous chapter. Two notable observations of the model are:

1. A shortcoming of the model which is not easy to properly account for is that a red submarine will continue to conduct engagements until the inputted number of days is completed. This occurs regardless whether the red submarine force may have fired all its torpedoes or whether blue targets remain in the operational area.

2. The model alone does not offer techniques for obtaining the required input parameters. However, the text of the thesis does suggest ideas of how forces other than naval ASW assets can be utilized in an ASW role.

B. RECOMMENDATIONS

Continued attention to a comprehensive campaign-wide concept of dealing with the submarine threat is recommended. More importantly, increased analysis of the use of non-uniquely naval ASW assets in an ASW role must be conducted. This will not be possible until all the services including the Navy comprehend the threat of an attack submarine, nuclear or diesel.

Regarding the Model:

1. The simplistic nature of the circulation model has its limitations. Future development of an ASW campaign or increased complexity may overcome or sidestep these limitations.

2. Optimization of each regime could be extremely helpful to the user's analysis. Along this line, optimization of a particular campaign could be conducted and incorporated into the user's manual.

3. More realistic time steps could be developed to account for varying lengths of time in the barrier regime and the time of individual engagements.

4. The duration of the operational area regime can be improved to account for the number of red submarine weapons and send the red submarines home after a given number of attacks.

Regarding the software:

1. The creation of a graphical user interface (GUI) was to make the model a deliverable and usable product. It is not necessary to use a GUI to develop a campaign but the software calculations are a great deal simpler and faster. The development of a simple, user friendly is the most significant accomplishment of this thesis.

2. Borland Delphi was chosen as the software platform because of its availability and ease of use. A similar GUI could have been created in JAVA, Virtual Basic or even C++. The use of these other programming mediums may yield improved interfaces.

3. Database interaction and help pages are areas which can be improved upon to make the model more user friendly.

APPENDIX A. DELPHI CODE

The code supplied in this appendix is for the main project (32 bit version) and all the forms used by the project. Other versions use the same code with the exception of specific difference between Delphi® 1.0 and 2.0. The 16-bit versions will not have the ReportSmith® print procedures. All the files are written in Borland® PASCAL® which is the programming language of Borland® Delphi® .

FILE: ASW32.DPR

```
program Asw32;

uses
  Forms,
  Asw_modl in 'A:\Model3\ASW_MODL.PAS' {DataForm},
  About in 'A:\Model3\ABOUT.PAS' {AboutBox},
  Asw_grid in 'A:\Model3\ASW_GRID.PAS' {DataSummary},
  Rsultgrd in 'A:\Model3\RSULTGRD.PAS' {ResultsForm},
  Helpmain in 'A:\Model3\helpmain.pas' {HelpMainForm},
  Hpurpose in 'A:\Model3\hpurpose.pas' {HModelPurpose},
  Hdata in 'A:\Model3\hdata.pas' {HDataEntry},
  Dbnav in 'A:\Model3\dbnav.pas' {HDBNav},
  Heqns in 'A:\Model3\heqns.pas' {HEquations};

{$R *.RES}

begin
  Application.CreateForm(TDataForm, DataForm);
  Application.CreateForm(TAboutBox, AboutBox);
  Application.CreateForm(TDataSummary, DataSummary);
  Application.CreateForm(TResultsForm, ResultsForm);
  Application.CreateForm(THelpMainForm, HelpMainForm);
  Application.CreateForm(THModelPurpose, HModelPurpose);
  Application.CreateForm(THDataEntry, HDataEntry);
  Application.CreateForm(THDBNav, HDBNav);
  Application.CreateForm(THEquations, HEquations);
  Application.Run;
end.
```

FILE: ASW_MODL.PAS

```
unit Asw_modl;

interface

uses
  About, Helpmain, Asw_grid, Rsultgrd,
  SysUtils, WinTypes, WinProcs, Messages, Classes, Graphics, Controls,
  StdCtrls, Forms, DBCtrls, DB, DBTables, Mask, ExtCtrls;

type
  TDataForm = class(TForm)
    ScrollBox: TScrollBox;
    DataSource1: TDataSource;
    MainformButtonPanel: TPanel;
    DataformDBNavigator: TDBNavigator;
    INPORTGroup: TGroupBox;
    OutboundGroup: TGroupBox;
    ResultsGroup: TGroupBox;
    LabelNAtksPoss: TLabel;
    LabelDailyAtksAchieved: TLabel;
    LabelPPatrolSurv: TLabel;
    LabelPSubSunkInOpArea: TLabel;
    LabelPSubSunk1stDay: TLabel;
    LabelPSubSunkOutbound: TLabel;
    LabelPSubSunkInPort: TLabel;
    EditPInPort: TDBEdit;
    LabelPInPortSurv: TLabel;
    LabelDInPort: TLabel;
    EditDInPort: TDBEdit;
    LabelOutDesc: TLabel;
    EditOut1Desc: TDBEdit;
    EditOut2Desc: TDBEdit;
    EditOut3Desc: TDBEdit;
    EditOut4Desc: TDBEdit;
    LabelOutPSurv: TLabel;
    EditPOut1: TDBEdit;
    EditPOut2: TDBEdit;
    EditPOut3: TDBEdit;
    EditPOut4: TDBEdit;
    EditEOut1: TDBEdit;
```

```
EditEOut2: TDBEdit;
EditEOut3: TDBEdit;
EditEOut4: TDBEdit;
LabelOutNEvents: TLabel;
OPAREAGroup: TGroupBox;
LabelPOpAreaSurv: TLabel;
EditPOpOff: TDBEdit;
LabelPDet: TLabel;
EditPDet: TDBEdit;
LabelPKD: TLabel;
EditPKillDet: TDBEdit;
LabelDop: TLabel;
EditDOpArea: TDBEdit;
LabelEngagements: TLabel;
EditNOpAreaAttks: TDBEdit;
ButtonPanel: TPanel;
ExitButton: TButton;
mainpanel: TPanel;
ASWTable: TTable;
InboundGroup: TGroupBox;
LabelInDesc: TLabel;
LabelInNEvents: TLabel;
LabelInPSurv: TLabel;
EditIn1Desc: TDBEdit;
EditIn2Desc: TDBEdit;
EditIn3Desc: TDBEdit;
EditIn4Desc: TDBEdit;
EditEIn1: TDBEdit;
EditEIn2: TDBEdit;
EditEIn3: TDBEdit;
EditEIn4: TDBEdit;
EditPIn1: TDBEdit;
EditPIn2: TDBEdit;
EditPIn3: TDBEdit;
EditPIn4: TDBEdit;
LabelPSubSunkInbound: TLabel;
ASWTablePInPort: TFloatField;
ASWTableDInPort: TFloatField;
ASWTableOut1Desc: TStringField;
ASWTableOut2Desc: TStringField;
ASWTableOut3Desc: TStringField;
ASWTableOut4Desc: TStringField;
ASWTablePOut1: TFloatField;
ASWTablePOut2: TFloatField;
```

```
ASWTablePOut3: TFloatField;
ASWTablePOut4: TFloatField;
ASWTableEOut1: TFloatField;
ASWTableEOut2: TFloatField;
ASWTableEOut3: TFloatField;
ASWTableEOut4: TFloatField;
ASWTablePOpOff: TFloatField;
ASWTablePDet: TFloatField;
ASWTablePKillDet: TFloatField;
ASWTableDOpArea: TFloatField;
ASWTableNOpAreaAttks: TFloatField;
ASWTablePSubSunkInPort: TFloatField;
ASWTablePSubSunkOutbound: TFloatField;
ASWTablePSubSunk1stDay: TFloatField;
ASWTablePSubSunkInOpArea: TFloatField;
ASWTableDailyAtksAchieved: TFloatField;
ASWTableTotalAtksAchieved: TFloatField;
ASWTableTotalPSubSunk: TFloatField;
ASWTableId: TFloatField;
ASWTableMemo: TStringField;
ASWTableIn1Desc: TStringField;
ASWTableIn2Desc: TStringField;
ASWTableIn3Desc: TStringField;
ASWTableIn4Desc: TStringField;
ASWTablePIn1: TFloatField;
ASWTablePIn2: TFloatField;
ASWTablePIn3: TFloatField;
ASWTablePIn4: TFloatField;
ASWTableEIn1: TFloatField;
ASWTableEIn2: TFloatField;
ASWTableEIn3: TFloatField;
ASWTableEIn4: TFloatField;
ASWTablePSubSunkInbound: TFloatField;
ViewData: TButton;
ViewResults: TButton;
EditPSubSunkInPort: TDBEdit;
EditPSubSunkOutbound: TDBEdit;
EditDailyAtksAchieved: TDBEdit;
EditTotalAtksAchieved: TDBEdit;
EditPSubSunkInOpArea: TDBEdit;
EditPSubSunkOn1stDay: TDBEdit;
EditTotalPSubSunk: TDBEdit;
LabelResultsPSubSunk: TLabel;
LabelResultsAttacksachieved: TLabel;
```

```
    CalculateButton: TButton;
    HelpButton: TButton;
    ImageUpLeftArrow: TImage;
    ImageLowerLeftArrow: TImage;
    ImageLowerRightArrow: TImage;
    Image1: TImage;
    RecordMemoGroupBox: TGroupBox;
    EditMemo: TDBEdit;
    AboutButton: TButton;
    EditPSubSunkInbound: TDBEdit;
    ASWTablePRedStartingForce: TFloatField;
    InitialRedSubFractinGroup: TGroupBox;
    EditPRedStart: TDBEdit;
    LabelRedFractionRemaining: TLabel;
    EditRedFractionRemaining: TDBEdit;
    ASWTableRedFractionRemaining: TFloatField;
    procedure FormCreate(Sender: TObject);
    procedure ExitButtonClick(Sender: TObject);
    procedure CalculateButtonClick(Sender: TObject);
    procedure HelpButtonClick(Sender: TObject);
    procedure AboutButtonClick(Sender: TObject);
    procedure ViewDataClick(Sender: TObject);
    procedure ViewResultsClick(Sender: TObject);

  private
    { private declarations }
  public
    { public declarations }
  end;

var
  DataForm: TDataForm;

implementation

{$R *.DFM}

procedure TDataForm.FormCreate(Sender: TObject);
{ The procedure TDataForm.FormCreate opens the data base table. }
begin
  ASWTable.Open;
end;

procedure TDataForm.ExitButtonClick(Sender: TObject);
```

```
{ The procedure TDataForm.ExitButtonClick closes the running program. }
begin
   close;
end;

{Power function to compute the Base to the Exponent power.}
function Power(Base,Exponent: real):real;
begin
   if (Exponent < 0.000001) then   {let zero to the zeroth power = 1}
   begin
     Power := 1.0;
     end
    else if (abs(Base) < 0.000001) then  { Prevent ln(0) }
     begin
       Power := 0.0;
     end
    else begin
      Power := exp(Exponent*ln(Base));
   end;
end;


{----------------------------------------------------------------}

procedure TDataForm.CalculateButtonClick(Sender: TObject);

{ The procedure TDataForm.CalculateButtonClick performs the bulk of the
calculations when the "Calculate" button is clicked.  It uses the
function Power(Base,Exponent: real):real to calculate the "base" to the
"exponent" power.  No other functions or procedures are called by this
procedure.  The input values for this procedure come from the data base
text boxes on the main form of the project.  These values are entered
by the user at run time.  The allowed values are determined by the data
base structure.  No checks for valid input are done in this procedure.
The calculated values are rounded to 5 digits for consistent, easy to
read display.  The values returned to the main form and data base are in
text format. }

var RedInit, qInPort, PSubSunkInPort, qOutbound, PSubSunkOutbound, qInbound,
   PSubSunkInbound, qPatrol, TotalPSubSunk, qDet, Pd, Pkd, PdPkd,
   qAtk, qAtkSum, qOff, PSubSunkOn1stDay, qOpArea, PSubSunkInOpArea,
   DailyAtksAchieved, TotalAtksAchievedSum, TotalAtksAchieved, qOp1stDay,
   RealNAtks, RealDop : Real;
```

i, j, k, NAtks, Dop : Integer;

PSubSunkInPortRounded, PSubSunkOutboundRounded,
PSubSunkOn1stDayRounded,
PSubSunkInOpAreaRounded, DailyAtksAchievedRounded,
PSubSunkInboundRounded,
TotalAtksAchievedRounded, TotalPSubSunkRounded,
RedFractionRemainingRounded : string;

{
Variable Definitions

Real Variables
RedInit: "Initial Red Sub Fraction",
qOff: "P(Survive Blue Daily Offensive)" in the op area,
Pd: "P(Screen Detects Sub)" in the op area,
Pkd: "P(Sub Killed|Screen Detects)" in the op area,

(The next two real variables are used for the fractional engagements loops.)
RealNAtks: Real "Daily # of Engagements" in the op area,
RealDop: Real "# Red Days in Op Area",

qInPort: Probability the red sub survives the inport attacks,
PSubSunkInPort: Probability the red sub is sunk by inport attacks,
qOutbound: Probability the red sub survives the outbound attacks,
PSubSunkOutbound: Probability the red sub is sunk by outbound attacks,
qInboundProbability: the red sub survives the inbound attacks,
PSubSunkInbound: Probability the red sub is sunk by inbound attacks,
qPatrol: Probability the red sub survives the all attacks (entire patrol),
TotalPSubSunk: Probability the red sub is sunk by all attacks (entire patrol),
qDet: Probability the red sub is not detected,
PdPkd: Probability the red sub is killed,
qAtk: Probability of red sub surviving blue attack in the op area,
qAtkSum: Daily op area survival probability,
PSubSunkOn1stDay: Probability the red sub is sunk on the first day in the op area,
qOpArea: Probability the red sub survives the op area attacks,
PSubSunkInOpArea: Probability the red sub is sunk by op area attacks,
DailyAtksAchieved: Number of attacks achieved daily by a red sub,
TotalAtksAchievedSum: Cumulative number of attacks achieved by a red sub,
TotalAtksAchieved: Total number of attacks achieved by a red sub,
qOp1stDay: Probability of red sub surviving the first day in the op area,

Integer Variables
(The two integer variables below are used for the integer loops.)

NAtks: Integer "Daily # of Engagements" in the op area,
Dop: integer "# Red Days in Op Area",

String Variables
All the string variables are use for rounding calculations.
}

```
begin
  RedInit := StrToFloat(EditPRedStart.text);
  {***IN PORT***}

  qInPort := RedInit*Power( StrToFloat(EditPInport.text),StrToFloat(EditDInport.text));
  PSubSunkInPort := 1.0 - qInPort;
  PSubSunkInPortRounded :=
                FloatToStr((round(PSubSunkInPort*100000.0))/100000);
  EditPSubSunkInPort.text := PSubSunkInPortRounded;

  {*** OUTBOUND ***}

  qOutbound := Power( StrToFloat(EditPOut1.text),StrToFloat(EditEOut1.text) )
          * Power( StrToFloat(EditPOut2.text),StrToFloat(EditEOut2.text) )
          * Power( StrToFloat(EditPOut3.text),StrToFloat(EditEOut3.text) )
          * Power( StrToFloat(EditPOut4.text),StrToFloat(EditEOut4.text) );
  PSubSunkOutbound := qInPort * (1.0 - qOutbound);
  PSubSunkOutboundRounded :=
                FloatToStr((round(PSubSunkOutbound*100000.0))/100000);
  EditPSubSunkOutbound.text := PSubSunkOutboundRounded;

  {*** OP AREA ***}

  {Op Area Variable Definitions}
  Pd := StrToFloat(EditPDet.text);
  Pkd := StrToFloat(EditPKillDet.text);
  PdPkd := Pd * Pkd;  {Probability of sub killed by detection-attack}
  {Probability of red sub surviving blue attack in the op area.}
  qAtk := 1.0 - PdPkd;

  qOff := StrToFloat(EditPOpOff.text);
  qDet := 1.0 - Pd;   {Probability do not detect}
  RealNAtks := StrToFloat(EditNOpAreaAttks.text);
  RealDop := StrToFloat(EditDOpArea.text);
  {Convert NAtks and Dop to integers values for integer looping}
  NAtks := round(RealNAtks);
```

```
Dop := StrToInt(EditDOpArea.text);

if (RealDop < 1.0) then  {Trivial zero days in the op area, NAtks doesn't matter}
begin
  PSubSunkOn1stDay := 0.0;
  PSubSunkInOpArea := 0.0;
  qOp1stDay := 1.0;
  DailyAtksAchieved := 0.0;
  TotalAtksAchieved := 0.0;
 end     {End of trivial condition.}

{Check for fractional engagements per day, (between 0.0 and 1.0)}
 else if (RealNatks>0.0) and (RealNAtks<1.0) then
 begin
  qOff := qOff * RealNAtks;  {Adjust qOff}
  Dop := round(RealDop * RealNatks); {Adjust Dop and convert it round to an
integer}
  PSubSunkOn1stDay := (1.0-qOff) + qOff*PdPkd;
  {Total Op Area Survival Probability}
  qOp1stDay := 1.0 - PSubSunkOn1stDay;
  PSubSunkInOpArea := 0.0;
  qOpArea := 0.0;
  for j := 0 to (Dop-1)  do begin
    qOpArea := qOpArea + Power( qOp1stDay,j );
  end;
  PSubSunkInOpArea := qInPort*qOutbound*PSubSunkOn1stDay * qOpArea;
 {Number of Daily Successful Attacks Possible by sub}
  DailyAtksAchieved := qOff * qDet;
 {Total number of attacks possible when sub has unlimited weapons and resolve}
  TotalAtksAchievedSum := 0.0;
  for k := 0 to (Dop-1)  do begin
    TotalAtksAchievedSum := TotalAtksAchievedSum
                    + ( DailyAtksAchieved * Power(qOff,k) );
  end;
  TotalAtksAchieved := qInPort*qOutbound*TotalAtksAchievedSum;

 end    {End of fractional condition}

{No engagements and at least 1 day in the op area so sub attrited by screen}
 else if (NAtks <= 0) then
 begin
  PSubSunkOn1stDay := 0.0;
  PSubSunkInOpArea := qInPort*qOutbound*Power((1.0-qOff),Dop);
 end    {End of no engagement condition.}
```

```
{At least 1 engagement/day and at least 1 day in the op area}
  else if (NAtks >= 1) then     {Normal Calculation}
   begin
     qAtkSum := 0.0;       {Daily Op Area Survival Probability}
    {Multiple engagements loop}
     for i := 0 to (NAtks-1)  do begin
       qAtkSum := qAtkSum + Power(qAtk,i);
     end;
     PSubSunkOn1stDay := (1.0-qOff) + qOff*PdPkd*qAtkSum;
   {Total Op Area Survival Probability}
     qOp1stDay := 1.0 - PSubSunkOn1stDay;
     PSubSunkInOpArea := 0.0;
     qOpArea := 0.0;
    {Multiple days loop}
     for j := 0 to (Dop-1)  do begin
       qOpArea := qOpArea + Power( qOp1stDay,j );
     end;
     PSubSunkInOpArea := qInPort*qOutbound*PSubSunkOn1stDay * qOpArea;
   {Number of Daily Successful Attacks Possible by sub}
     DailyAtksAchieved := qOff * qDet * qAtkSum;
   {Total number of attacks possible when sub has unlimited weapons and resolve}
     TotalAtksAchievedSum := 0.0;
     for k := 0 to (Dop-1)  do begin
       TotalAtksAchievedSum := TotalAtksAchievedSum
                   + ( DailyAtksAchieved * Power(qOff,k) );
     end;
     TotalAtksAchieved := qInPort*qOutbound*TotalAtksAchievedSum;

 end;    {End of normal condition.}

{------ Op Area Probabilities Output ------}

PSubSunkOn1stDayRounded
       := FloatToStr((round(PSubSunkOn1stDay*100000.0))/100000);
EditPSubSunkOn1stDay.text := PSubSunkOn1stDayRounded;

PSubSunkInOpAreaRounded
      := FloatToStr((round(PSubSunkInOpArea*100000.0))/100000);
EditPSubSunkInOpArea.text := PSubSunkInOpAreaRounded;

{------ Op Area Attacks Output ------}

DailyAtksAchievedRounded
```

```
        := FloatToStr((round(RedInit*DailyAtksAchieved*100000.0))/100000);
  EditDailyAtksAchieved.text := DailyAtksAchievedRounded;

  TotalAtksAchievedRounded
        := FloatToStr((round(TotalAtksAchieved*100000.0))/100000);
  EditTotalAtksAchieved.text := TotalAtksAchievedRounded;

  {*** INBOUND ***}

  qInbound := Power( StrToFloat(EditPIn1.text),StrToFloat(EditEIn1.text) )
          * Power( StrToFloat(EditPIn2.text),StrToFloat(EditEIn2.text) )
          * Power( StrToFloat(EditPIn3.text),StrToFloat(EditEIn3.text) )
          * Power( StrToFloat(EditPIn4.text),StrToFloat(EditEIn4.text) );
  PSubSunkInbound := qInPort*qOutbound*Power(qOp1stDay,Dop)*(1.0 - qInbound);
  PSubSunkInboundRounded
        := FloatToStr((round(PSubSunkInbound*100000.0))/100000);
  EditPSubSunkInbound.text := PSubSunkInboundRounded;


  {OVERALL MODEL CALCULATIONS}

  qPatrol := qInPort*qOutbound*Power(qOp1stDay,Dop)*qInbound;
  TotalPSubSunk := 1.0 - qPatrol;
  TotalPSubSunkRounded
        := FloatToStr((round(TotalPSubSunk*100000.0))/100000);
  EditTotalPSubSunk.text := TotalPSubSunkRounded;

  RedFractionRemainingRounded
        := FloatToStr((round(qPatrol*100000.0))/100000);
  EditRedFractionRemaining.text := RedFractionRemainingRounded;

end;

procedure TDataForm.HelpButtonClick(Sender: TObject);
{ The procedure TDataForm.HelpButtonClick shows the main help form when
the "Help" button is clicked. }

begin
  HelpMainForm.ShowModal;
end;

procedure TDataForm.AboutButtonClick(Sender: TObject);
{ The procedure TDataForm.AboutButtonClick shows the about form when
```

```
the "About Model" button is clicked. }
begin
   AboutBox.ShowModal;
end;

procedure TDataForm.ViewDataClick(Sender: TObject);
{ The procedure TDataForm.ViewDataClick shows the Data Summary form when
the "View All Data" button is clicked. }
begin
   DataSummary.ShowModal;
end;

procedure TDataForm.ViewResultsClick(Sender: TObject);
{ The procedure TDataForm.ViewResultsClick shows the Results Summary form
when the "View Results Only" button is clicked. }
begin
   ResultsForm.ShowModal;
end;


end.
```

FILE: ABOUT.PAS

```
unit About;

interface

uses
  Helpmain, SysUtils, WinTypes, WinProcs, Messages, Classes, Graphics,
  Controls, Forms, Dialogs, ExtCtrls, StdCtrls, Buttons;

type
  TAboutBox = class(TForm)
    OKButton: TBitBtn;
    BackgroundPanel: TPanel;
    Copyright: TLabel;
    ProductName: TLabel;
    ProgramIcon: TImage;
    Version: TLabel;
    Image1: TImage;
    Name: TLabel;
    HelpButton: TButton;
    LabelCommentText: TLabel;
    Label2: TLabel;
    procedure HelpButtonClick(Sender: TObject);
  private
    { Private declarations }
  public
    { Public declarations }
  end;

var
  AboutBox: TAboutBox;

implementation

{$R *.DFM}

procedure TAboutBox.HelpButtonClick(Sender: TObject);
begin
  HelpMainForm.ShowModal;
end;

end.
```

FILE: ASW-GRID.PAS

```
unit Asw_grid;

interface

uses
  SysUtils, WinTypes, WinProcs, Messages, Classes, Graphics, Controls,
  Forms, Dialogs, StdCtrls, Buttons, DBTables, DB, Grids, DBGrids,
  ExtCtrls, DBCtrls, Report;

type
  TDataSummary = class(TForm)
    Gridheader: TLabel;
    DBNavigator1: TDBNavigator;
    DataGrid: TDBGrid;
    OKButton: TBitBtn;
    DataSource1: TDataSource;
    AllDataReport: TReport;
    DataReportButton: TButton;
    ASWTable: TTable;
    ASWTableMemo: TStringField;
    ASWTablePInPort: TFloatField;
    ASWTableDInPort: TFloatField;
    ASWTableOut1Desc: TStringField;
    ASWTablePOut1: TFloatField;
    ASWTableEOut1: TFloatField;
    ASWTableOut2Desc: TStringField;
    ASWTablePOut2: TFloatField;
    ASWTableEOut2: TFloatField;
    ASWTableOut3Desc: TStringField;
    ASWTablePOut3: TFloatField;
    ASWTableEOut3: TFloatField;
    ASWTableOut4Desc: TStringField;
    ASWTablePOut4: TFloatField;
    ASWTableEOut4: TFloatField;
    ASWTablePOpOff: TFloatField;
    ASWTablePDet: TFloatField;
    ASWTablePKillDet: TFloatField;
    ASWTableNOpAreaAttks: TFloatField;
    ASWTableDOpArea: TFloatField;
    ASWTableIn1Desc: TStringField;
    ASWTablePIn1: TFloatField;
    ASWTableEIn1: TFloatField;
```

```
    ASWTableIn2Desc: TStringField;
    ASWTablePIn2: TFloatField;
    ASWTableEIn2: TFloatField;
    ASWTableIn3Desc: TStringField;
    ASWTablePIn3: TFloatField;
    ASWTableEIn3: TFloatField;
    ASWTableIn4Desc: TStringField;
    ASWTablePIn4: TFloatField;
    ASWTableEIn4: TFloatField;
    ASWTablePSubSunkInPort: TFloatField;
    ASWTablePSubSunkOutbound: TFloatField;
    ASWTablePSubSunk1stDay: TFloatField;
    ASWTablePSubSunkInOpArea: TFloatField;
    ASWTablePSubSunkInbound: TFloatField;
    ASWTableTotalPSubSunk: TFloatField;
    ASWTableDailyAtksAchieved: TFloatField;
    ASWTableTotalAtksAchieved: TFloatField;
    ASWTableId: TFloatField;
    ASWTablePRedStartingForce: TFloatField;
    ASWTableRedFractionRemaining: TFloatField;
    procedure DataReportButtonClick(Sender: TObject);
  private
    { Private declarations }
  public
    { Public declarations }
  end;

var
  DataSummary: TDataSummary;

implementation

{$R *.DFM}

procedure TDataSummary.DataReportButtonClick(Sender: TObject);
begin
  AllDataReport.run;
end;

end.
```

FILE: RSULTGRD.PAS

```
unit Rsultgrd;

interface

uses
  SysUtils, WinTypes, WinProcs, Messages, Classes, Graphics, Controls,
  Forms, Dialogs, Grids, DBGrids, StdCtrls, Buttons, ExtCtrls, DBCtrls,
  DBTables, DB, Report, Quickrep;

type
  TResultsForm = class(TForm)
    DataSource1: TDataSource;
    ResultsDBNavigator: TDBNavigator;
    ResultsOKButton: TBitBtn;
    ResultsDataGrid: TDBGrid;
    ResultsSummary: TLabel;
    ResultsReport: TReport;
    ResultsReportButton: TButton;
    LAbelSurvivalProb: TLabel;
    LabelAttacksAchieved: TLabel;
    ASWTable: TTable;
    ResultsMemo: TStringField;
    ASWTablePSubSunkInPort: TFloatField;
    ASWTablePSubSunkOutbound: TFloatField;
    ASWTablePSubSunk1stDay: TFloatField;
    ASWTablePSubSunkInOpArea: TFloatField;
    ASWTablePSubSunkInbound: TFloatField;
    ASWTableTotalPSubSunk: TFloatField;
    ASWTableDailyAtksAchieved: TFloatField;
    ASWTableTotalAtksAchieved: TFloatField;
    ASWTablePRedStartingForce: TFloatField;
    procedure ResultsReportButtonClick(Sender: TObject);

  private
    { Private declarations }
  public
    { Public declarations }
  end;

var
  ResultsForm: TResultsForm;
```

```
implementation

{$R *.DFM}


procedure TResultsForm.ResultsReportButtonClick(Sender: TObject);
begin
  ResultsReport.run;
end;

end.
```

FILE: HELPMAIN.PAS

```
unit Helpmain;

interface

uses
  HPurpose, HData, DBNav, HEqns,
  SysUtils, WinTypes, WinProcs, Messages, Classes, Graphics, Controls,
  Forms, Dialogs, StdCtrls, ExtCtrls, Buttons;

type
  THelpMainForm = class(TForm)
    HelpRadioGroup: TRadioGroup;
    HelpMainBackToMainForm: TBitBtn;
    HMainMemo: TMemo;
    InputLimitsMemo: TMemo;
    procedure HelpRadioGroupClick(Sender: TObject);
  private
    { Private declarations }
  public
    { Public declarations }
  end;

var
  HelpMainForm: THelpMainForm;

implementation

{$R *.DFM}

procedure THelpMainForm.HelpRadioGroupClick(Sender: TObject);
begin
  If HelpRadioGroup.Items.Strings[HelpRadioGroup.ItemIndex]
          = ' Model Purpose and Description' then
  begin
    HModelPurpose.ShowModal;
  end;

  If HelpRadioGroup.Items.Strings[HelpRadioGroup.ItemIndex]
          = ' Data Entry and Manipulation' then
  begin
    HDataEntry.ShowModal;
  end;
```

```
  If HelpRadioGroup.Items.Strings[HelpRadioGroup.ItemIndex]
          = ' Navigating the Data Base' then
  begin
    HDBNav.ShowModal;
  end;

  If HelpRadioGroup.Items.Strings[HelpRadioGroup.ItemIndex] = ' Equations' then
  begin
    HEquations.ShowModal;
  end;

end;


end.
```

FILE: HPURPOSE.PAS

```
unit Hpurpose;

interface

uses
  SysUtils, WinTypes, WinProcs, Messages, Classes, Graphics, Controls,
  Forms, Dialogs, StdCtrls, Buttons;

type
  THModelPurpose = class(TForm)
    HPurposeButton: TBitBtn;
    HPurposeMemo: TMemo;
  private
    { Private declarations }
  public
    { Public declarations }
  end;

var
  HModelPurpose: THModelPurpose;

implementation

{$R *.DFM}

end.
```

FILE: HDATA.PAS

```
unit Hdata;

interface

uses
  SysUtils, WinTypes, WinProcs, Messages, Classes, Graphics, Controls,
  Forms, Dialogs, StdCtrls, Buttons;

type
  THDataEntry = class(TForm)
    HDataEntryButton: TBitBtn;
    HDataEntryMemo: TMemo;
  private
    { Private declarations }
  public
    { Public declarations }
  end;

var
  HDataEntry: THDataEntry;

implementation

{$R *.DFM}

end.
```

FILE: DBNAV.PAS

```
unit Dbnav;

interface

uses
  SysUtils, WinTypes, WinProcs, Messages, Classes, Graphics, Controls,
  Forms, Dialogs, ExtCtrls, StdCtrls, Buttons, DBCtrls;

type
  THDBNav = class(TForm)
    HDBNavButton: TBitBtn;
    HDBNavMemo: TMemo;
    DBNavigator1: TDBNavigator;
    DBNavTopLabel: TLabel;
    DBNavBottomLabel: TLabel;
  private
    { Private declarations }
  public
    { Public declarations }
  end;

var
  HDBNav: THDBNav;

implementation

{$R *.DFM}

end.
```

FILE: HEQNS.PAS

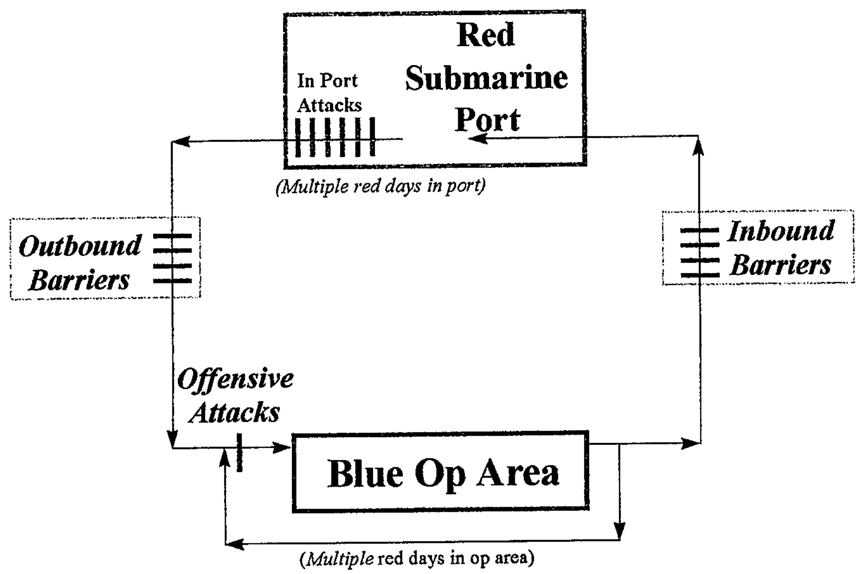
```
unit Heqns;

interface

uses
  SysUtils, WinTypes, WinProcs, Messages, Classes, Graphics, Controls,
  Forms, Dialogs, StdCtrls, Buttons, Grids;

type
  THEquations = class(TForm)
    HEqnsButton: TBitBtn;
    HEquationsMemo: TMemo;
  private
    { Private declarations }
  public
    { Public declarations }
  end;

var
  HEquations: THEquations;

implementation

{$R *.DFM}

end.
```

APPENDIX B. USER'S MANUAL

The user's manual contained in this appendix is distributed with the software for the executable model. It provides a description of the model along with specifics on how the model works. Also contained are instructions on how to load and use the graphical interface.

Note: The page numbers used in this appendix are those found in the actual user's manual.

JOINT ASW CIRCULATION MODEL



USER'S MANUAL

Version 1.0

Richard D. Feustel and Wayne P. Hughes

Naval Postgraduate School, Monterey, California

September 1996

A JOINT CAMPAIGN ANALYSIS APPROACH TO ANTISUBMARINE WARFARE USING A CIRCULATION MODEL TEMPLATE

Richard D. Feustel - Lieutenant, United States Navy
B.S., University of Wisconsin-Madison, 1989
B.S., Southern Illinois University-Carbondale, 1989

To enhance insight into a war at sea, a general, aggregated and highly flexible model of the ASW campaign is offered. This thesis provides a simple and usable circulation model template. The generality and simplicity of the model allows for "jointization" of an ASW campaign by allowing the user to utilize other resources to define the force mix. The model is designed, first and foremost, to examine the change in the marginal effectiveness of friendly ASW forces due to changes in force level, mix, effectiveness, and force employment strategies. The model is keyed to the interaction of a threat submarine with friendly ASW forces and merchant or military shipping. Specific features of the model provide for three unique attack regimes. The in port and operational regimes control friendly attacks on a daily basis while the enroute regime controls barriers by events. The campaign model is a deliverable product programmed using *Borland®* *Delphi™* for use in *Microsoft®* *Windows.®*

Master of Science in Operations Research - September 1996

Advisor: Wayne P. Hughes, Department of Operations Research
Second Reader: James N. Eagle, Department of Operations Research

Unclassified/A

NAVAL POSTGRADUATE SCHOOL
Monterey, California

USER'S MANUAL

A JOINT CAMPAIGN ANALYSIS APPROACH TO ANTISUBMARINE WARFARE USING A CIRCULATION MODEL TEMPLATE

by

Richard D. Feustel

September, 1996

Thesis Advisor: Wayne P. Hughes

Approved for public release; distribution is unlimited.

DISCLAIMER

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

TABLE OF CONTENTS

I. ASW CIRCULATION MODEL INSTALLATION GUIDE

The ASW Circulation Model software is UNCLASSIFIED. A data base which uses the software may be classified.

A. INSTALLATION INSTRUCTIONS

1. Assumptions

a. These instructions assume that the user is familiar with the Windows environment.

b. These instructions also assume the hard disk drive (Destination Drive) is Drive c: and that the floppy disk drive (Source Drive) is Drive a:. If your system is configured differently, change the Source and Destination Drive as appropriate.

2. Installing the Software

Windows® 3.x : Loading the Executable Files

a. From the Windows **Program Manager** open the **File Manager**:
   i. Double Click on **Main**.
   ii. Double Click on **File Manager**.

b. Creating the ASW Circulation Model working directory:
   ii. Click on the root directory (c:\)
   iii. Select|File Create Directory…
   iv. In the name box type **ASW**.
   v. Select the **ASW** directory.

c. Copying required Files to the **ASW** directory:
   iii. Insert the ASW Circulation Model install disk into the Source Drive (a:\).
   iv. Click on Drive a:.
   v. Click and hold the a:\ directory and drag to the Destination Drive(c:\).
   vi. The following Files should be copied to the c:\ASW\ directory:

ASW3.EXE	*The executable file.*
IDAPI16.CFG	*The database configuration file.*

ASW.DB *The database file.*

Windows® 3.1 : Creating the ASW Program Icon

a. Exit the **File Manager**.

b. From the **Program Manager** select **File|New**.

c. Select the **Program Group** and Click **OK**.

d. In the **Description Box** and **Group File Box** type ASW Circulation Model and Click **OK**.

e. Select **File|New** again.

f. Select **Program Item** and Click **OK**.

g. In the **Description Box** type ASW Circulation Model.

h. In the **Command Line Box** type c:\ASW\ASW3.EXE.

i. In the **Working Directory Box** type c:\ASW3\.

j. Click on **Change Icon**…

k. In the **File Name Box** type c:\ASW\ASW3.EXE and click **OK**.

l. Click **OK** again.

Windows® 95 and Windows® NT : Installation

a. Accessing the software:
   i. Insert ASW installation disk 1 into Drive a:.
   ii. Click the **Start** button on the Taskbar to bring up the Start menu.
   iii. Select **Settings**, and Click on **Control Panel**, double-click on the **Add/Remove Programs** icon.
   iv. On the upper portion of the **Install/Unstall** tab, click on the **Install** button.

b. Installing the software using Install Shield®:
   i. Click on **Next** when you are instructed to place the disc in your Source Drive (a:\)

ii. Windows 95 (Windows NT) will scan your Source Drive for SETUP.EXE.
iii. The Run Installation program dialog box appears and instructs you to verify that the Command Line information is correct. This information should read **a:\setup.exe**.
iv. Click **Finish** to start the installation process and follow the onscreen instructions.

B. RUNNING THE ASW CIRCULATION MODEL

Windows® 3.1

1. From the Program Manager double-click on the ASW Circulation Model Program Group.
2. Double-click on the ASW Circulation Model Program Icon to start the model.
3. Run the model as desired.
4. Table 1 describes each form used by the model.

Windows® 95 and Windows® NT

1. Click on Programs from Start menu.
2. Select ASW Circulation Model from the cascading submenu and double-click on the ASW Circulation Model icon to start the program.
3. Run the model as desired.
4. Table 1 describes each form used by the model.

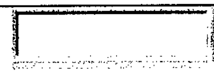
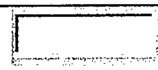
FORM	ITEM / BUTTON	DESCRIPTION
Main	ASW CIRCULATION MODEL DATAFORM	Allows for input, viewing output, and accessing all other forms.
		Input data in the white boxes. Accessed using the mouse or tab key.
		Output for that *record* or patrol is displayed in the aqua boxes.
All buttons can be clicked using the	CALCULATE	Click the Calculate button to compute the output for the entered input.
mouse or pressing the	Exit	Click the Exit button to exit the program.
Alt key along with the underlined letter on the		The *data base navigator a*llows for navigation of the data base.
desired button.	View All Data	Click to view the Data Summary form.
	View Results Only	Click to view the Results Summary form.
	Help	Click to view the Main Help Menu form.
	About Model	Click to view the About form.
Data Summary ASW Model Data Summary	View All Data	Allows viewing of all the data base records, input and output.
Results Summary ASW Model Results Form	View Results Only	Allows viewing of just the results section of the data base.
Main Help Menu ASW Model Help Menu	Help	Allows viewing of basic model information and access to all scroll-able help topics. Provides a table of allowed input values.
	Model Purpose and Description	Provides information regarding the purpose of the model a basic description of its parts.
	Data Entry and Manipulation	Provides information on how data is entered and manipulated using the main data form.
	Navigating the Data Base	Explains how data in the dataset is accessed and how to navigate the data base using the *data base navigator*.
	Equations	Provides in-depth explanation of what equations are used to calculate the results. Shortcomings of the model and software are presented here.

Table 1. Description of the model's forms and some of their parts.

II. INTRODUCTION

A. BACKGROUND

A dramatic change in mind set of military analysts must occur to fully utilize all the available forces for a "traditional-navy-mission" -- ASW. It must become clear to the Air Force, Army and Marine Corps that they no longer can ignore the consequences of an enemy's submarine blockade. Just as a tactical air campaign precedes the primary ground offensive, so too must the sea lanes be secured to an uninterrupted flow of war material before even the air campaign can begin This realization is the first step in the "jointization" of anti-submarine warfare.

> To provide historical backing: Analysis of RAF data from World War II shows where British bombers were integrated into the anti-U-boat patrols in the Atlantic. Long range RAF Sutherland, Liberator, and Catalina aircraft and shorter-range Willington, Whitley, Maruader, and Hudson aircraft accounted for 247 of the reported 781 U-boat losses in the Atlantic. Ships and aircraft working in tandem destroyed another 32 submarines.
>
> (MacMillan, 1950)

The "traditional-navy" ASW platforms are submarines, maritime patrol aircraft (MPAs), and surface ASW ships and their aerial complement. Non-traditional ASW platforms could be Air Force F-117s, B-52s and tankers, Marine Harriers and helicopters, and SOCOM special forces. Joint ASW tactics could include submarine port bombing, radar flooding, satellite system targeting, and harbor mining.

To rapidly respond there must be a plan for such a campaign. This aim of the thesis which created this model was to provide a tool to the military decision-maker, a large-scale, aggregated, highly flexible model of the ASW campaign that is not limited by force mix or tactics. The user friendly campaign decision aid developed provides an integrated look at all the ASW forces' effects in concert, and the total threat of a submarine fleet to shipping (or warships) over their operating lifetime. The deliverable graphical user interface developed will function as the analytical tool for flexible and robust ASW campaign analysis.

B. MODEL APPLICABILITY

With the de-emphasizing of ASW training and equipment procurement, there will be fewer and fewer naval forces available. Yet, third world submarine acquisition is not seeing the same de-emphasis. A strong ASW force must come from the available assets or be made available from joint and combined forces. The task then becomes the development of an effective antisubmarine warfare campaign plan against any country possessing a viable submarine threat. The flexibility and robustness of this model allows it to be applied to any scenario that poses a submarine threat.

The model can be applied to scenarios where:pre-war or post-war analyses are required,

- on-going war analysis is required,
- single patrol or single submarine campaign is desired,
- multiple patrol or multiple op area campaign is desired,
- force allocation is desired,
- littoral and open water analysis are desired,
- any specific starting or stopping point is desired,

- the submarine platform varies,
- the number of submarines varies,
- submarine tactics vary,
- deployment schedules vary,
- ASW tactics vary,
- campaign aggregation is desired,
- varying coalition forces will be employed.

*(Throughout this manual and when using the model, the term "**red submarine**" can be thought of as **a single enemy submarine** or **an entire enemy submarine pack or force**.)*

The user is reminded that this is an expected value model and the compounded results are expected (mean) values.

III. THE MODEL

The Joint ASW Circulation Model is written to evaluate an ASW campaign utilizing various assets in ASW roles. The model provides the user an interface to enter the survival probabilities along with other related campaign parameters based on available ASW resources. The user is then provided as output the survival probabilities in three regimes, an overall survival prediction of the red submarine as well as the number of daily and total attacks the red submarine can achieve. Finally, the input and output are stored as a database for further evaluation. This information can aide in determining force mix while providing an idea of how much of a submarine attack the blue forces are willing to endure.

It is hoped that follow-on research will attempt to optimize this problem to better evaluate the Joint ASW campaign. Optimization of this topic was not conducted due to time constraints and the ultimate focus of the initial development of the model.

A. DESCRIPTION

The primary modeling effort of this thesis focuses on the construction of an ASW campaign template that is easy to understand and use. The Jack Hall (1969) circulation model was the initial basis for the campaign template. A circulation model with multiple barriers is necessary to incorporate all possible traditional naval ASW assets along with as many joint elements that can be made available to the ASW mission. In template form, these will be nothing more than simple aggregated probability of kill inputs.

In order to use the graphical interface, various survival probabilities of an enemy (red) submarine must be known based on the friendly (blue) ASW combat effectiveness in four different regimes. The regimes for attack are:

- In port (prior to departure),
- Outbound (enroute to the op area),
- Op areas, and
- Inbound (enroute to the red submarine port).

The ASW forces can range from none to a large aggregation of subsurface, surface, air, and space resources. A single ASW "barrier" can include naval as well as joint and combined service components which contribute to the ASW campaign. The objective of the ASW barrier must be to kill the red submarine during its transit. This equates to increased survivability of friendly ships. It is important to note that shipping protection can be accomplished in many ways, to include delaying the red submarine, knowing where the red sub is located to avoid it and of course localizing and killing it. The delays which may be accomplished by repair facility bombing or delays while overt mines are swept are not directly accounted for in the model. These tactics may be indirectly accounted for in the number of days or events endured by the red submarine in a particular regime.

The equations presented in this section are derived from a simple circulation model. ASW resources can be used alone or as a coordinated barrier. The probability of survival through any single "barrier attack" must be determined by separate tactical analysis prior to execution of the model. This will require a **pre-determination of the**

and their performance in the ASW barrier and **how the aggregation of forces defines the probability of survival** of the red submarine as it passes through the barrier. Along with this determination, it is important that the user have a variety of barrier packages defined as survival probabilities. This will allow the user to best determine how the available ASW assets can be mixed and their performance enhanced.

The model depicts one red submarine's single operational cycle. The cycle is then used as the skeleton for the blue ASW campaign. The equations used follow classical circulation models like those developed by Philip Morse and George Kimball (1946), Jack Hall (1969), and Brian McCue (1990). For simplicity, the time steps in the model are one day in both the submarine port and the operational areas while the outbound and inbound regime time steps are one "*event.*" For instance, two "similar" air attacks equal to two events for an enroute air attack barrier.

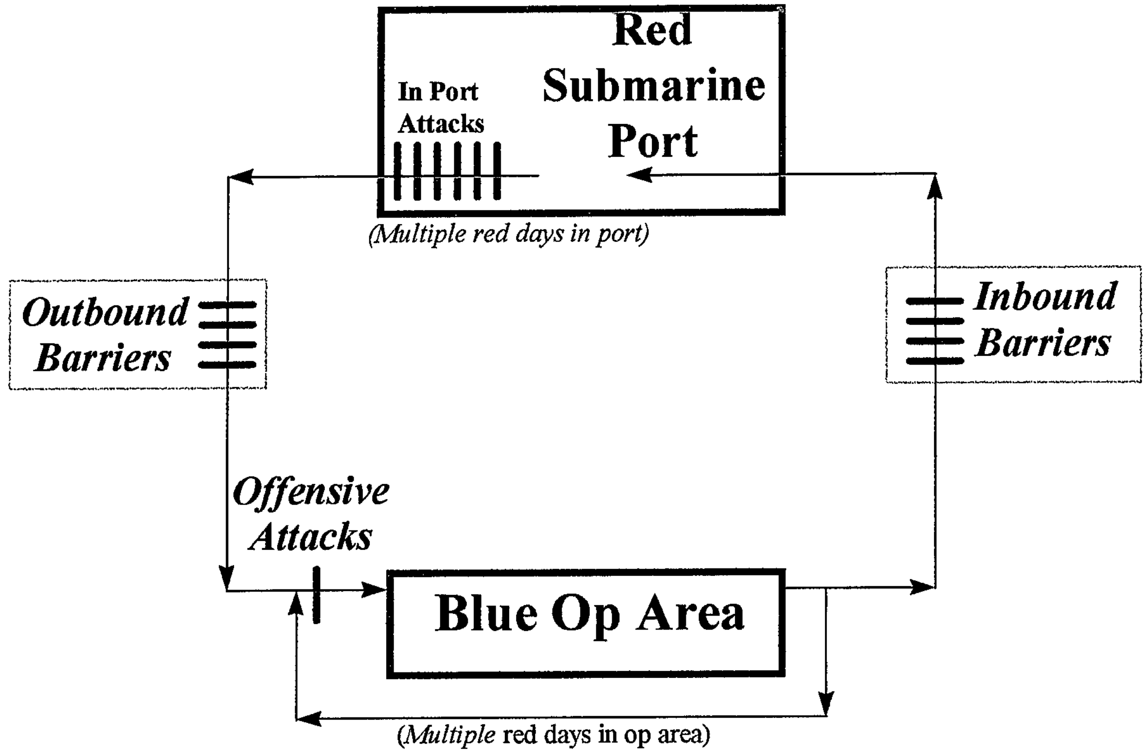


Figure 1. Basic circulation model for an ASW campaign. Note: The number of attacks presented serves to illustrate that multiple attacks are possible.

Figure 1 illustrates a red submarine operation cycle and the blue ASW campaign to combat it. For instance, a red submarine spends a number of days in port (6 days are depicted in the Figure 1). While in port, it is subject to daily in port attacks. The probability that it survives is a function of the number of days spent in port and daily survival rate, which is affected by the magnitude of the blue offensive. Surviving the in port attacks, the red submarine begins to transit toward its operational area. Along the way, the blue forces have assembled various ASW barriers. (Four barriers are depicted in the Figure 1.) The outbound barrier's effectiveness is a function of the capabilities of the barrier, the ASW attacks during the sub transit of the barrier, and the number of barriers. These barriers will be explained in more detail in a later section.

When the red submarine arrives in its op area, it is subject to attrition by ASW forces in the op area each day it remains there. In addition to the daily effectiveness of blue offensive ASW forces, the probability of red survival in the op area is a function of the engagement rate of the submarine and the blue screen's capability. The screen must detect and then prosecute based on the detection. Once the red submarine leaves the op area it is again subject to ASW barriers during its return transit to port. The cycle is complete when the red submarine reaches port. The expected number of attacks it makes and the probability of kill for the cycle is recorded.

B. REGIMES - DEFINITIONS AND EQUATIONS

The equations are broken down into the four regimes (shown in gray): in port attacks, outbound barriers, operational areas, and inbound barriers. Figure 2 shows an example of the user's data form. It is used for data input, viewing a record of output and accessing other forms such as help files and the data set being created.

The input regimes depicted in Figure 2 in the dark gray boxes are described in detail below. ***Each regime description below is encapsulated in a light gray box like this to provide continuity and clarity***. The equations for each regime are presented to provide an understanding of how the results are determined. The final section of this chapter provides the equations for the calculated Results (shown in the green box). The term record refers to a data set entry consisting of inputs and results an entire patrol calculation. Each time the "Calculate" button is clicked a new record is created that can be added to the data set. (See the Appendix A for data base navigation.)

(The numbers presented in the following descriptions of input and output are just an example and do not represent a real world campaign.)

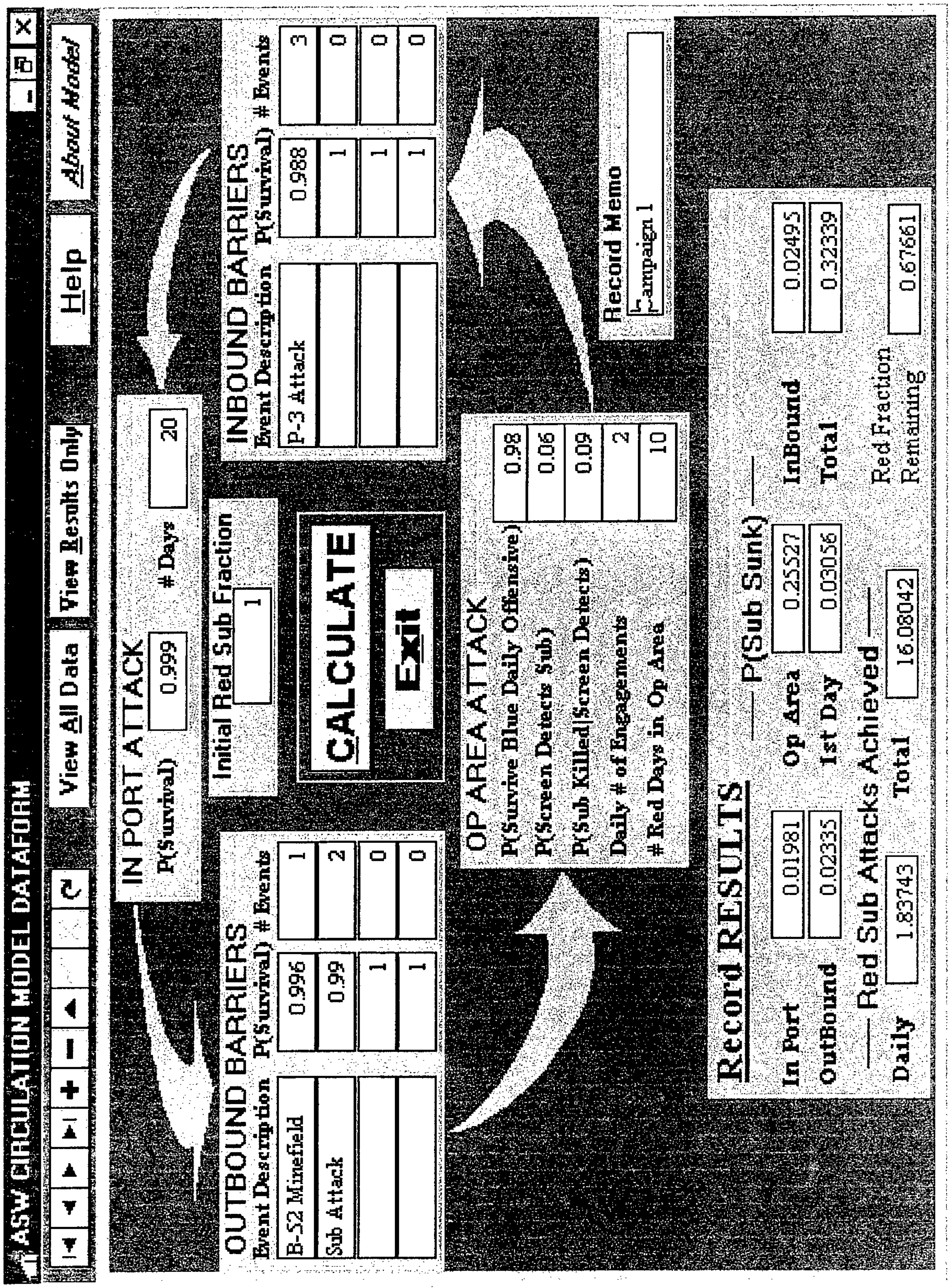


Figure 2. Example of ASW circulation model main data form. This form is used for inputting parameters, calculations, viewing a single record and accessing other features such as viewing datasets and getting help.

1. Initial Red Sub Fraction

The nature of the model provides for multiple runs of the model or aggregated campaigns. For a typical first run or patrol of a red submarine force the *initial red sub fraction* is one.

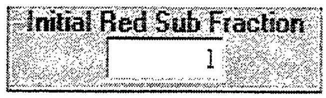


Figure 3. Example of user input for the initial red submarine fraction box

When the red submarine force has been attrited by one or more previous patrols, then the *initial red sub fraction* becomes the expected *"red fraction remaining"* from the previous run. The *"red fraction remaining"* is given in the green results box.

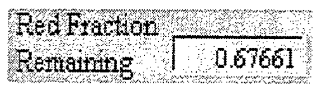


Figure 4. Example of output for the fraction of red submarine force remaining

2. In Port Regime

For simplicity of the model, only attacks against the red submarine are of interest. As mentioned previously only direct attacks are accounted for in the model calculations. Examples of direct attacks on a submarine are bombing, missile attack, and hull mining. Less direct and effective attacks must be accounted for by increased in port time due to bombing of submarine piers, repair facilities, weapon storage facilities, communication sites, harbor mining, and jamming of submarine communications.

IN PORT ATTACK

User entries:
P(Survival) := qPort = Probability of survival of the red submarine in port
 # Days := Dport = Number of Days the red submarine spends in port

Figure 5. Example of user input for the in port attack box

The in port survival formulation is: $qInPort = qPort^{Dport}$ (1)

The model formulation to this point is:

$$PSubSunkInPort = (1 - RedInit \bullet qInPort) \quad (2)$$

3. Outbound Regime

The outbound barriers can take the form of any anti-submarine tactic that hinders the red submarine's progress to its op area. Examples include harbor and sea lane mining, traditional Naval ASW consisting of submarines, P-3s, destroyers, and others, and various assets used for C4ISR such as aircraft and satellites for communication interception and reconnaissance. Any of these assets can be used alone or as an aggregated barrier. The probability of survival through any barrier must be determined by the user prior to execution of the model. This will require a prior determination of the assets to be assigned to the ASW barrier which in turn determines the probability of survival of the red submarine passing through the barrier. Along with this determination it is important that the user have a variety of barrier survival probabilities for various

ASW asset mixes. This allows the user to determine how the available ASW assets can best be allocated.

OUTBOUND BARRIERS

User entries:
Event Description := Text description of barrier
P(Survival) := $qOut_i$ = Probability of red sub surviving one blue attack event in barrier *i*
 # Events := NOut = Number or type of events of the outbound barrier

An example of the outbound formulation for 4 barriers is:

$$qOut_1^2 \bullet qOut_2 \bullet qOut_3^5 \bullet qOut_4$$

where the first barrier has 2 events, the second and fourth have 1 event, and the third has 5 events.

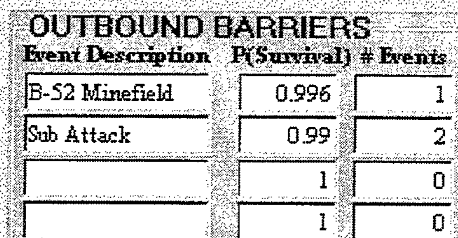


Figure 6. Example of user input for the outbound barrier box

The Outbound survival formulation is: $$qOutbound = \prod_{i=1}^{N_{Out}} qOut_i^{n_i} \qquad (3)$$

where $qOut_i^{n_i}$ *is the probability of survival for barrier i,* n_i *is the number of days in barrier i and* N_{Out} *is the number or type of Outbound barriers.*

The model formulation to this point is:

$$PSubSunkOutbound = RedInit \bullet qInPort \bullet (1 - qOutbound) \qquad (4)$$

4. Operational Area Regime

The operational area of the blue forces is defined as the area where the blue ships will operate, loiter and seek targets to attack. It is the objective destination of the red submarine. The blue ASW campaign objective is to successfully operate in this area while minimizing ship loss to red submarines.

Merchant or cargo vessels are generally thought of as **defenseless** against a submarine. They can travel independently or in convoys, with protective escort or without. **High value units** (HVU) such as aircraft carriers, while somewhat defenseless without their complement of aircraft, have ASW assets available and will always travel with an escort.

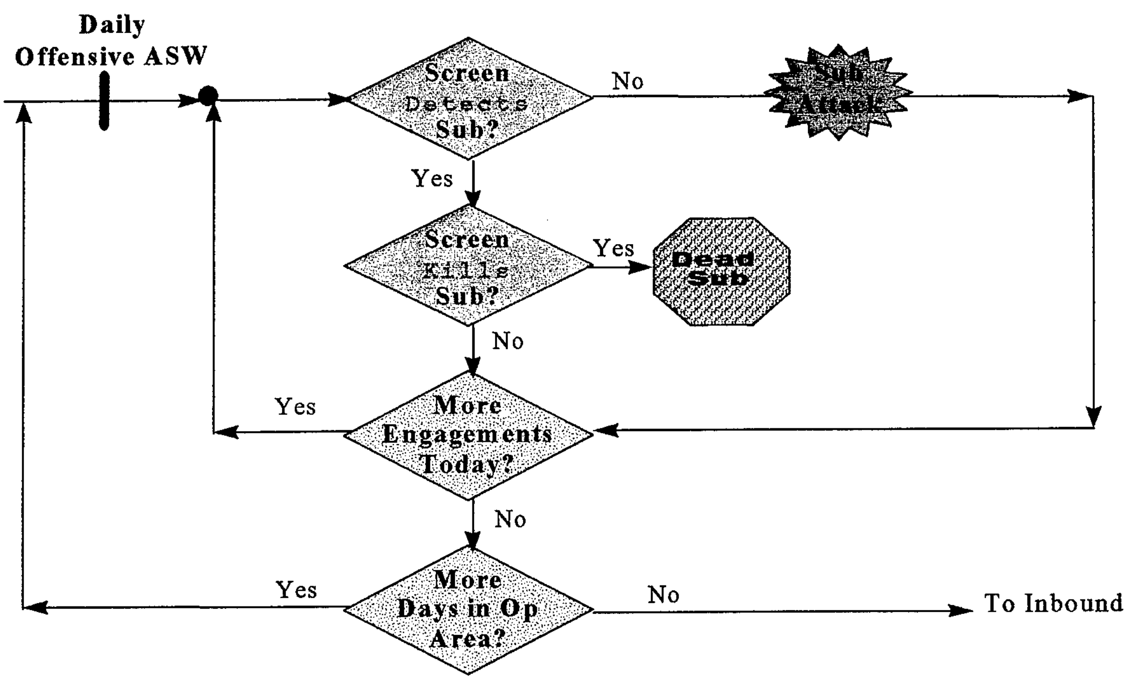


Figure 7. Wire diagram of red submarines' transit through a blue Operational Area.

OP AREA ATTACK
User entries:
P(Survive Offensive) := qOff = Probability of red sub surviving daily offensive ASW
P(Screen Detects Sub) := Pd = Probability blue screen detects the red sub that attempts to attack a target
P(Red Killed | Blue Detects) := Pk|d = Probability blue kills red given red is detected

Daily # of Engagements := Engage = Number of red attacks plus blue detections based on a daily rate or number of attempted attacks by red sub per day
 # Red Days in Op Area := Dop = Number of days the red sub spends in operational area (model assumes sub does not exhaust its torpedoes)

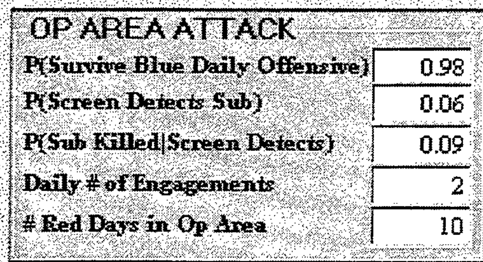


Figure 8. Example of user input for the operational area attack box

Useful relations:
$(1-qOff)$ = Probability of red sub being killed by (daily) offensive ASW
$Pd \bullet Pk|d$ = Probability of red sub being killed by a screen attack
$(1-Pd \bullet Pdk|d)$ = Probability of red sub surviving a screen attack

Daily Probability of Red Sub Being Sunk in the Op Area

$$PSubSunkOn1stDay = (1-qOff) + qOff \bullet Pd \bullet Pk|d \bullet \sum_{i=0}^{Engage-1}(1-Pd \bullet Pk|d)^i \qquad (5)$$

let qDailyOpArea = 1 - PSubSunkOn1stDay

Probability of Red Sub Being Sunk in the Op Area

$$RedInit \bullet qInPort \bullet qOutbound \bullet PSubSunkOn1stDay \bullet \sum_{j=0}^{Dop-1}(qDailyOpArea)^j \qquad (6a)$$

If $0 < Engage < 1$ then the daily probability of the red sub being sunk is handled in a special way explained below. If the number of days in the op area is less than one, then these probabilities are zero. If *Engage =0 but Dop >= 1* then the red submarine is being killed only by the screen and the probability of the red sub being sunk is:

$$RedInit \bullet qInPort \bullet qOutbound \bullet \sum_{j=0}^{Dop-1}(1-qOff)^j \qquad (6b)$$

---------- **Equation 6a or 6b is the equation to this point.** ------------

Attacks Achieved:

Daily Op Area Attacks Achieved by the Red Sub

$$DailyAttacksAchieved = qOff \bullet (1 - Pd) \bullet \sum_{k=0}^{Engage-1} (1 - Pd \bullet Pk|d)^k \qquad (7)$$

Total Op Area Attacks Achieved by the Red Sub:

$$RedInit \bullet qInPort \bullet qOutbound \bullet DailyAttacksAchieved \bullet \sum_{m=0}^{Dop-1} qOff^m \qquad (8)$$

Fractional Number of Engagements:

The model allows for the case where the number of engagements is between 0.0 and 1.0 since a fractional number in this range seems realistic for a daily engagement rate. Fractional values greater than one are not allowed but attacks per day (2, 3, 4, ...) are permitted. The fractional case is handled by adjusting the daily offensive ASW and the number of days the red sub spends in the op area. This allows the number of engagements *(Engage)* to take on the integer value 1 which is necessary for the software programming. The new values become:

Engage is a fraction so Engage* $\Rightarrow$ 1,
qOff* = qOff / Engage,
Dop* = Dop / Engage.

This summation assumes that the number of engagements is greater than zero. If the number of engagements is zero then the model accounts for this by ignoring the engagement term.

5. Inbound Regime

The inbound barriers can take the form of any anti-submarine tactic that hinders the red submarine's progress. The inbound regime is similar to the outbound regime.

INBOUND BARRIERS

User entries:
Event Description := Text description of barrier
P(Survival) := qIn_i = Probability of red sub surviving one blue attack event in barrier *i*
 # Events := NIn = Number of events of the Inbound barrier

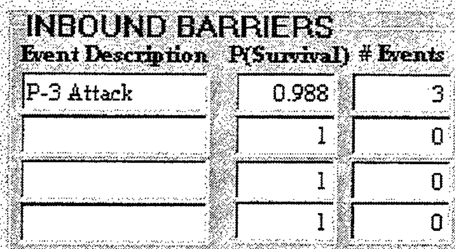


Figure 9. Example of user input for the Inbound barrier box

The Inbound survival formulation is: $$qInbound = \prod_{i=1}^{N_{In}} qIn_i^{n_i} \quad (9)$$

where $qIn_i^{n_i}$ *is the probability of survival for barrier i,* n_i *is the number of days in barrier i and* N_{In} *is the number or types of Inbound barriers.*

Letting:

- qInPort = 1 - PSubSunkInPort,
- qOutbound = 1 - pSubSunkOutbound,
- qOpArea = 1 - PSubSunkInOpArea

the equation to this point becomes:

$$PSubSunkInbound = \mathrm{Red}Init \bullet qInport \bullet qOutbound \bullet qOpArea \bullet (1 - qInbound) \quad (10)$$

6. Output Results

The probability results can be interpreted as the fraction, on the average, of the red submarine force remaining after one patrol or cycle. The user must decide if the submarine threat has been sufficiently reduced in this one patrol based on the desires and capabilities of the campaign plan. Also considered must be the number of attacks the red submarine is able to achieve keeping in mind the simplifying assumption that the red submarine has a sufficient arsenal to conduct the calculated number of attacks achieved.

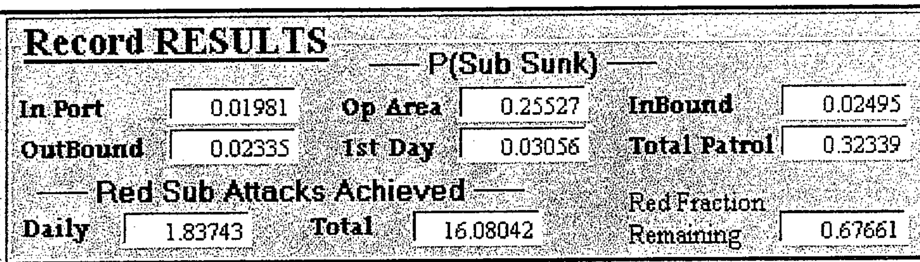


Figure 10. Example of user output for the record results box

P(Sub Sunk):

In Port := Probability the sub is sunk in port after *Nport* days in port

$$PSubSunkInPort = 1 - RedInit \bullet qPort^{Nport} \tag{11}$$

Outbound = Probability the sub is sunk in an outbound barrier

$$PSubSunkOutbound = RedInit \bullet qInPort \bullet (1 - qOutbound) \tag{12}$$

Op Area - First Day := Probability sub is sunk the first day in the operational area

$$PSubSunkOn1stDay = (1 - qOff) + qOff \bullet Pd \bullet Pk|d \bullet \sum_{i=0}^{Engage-1} (1 - Pd \bullet Pk|d)^i \tag{13}$$

Op Area := Probability sub is sunk in the operational area

PSubSunkInOpArea =

$$RedInit \bullet qInPort \bullet qOutbound \bullet PSubSunkOn1stDay \bullet \sum_{j=0}^{Dop-1} (1 - qDailyOpArea)^j \tag{14}$$

Inbound := Probability sub is sunk in an inbound barrier

$$PSubSunkInbound = RedInit \bullet qInport \bullet qOutbound \bullet qOpArea \bullet (1 - qInbound) \tag{15}$$

Total := Total probability sub is sunk {entire patrol}

$$TotalPSubSunk = 1 - RedInit \bullet qInport \bullet qOutbound \bullet qOpArea \bullet qInbound \tag{16}$$

Attacks Achieved:

Daily := Number of daily attacks achieved

$$DailyAttacksAchieved = qOff \bullet (1 - Pd) \bullet \sum_{k=0}^{Engage-1} (1 - Pd \bullet Pk|d)^k \tag{17}$$

Total = Total number of attacks achieved

$$\mathrm{Re}dInit \bullet qInPort \bullet qOutbound \bullet DailyAttacksAchieved \bullet \sum_{m=0}^{Dop-1} qOff^{m} \quad (18)$$

C. SOFTWARE AND CODING

The Joint Anti-Submarine Warfare Model uses a graphical user interface (GUI) created in Borland® Delphi™ for Microsoft® Windows®. It requires Windows® 3.x or later to run the executable file, 16-bit and 32-bit versions are available.

This model is written to evaluate an ASW campaign utilizing various assets in ASW roles. The model provides the user an interface to enter the survival probabilities along with other related campaign parameters based on available ASW resources. The user is then provided as output the survival probabilities in three regimes, an overall survival prediction of the red submarine as well as the number of daily and total attacks the red submarine can achieve. Finally, the input and output are stored as a data base for further evaluation. This information can aide in determining force mix while providing an idea of how much of a submarine attack the blue forces are willing to endure.

Once the model was structured it was made interactive using the low level computer programming language PASCAL in Delphi. Other programming languages, analysis tools or graphical interfaces could have been used in a similar fashion. The ability of the model to be dynamic and interactive allows the user to easily tailor his ASW campaign forces to the model regimes. Along with applying traditional and joint

ASW assets, new ASW employment and tactics specifically designed for the areas along the littoral could easily be analyzed.

The flexibility of the input parameters allow use of all available assets as well as the ability to easily incorporate new technologies as they become available. A working knowledge of how various probabilities of kills and ASW barrier strategies is assumed and necessary for valid data input and interpretation of the results. (A description of a circulation model and survival probabilities is presented in McCue, 1990.) Along with the application of assets, the varying of the asset mix to achieve the best possible ASW strategy without drawing too many assets from other areas of the campaign is explained. This critical mixing is the key to the joint applicability of the model. All available assets must be "fully" utilized. If some assets are over utilized by one facet of the war then the attempt at full utilization is wrong. For example, if B-52s are allocated to the ground campaign for large area bombing when the ground war is actually being delayed because enemy submarines are slowing the resupply effort then B-52s are not being properly utilized. Using the B-52s for a few days of submarine port bombing or harbor mining may be a better way to fully utilize available assets. The same is true if B-52s are performing ASW missions when the ground campaign is the primary focus of attack. This is the mind set the model user must achieve to begin to tap the benefits of a joint ASW model.

D. SHORTCOMINGS OF THE MODEL INTERFACE

Due to a number of factors, including time and inexperience with the software, certain shortcomings of the usable model exist which must be known. These shortcomings are simply issues that the user should be aware of when using this analytical tool.

1. Limited Input Value Ranges

Abnormal values such as probabilities less than zero are not allowed by the model. The model will only accept values in the allowed ranges. The user will receive an error message and be prompted for another input if a value is outside the allowed range.

The ranges of allowed values are:

- **All probabilities and "Initial Red Sub Fraction" = {0.0, 1.0},**
- **Number of days and events = {0, 999} (this must be an integer value),**
- **Number of engagements = {0.0, 1.0} and {1, 99 (integer values ≥ 1) }**
- **Event descriptions = 20 characters or less**
- **Memo Record = 50 characters or less**

The default parameters are such that not all of the input parameters need to be entered. The data is entered in a screen which is defined as the main form of the model. All other screens or forms can be accessed from the main form. In order to input data, click on the desired input box and type a value. It may be necessary to delete the value that is already in the box by backspacing or highlighting and deleting the value. It is possible to tab through the input boxes and enter values without having to delete old values.

2. Number Of Days And Engagements Per Day

Some values such as the number of days must be an integer value since these values are part of a summation or product index which is handled by program looping. The same is true of the number of engagements for values greater that or equal to one. The special case where the number of engagements is a fraction in the range of {0.0, 1.0} is coded by number manipulation and then rounding the value of the number of engagements to one. This number manipulation was explained in detail in the section on *"Op Area Attack."* This fractional range was deemed important and easily codable for the model, but whole numbers greater than one are allowed.

3. Limited Number Of Barriers

Only four outbound and inbound barriers are allowed for a single patrol due size limitations of the input screen. This has, thus far, not been a problem for any verification campaigns.

4. Simple Help Files

The graphical interface does not allow the use of pull down menus like some software products because of time and the complexity of the coding required to accomplish these tasks. The help available to the user during the running of the model consists of a number of scrollable text files. If this is insufficient then the user's manual (Appendix A) or this thesis can be used.

5. Rounding Output

Values had to be rounded to five decimal places to fit on the main form screen. This should not be a problem given the accuracy of most probability information.

6. Time Steps

The selection of daily and event time steps is based on convenience and is supported by previous models [Eagle, 1987] and [Washburn, 1980]. The time step need not be one 24 hour day but simply a convenient unit of time that is consistent for all regimes. For example, a time step of one hour can be used provided that each regime uses the same time step. This can be done by adjusting the value for the number *"days" in port, "days" in the op area,* and the *"daily" number of engagements* to hours. The number of barrier events must also be adjusted accordingly. This may be another way to account for a fractional engagement rate.

7. What The Model Does Not Know In The Op Area

The model is not able to know if the red submarine has sufficient weapons to continue attacking for the inputted number of days in the operational area. Along these lines, the model cannot know if the red submarine would interrupt its attack cycle due to damage or some other reason. The damage in hits achieved by a red submarine attack is not a part of the model. Instead, just the number of attack opportunities are tallied and the user must decide how many merchant ships or warships were put out of action or sunk in each attack. Also, the time required for *individual* engagements cannot be easily inputted into the model. Only a single daily engagement rate can be handled by the model.

IV. USING THE MODEL AND DATA MANIPULATION

Each set of input parameters is considered a record for the database which is being built when the database navigator is used. (See section VI for navigator instructions.) Therefore, the results displayed when the "Calculate" button is clicked are for that particular record of input parameters. A record need not be entered in the data base after each calculation. Once a desired record is achieved it is recommended that the record be entered in the data base for future reference. Each record can be made unique and recognizable by entering a record memo of text.

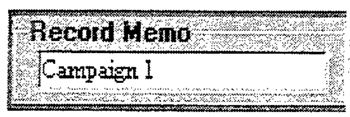


Figure 11. Example of user input for a record memo

•The data is entered in a screen which is defined as the main form of the model. **All other screens or forms can be accessed from the main form. In order to input data, click on the desired input box and type a value.** It may be necessary to delete the value that is already in the box by backspacing or highlighting and deleting the value. It is possible to **tab through the input boxes and enter values** without having to delete old values. Entering improper values will result in an error message

The default parameters are such that not all of the input parameters need be entered. For instance, if no in port information is entered then a default *qPort (Probability of red sub survival in port)* equal to 1.0 and a default *Dport (Number of days the red sub is in port)* equal to 0.0 would be used having no effect on other calculations.

V. BUTTONS AND FORMS

In order to perform a calculation with the parameters entered in the input boxes the user must click the "Calculate" button in the middle of the main form screen.

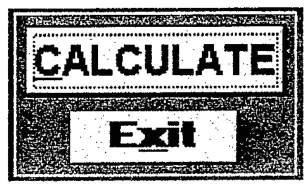


Figure 12. Calculate and Exit buttons

Clicking this button performs the above described equations by the executable program. To exit the model normally, the user can click the "Exit" button.

Figure 13. View data, Help, and About buttons

Viewing a table of the data is possible while running the model is possible by clicking on one of the view buttons. The "View All Data" button allows viewing of a scroll-able table which contains both input and output values.

ASW Model Data Summary

Return to Main

Data Summary

Print Report

Memo	PRedStartingForce	PInPort	DInPort	Out1Desc	POut1	EOut1	Out2Desc
Default Values	1	1	0		1	0	
Campaign 2b	0.67054	1	0	P-3 (F-15) at	0.9	3	
Campaign 2a	0.70157	1	0	SSN Attack	0.985	2	
Campaign 2	1	0.999	20	B-52 Minefie	0.996	1	Sub Attack
Campaign 1b	0.46373	0.9999	10	B-52 Minefie	0.999	1	Sub Attack
Campaign 1a	0.67661	0.9999	5	B-52 Minefie	0.998	1	Sub Attack
Campaign 1	1	0.999	20	B-52 Minefie	0.996	1	Sub Attack

Figure 14. Example of the Data Summary form

The "View Results" button allows viewing of a scroll-able table containing the record memos along with the calculated results values. A database navigator is also provided to manipulate each table.

ASW Model Results Form

Return to Main

Results Summary

Print Report

	Survival Probabilities							Attacks Achieved	
Memo	Initial	InPort	Outbound	OpArea	1stDay	Inbound	Total	Daily	Total
Default Values	1	0	0	0	0	0	0	0	0
Campaign 2b	).67054	0.32946	0.18172	0.44136	0.208	0.00024	0.95277	0.3983	2.77637
Campaign 2a	).70157	0.29843	0.02089	0.01014	0.003	0	0.32946	2.06055	9.996
Campaign 2	1	0.01981	0.02335	0.25527	0.03056	0	0.29843	1.83743	16.08042
Campaign 1b	).46373	0.53673	0.00967	0.24083	0.1405	0.00528	0.79252	0.35475	1.421
Campaign 1a	).67661	0.32373	0.01612	0.19642	0.0347	0	0.53627	0.59981	5.47261
Campaign 1	1	0.01981	0.02335	0.25527	0.03056	0.02495	0.32339	1.83743	16.08042

Figure 15. Example of Data Results form

The help function offers a number of scroll-able help files which provide information ranging from basic model description and its use to equations which are used to determine the results. The various help forms can be accessed by clicking in the radial button for the desired help topic.

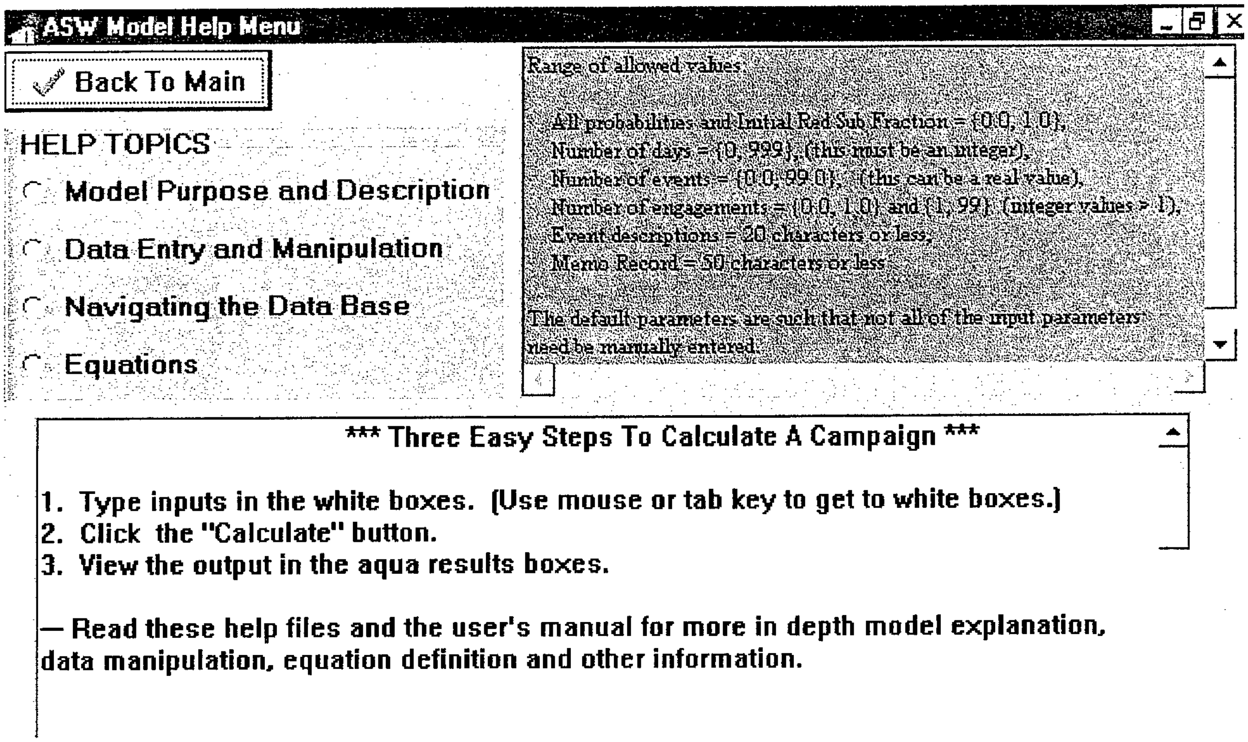


Figure 16. Example of the Help Menu form

The *About* form simply tells the title, authors and the underlying reason the model was created.

V. NAVIGATING THE DATA BASE

The database navigator component (TDBNavigator) enables users to navigate through records and to perform operations such as inserting records and posting changes. TDBNavigator enables users to navigate a data base and manipulate its data interactively. The navigator provides a series of buttons that enables a user to scroll forward or backward through records one at a time, go to the first record, go to the last record, insert a new record, update an existing record, post data changes, cancel data changes, delete a record, and refresh record display. Not all of the buttons are available in every form.

Clicking the "+" adds the current input and output values to the data base as a *record*. A record is one complete cycle consisting of input and output values. Clicking the "+" also inserts the default values into the input boxes. These default values can be left as or modified as deemed necessary by the user.

Simply entering values in the input fields does not change the data base. A variety of patrol calculations can be done without entering them into the data base by clicking the "Calculate" button (and not clicking the "+" on the TDBNavigator). Once the "+" is clicked the record is added to the data base and it can be accessed again. Accessing a database record simplifies data entry because some or all of the old record values can be viewed and used. Once an old record is accessed (using the arrows on the TDBNavigator), the record can be altered by entering different input values and clicking the "Calculate" button. The modified record can then replace the old record by clicking the "+" or modified again until the desired input is achieved. The values can then be reviewed in the two data base forms described previously.

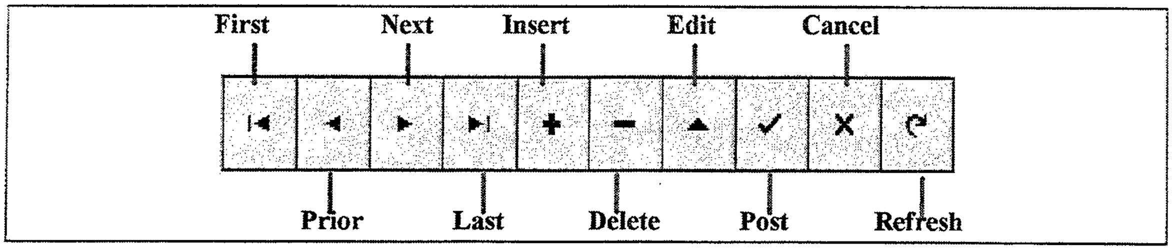


Figure 17. The database navigator (TDBNavigator)

First
Moves to the first row in a dataset by calling the First method.

Prior
Moves to the previous row in a dataset by calling the Prior method.

Next
Moves to the next row in a dataset by calling the Next method.

Last
Moves to the last row in a dataset by calling the Last method.

Insert
Inserts a new row above the current row in a dataset by calling the Insert method, and places the dataset in Insert state.

Delete
Deletes the current row in a dataset by calling the Delete method. If the ConfirmDelete property is True, it prompts for confirmation before deletion.

Edit
Places the dataset in Edit state and enables the user to edit data by calling the Edit method.

Post
Posts the current row in a dataset by calling the Post method.

Cancel
Cancels changes made to the current row in a dataset by calling the Cancel method, and returns the dataset to Browse state.

Refresh
Refreshes the display of a dataset with current data from the database by calling the Refresh method. Useful if another user or application changes the underlying data. It is necessary to use this in all of the forms since all of the forms utilize the same dataset.

VI. SUMMARY AND RECOMMENDATIONS

A. SUMMARY

"No other single weapon available to the world's regional powers today can derail a modern military campaign so totally and rapidly as a submarine." *(Linder, 1995)*

The change in the world situation has prompted the emergence of an old problem that was never completely solved. The diesel threat was virtually disregarded during the development of nuclear power for submarines and the subsequent build up of the Soviet submarine force. ASW resources throughout the 1970s and 1980s were centered on the nuclear threat (SSNs/SSGNs) but the in the 1990s the threat has shifted to the significantly less expensive but prevalent diesel. Better use of available assets coupled with new tactics are required to deal with the diesel submarine.

The circulation model adapted for use in this thesis provides a flexible, robust approach to ASW campaign analysis. To rapidly respond there must be a plan for such a campaign. The aim of this thesis was to provide a tool to the military decision-maker, a large-scale, aggregated, highly flexible model of the ASW campaign that is not limited by force mix or tactics. The user friendly campaign decision aid developed in this thesis provides an integrated look at all the ASW forces' effects in concert, and the total threat of a submarine fleet to shipping (or warships) over their operating lifetime. The deliverable graphical user interface is the analytical tool for flexible and robust ASW campaign analysis.

More specifically, the model allows for changing threats, unlimited tactics, unlimited force mix, and varying campaign lengths. It uses fixed time steps of days and number of events for the various regimes which seem to characterize ASW campaign analyses. In fact, the unit of time for an entire patrol can be altered by the user if the desired.

This thesis develops a model distributable as a graphical user interface (GUI) for an antisubmarine warfare campaign. The use of the GUI as an analytical tool can aid in the planning and analysis of naval and joint force mix to combat an ASW threat. The GUI is based on the circulation model developed by Jack Hall (Hall, 1969). Instead of limiting the user to uniquely naval assets and specific blue water tactics, this model allows the user the flexibility to utilize all available ASW assets in any manner or tactic desired.

The model was developed in *Borland® Delphi™* for use in *Microsoft® Windows.®* It is distributable with a nearly empty database and the necessary configuration software (Borland Database Engine® and Reportsmith®) to set up and run the executable file. The file can be run from a file manager or a File|Run command window.

Some problems encountered with the model and its coding are discussed in the previous chapter. Two notable observations of the model are:

1. A shortcoming of the model which is not easy to properly account for is that a red submarine will continue to conduct engagements until the inputted number of days is completed. This occurs regardless whether the red submarine force may have fired all its torpedoes or whether blue targets remain in the operational area.

2. The model alone does not offer techniques for obtaining the required input parameters. However, the text of the thesis does suggest ideas of how forces other than naval ASW assets can be utilized in an ASW role.

B. RECOMMENDATIONS

Continued attention to a comprehensive campaign-wide concept of dealing with the submarine threat is recommended. More importantly, increased analysis of the use of non-uniquely naval ASW assets in an ASW role must be conducted. This will not be possible until all the services including the Navy comprehend the threat of an attack submarine, nuclear or diesel.

Regarding the Model:

1. The simplistic nature of the circulation model has its limitations. Future development of an ASW campaign or increased complexity may overcome or sidestep these limitations.

2. Optimization of each regime could be extremely helpful to the user's analysis. Along this line, optimization of a particular campaign could be conducted and incorporated into the user's manual.

3. More realistic time steps could be developed to account for varying lengths of time in the barrier regime and the time of individual engagements.

4. The duration of the operational area regime can be improved to account for the number of red submarine weapons and send the red submarines home after a given number of attacks.

Regarding the software:

1. The creation of a graphical user interface (GUI) was to make the model a deliverable and usable product. It is not necessary to use a GUI to develop a campaign but the software calculations are a great deal simpler and faster. The development of a simple, user friendly is the most significant accomplishment of this thesis.

2. Borland Delphi was chosen as the software platform because of its availability and ease of use. A similar GUI could have been created in JAVA, Virtual Basic or even C++. The use of these other programming mediums may yield improved interfaces.

3. Database interaction and help pages are areas which can be improved upon to make the model more user friendly.

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