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AN ANALYSIS OF THE INFLUENCE OF SIGNALS INTELLIGENCE THROUGH WARGAMING

by

Charles W. McCaffrey

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Thesis Advisor: Wayne P. Hughes
Second Reader: Gordon H. Bradley

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Signals intelligence (SIGINT), information derived from the monitoring, interception, decryption and evaluation of an adversary's electronic communications, has long been viewed as a significant factor in modern warfare. However, relatively little research has been conducted to quantify the influence of SIGINT in war. The purpose of this thesis is to investigate and quantify the influence of SIGINT in warfare by developing an interactive wargame based on the McCue simulation of the U-boat War in the Atlantic. The research comprises two phases. Phase one consists of constructing an interactive wargame version of McCue's simulation. In the wargame, a human player directs convoys across a chessboard representation of the North Atlantic while the computer controls the movement of the U-boats and tabulates the number of U-boat attack-days. Phase one tests how well the wargame models reality using historical data. The second phase of research consists of experimenting within the wargame to explore the effects of varying levels of SIGINT. Each iteration of the wargame, reflecting one of four possible SIGINT conditions, is repeated to derive statistics about the influence of signals intelligence. The results show about a twenty-five percent net change in the number of attack-days for the side utilizing SIGINT.

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AN ANALYSIS OF THE INFLUENCE OF SIGNALS INTELLIGENCE THROUGH WARGAMING

Charles W. McCaffrey
Lieutenant, United States Navy
B.S., Georgia Institute of Technology, 1994

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Author: ______________________
Charles W. McCaffrey

Approved by: ______________________
Wayne P. Hughes, Thesis Advisor

____
Gordon H. Bradley, Second Reader

____
James N. Eagle, Chairman
Department of Operations Research

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ABSTRACT

Signals intelligence (SIGINT), information derived from the monitoring, interception, decryption and evaluation of an adversary's electronic communications, has long been viewed as a significant factor in modern warfare. However, relatively little research has been conducted to quantify the influence of SIGINT in war. The purpose of this thesis is to investigate and quantify the influence of SIGINT in warfare by developing an interactive wargame based on the McCue simulation of the U-boat War in the Atlantic. The research comprises two phases. Phase one consists of constructing an interactive wargame version of McCue's simulation. In the wargame, a human player directs convoys across a chessboard representation of the North Atlantic while the computer controls the movement of the U-boats and tabulates the number of U-boat attack-days. Phase one tests how well the wargame models reality using historical data. The second phase of research consists of experimenting within the wargame to explore the effects of varying levels of SIGINT. Each iteration of the wargame, reflecting one of four possible SIGINT conditions, is repeated to derive statistics about the influence of signals intelligence. The results show about a twenty-five percent net change in the number of attack-days for the side utilizing SIGINT.

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DISCLAIMER

The reader is cautioned that the 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 planner.

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EXECUTIVE SUMMARY

Military leaders have predicted a future battlefield much different than that of today. Joint Vision 2010 creates a framework for planning a future force to succeed on that battlefield. Information superiority is a prime tenet of Joint Vision 2010 and can lead to dominant battlespace awareness – providing military leaders a more accurate assessment of own-force and enemy operations. [1]

Signals intelligence (SIGINT), information derived from the monitoring, interception, decryption and evaluation of an adversary's electronic communications, is a means to gaining information superiority and has long been viewed as a significant factor in modern warfare. However, relatively little research has been conducted to quantify the influence of signals intelligence in war. The field of operations research specializes in using models of the real world to solve problems, and providing information and insight to decision makers. Therefore, the objective of this thesis is to create and employ a model that measures the value of SIGINT.

Before such a model can be applied to modern warfare (and the battlefield of the future) it must first be proven to work on an historical case using an applicable measure of effectiveness (MOE). The Second World War's Atlantic campaign lends itself to such a model for several reasons: 1) fairly complete accounts about each side's activities are readily available, 2) it is an analyzable naval battle which allows the researcher to focus on the aspects (in this case SIGINT) under study, and 3) because each side used signals intelligence for only part of the time, the battle can be studied almost as if it were a laboratory experiment.

This thesis attempts to quantify the influence of signals intelligence in warfare utilizing an interactive wargame representation of the U-boat campaign in the Atlantic. In the wargame, a human player directs convoys across a chessboard representation of the North Atlantic while the wargame controls the movement of the U-boats and tabulates the number of U-boat attack-days for each play of the game. Both sides maneuver based on intelligence of the locations of the opposing force. U-boat attack-days, an applicable MOE, are a measure of the overall success of the U-boat force in attacking convoys.

The wargame is designed to allow for examination of the four possible conditions of signals intelligence: neither side having SIGINT, one side or the other having it and both sides having it. After verifying that the wargame models history well, an examination of the four intelligence conditions, with all other variables held constant, is undertaken to place value on SIGINT. The results of thirty trials show about a twenty-five percent net change in the number of attack-days for the side utilizing SIGINT. While significant in this analysis, SIGINT is not the "make or break" factor in warfare that has sometimes been postulated.

A similar model might then be applied to the future battlespace so that SIGINT can be evaluated along with other assets, thus providing information and insight to decision makers.

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I. INTRODUCTION

Signals intelligence (SIGINT), information derived from the monitoring, interception, decryption and evaluation of an adversary's electronic communications, has long been viewed as a significant factor in modern warfare. [14] However, relatively little research has been conducted to quantifying the influence of signals intelligence in war. The Second World War's U-boat campaign in the Atlantic, in which German submarines (or U-boats) sought to interdict Allied transatlantic shipping, lends itself to such research for several reasons: 1) fairly complete accounts about each side's activities are readily available, 2) it is an analyzable naval battle which allows the researcher to focus on the signals intelligence aspects under study, and 3) because each side used signals intelligence for only part of the time, the battle can be studied almost as if it were a laboratory experiment. [9]

In the intervening years since World War II, extensive historical research has been undertaken of the Atlantic campaign including limited analysis of the role of signals intelligence. Such analysis has enabled historians to make broad, speculative statements regarding the value of signals intelligence, but it has been unable to quantify this value or to answer the "what if" questions that are so important to operations analysis.

For many years, analysts suffered from the same ignorance as the historians in their study of the Battle of the Atlantic – a lack of knowledge and data concerning the use of signals intelligence. One exception was analysis conducted by the Operations Evaluation Group (OEG). Shortly after the war, the Operations Evaluation Group, predecessor to today's Center for Naval Analyses, sought to investigate the effects each side's signals intelligence had in the Battle of the Atlantic employing a largely statistical approach. The operations analysts focused on modeling the U-boat operational search rate – the amount of ocean (measured in square miles) each U-boat would have to search each day to result in the given number of convoys sighted. This approach ran into several difficulties stemming from an inadequate measure of effectiveness (MOE).

Rather than look at U-boat search rates, therefore, Brian McCue examined the Atlantic campaign using U-boat attack-days, the overall success of the U-boat force in attacking convoys, as the MOE. McCue created a simulation of the U-boat campaign (based on data covering the period from July 1942 to May 1943), established that it reproduced history well, and then experimented within the simulation to explore the effects of signals intelligence. [9]

A. OBJECTIVE

As an extension of McCue's work, this thesis attempts to quantify the influence of signals intelligence in warfare utilizing an interactive wargame representation of the U-boat War in the Atlantic. The research comprises two phases. Phase one consists of constructing an interactive wargame version of the McCue U-boat simulation. The wargame is programmed in Java. [Sun Microsystems, 1998] In the wargame, a human player directs convoys across a chessboard representation of the North Atlantic (westbound and eastbound) while the computer controls the movement of the U-boats and tabulates the number of U-boat attack-days for each play of the game. One turn of the game represents one day of actual warfare and each play of the wargame represents approximately 30 days of actual warfare. Both sides maneuver based on intelligence of the locations of the opposing force. The wargame is designed to allow for the examination of the four possible conditions of signals intelligence: each side having

SIGINT, one side or the other having it, and neither side having it. Phase one tests how well the wargame models reality through use of historical data and verifies that the wargame remains true to the original McCue simulation.

The second phase of research consists of experimenting within the wargame to explore the effects of varying levels of SIGINT. Each iteration of the wargame, reflecting one of four possible conditions of signals intelligence with all other variables held constant, is repeated to derive statistics about the influence of signals intelligence as a percentage increase or decrease in U-boat attack-days.

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II. BACKGROUND

A. HISTORICAL REVIEW

The Battle of the Atlantic was the longest campaign of the Second World War – lasting from the first day of the war until the last. German submarines (or U-boats) sought to interdict Allied transatlantic shipping bringing essential materials and supplies to Britain and taking money-earning goods to her allies. During the course of the war, the Germans built over 1000 U-boats, of which some 830 participated in naval operations sinking nearly 2800 merchant ships. [3] The campaign cost the Germans a total of 784 U-boats. [5] The Atlantic campaign took on many forms during the war years and by the period under examination (July 1942 – May 1943) it had entered what Jurgen Rowher has termed "the Fifth Phase" of combat – the Allies having reverted to the protective convoy system with the Germans utilizing the wolfpack tactic in the North Atlantic. [13] A convoy comprised 60 to 100 ships protected by escorts and occasional aircraft. It was limited to a speed of about 8 knots due to both ship speed limitations and the difficulties of steaming in formation. German submarines, on the other hand, could run at speeds of 18.2 knots surfaced or 7.3 knots submerged (but only for short durations of less than an hour). They operated in units of ten to twelve U-boats (known as wolfpacks). [7] At the peak of the Battle of the Atlantic, some 100 U-boats were deployed and a dozen convoys were at sea. [3] Strategically, German success in the Atlantic did not automatically mean they would win the war, but loss of the ability to use the Atlantic would virtually rule out any possibility of Allied victory.

Paralleling this visible battle at sea was the invisible code war. The two sides relied heavily on enciphered messages to maintain communications with their convoys and submarines at sea. By early 1940, the German observation service, the Beobachtungs Dienst (B-Dienst), had penetrated both the British Merchant Navy code and the Royal Navy Administrative cipher and could use information (referred hereafter to as X-B) extracted from naval intercepts to interdict Allied transatlantic shipping. [14] Control of the attacking U-boats rested with Admiral Karl Donitz (Commander of Submarines) and required constant radio communications enciphered by the Enigma machine. Donitz believed that the Allies' inability to decipher the U-boat communications would deprive them of advanced information needed to thwart the submarines. [7]

On the Allied side, the British Government Code and Cypher School (GC&CS) at Bletchley Park, some 50 miles northwest of London, and the American OP-20-GI-2(A), the Navy's communications intelligence section specializing in U-boat matters located in Washington, D.C., raced against time to crack the German naval code. Once broken, the Allies would use this information about U-boat movements to divert convoys and sink submarines. Intelligence extracted from Axis communications enciphered by Enigma was covered under the generic term Ultra.

The Battle of the Atlantic is probably the most fruitful example of the effects of SIGINT in the decision making process and the operations of World War II. [13] As such, it has lent itself to several forms of research and evaluation.

B. THE HISTORIANS' APPROACH

In the half-century since World War II, extensive historical research has been undertaken of the Atlantic campaign. However, for the first 30 years after the end of the war, all historical analysis of the Battle of the Atlantic was undertaken without knowledge of the existence of signals intelligence. Ultra was a closed subject unknown to all but the individuals involved in codebreaking activities and to very few others. Even as late as 1974, Vice-Admiral Sir Peter Gretton, a convoy commander during the war, when attributing the German loss of the Atlantic campaign at least in part to Allied use of advanced electronic warfare technology (asdic, radar and HFDF), neglects to mention the role of SIGINT. [4]

It was not until the release of Fredrick W. Winterbotham's *The Ultra Secret* (1974) and Anthony Cave Brown's *Bodyguard of Lies* (1975) that the role of signals intelligence began to be the focus of research. Donal J. Sexton's *Signals Intelligence in World War II* is an excellent resource for the researcher undertaking an investigation of the deluge of material published on SIGINT since Ultra's revelation. Winterbotham, writing without the aid of documentary sources, made historians aware of the remarkable degree to which they had worked with incomplete knowledge. [14]

But if previous historical works were lacking in their treatment of signals intelligence then the opposite may be true after 1975. There began an "Ultra as the magic ingredient" phase of historical analysis. Assumptions of Ultra's potency were made which were not justified and rarely supported by analysis of decent rigor. [3] In recent years, the tide has turned yet again to a more dispassionate appraisal.

Some historians have attempted to assess the use commanders made of Ultra and other intelligence during the war and how this impacted on operations. Others have focused on the technology or the personalities involved in both sides' codebreaking activities. Such analysis has enabled historians to make broad but often times speculative statements regarding the value of SIGINT. According to David Kahn "the benefit of Enigma solutions was intangible but real." [7] But historians tend to shy away from addressing the "what if" or counterfactual questions that are so important to operations analysis.

C. THE ANALYSTS' APPROACH

For many years, analysts suffered from the same ignorance as the historians in their study of the Battle of the Atlantic – a lack of knowledge and data concerning the use of signals intelligence.

Morse and Kimball refer to wartime analysis regarding the convoy versus submarine exchange (1941-1942) in order to examine measures of effectiveness – in this case the exchange rate of submarines sunk to merchant vessels sunk. Notably absent from the wartime analysts' data set is the use of SIGINT. The conclusions drawn by the war planners included: 1) the number of merchant vessels sunk per wolfpack attack is independent of the number of merchant vessels in the convoy, 2) the number of merchant vessels sunk per engagement is dependent upon the number of escort vessels and on the number of U-boats in the wolfpack, 3) U-boats sunk during an attack is proportional to the number of U-boats in the wolfpack and the number of escorts, and 4) the exchange rate is proportional to the square of the number of escort vessels per convoy. [11] These results were presented to appropriate wartime authorities who in turn increased the average size of the convoys. Morse and Kimball assert that this action increased the exchange rate in favor of the Allies and was a contributing factor in the German defeat in the North Atlantic.

In 1972, Tore Kristiansen, working for Supreme Allied Commander, Atlantic (SACLANT), undertook to validate a Defense of Shipping model used by SACLANT's operations analysts to evaluate a future NATO-Warsaw Pact Battle of the Atlantic involving Soviet submarines. Kristiansen's intention was to apply the models used in the Soviet submarine campaign and compare the results with the actual World War II campaign and gain confidence in the validity of the models. [8] The study used World War II U-boat detection capabilities to determine individual engagement rates, expected number of engagements of the U-boats at sea and casualties inflicted on shipping. Kristensen concluded that the model underestimates the number of convoy engagements and believed that adding the effect of intelligence would lead to accurate results. In effect he deduced that a viable model must therefore include a way of handling intelligence including SIGINT. [8] Analysis conducted in 1951 and 1952 by the Operations Evaluation Group (OEG Report Numbers 66 and 68), classified until 1987, created such a model and was the one exception to general ignorance until 1974 of SIGINT use during the war.

The Operations Evaluation Group, predecessor of today's Center for Naval Analyses, sought to investigate the effects each side's signals intelligence had in the Battle of the Atlantic using a largely statistical approach. [9] The operations analysts focused on modeling the U-boat operational search rate – the amount of ocean (measured in square miles) each U-boat would have to search each day to result in the given number of convoys sighted. In this case, they represented the operational search rate as

$$Q_{\text{est}} = C/(T \bullet (N/A)) = (CA)/(TN),$$

where Q_{est} is the estimated operational search rate, C is the number of contacts, T is the amount of time the U-boats spent searching, N is the number of convoys at sea, and A is the area of the region in which they are to be found. The OEG found that the search rate of U-boats when looking for convoys compromised by X-B intelligence was about double that of U-boats without such guidance. These early post-war analysts, with knowledge from captured German documents when and where the Germans had used SIGINT, computed the operational search rate under various conditions of signals intelligence (the Germans had X-B but the Allies didn't have Ultra, both sides had their signals intelligence, neither side did and only the Allies did) on a month-by-month basis. They then tried to relate the conditions of SIGINT to the search rates. A summary of their results appears in Table 1.

DATES	U-BOAT SEARCH RATE (SQ NM/DAY)			ULTRA
	NO X-B	X-B USED	X-B NOT USED	
7-12/'42	2,450	8,400	2,600	NONE
1-5/'43	1,400	3,400	1,650	SOME
6-8/'43	U-BOAT "RETRENCHMENT"			
9/'43-3/'44	1,700	4,050	--	PLENTY

Table 1. Summary of OEG Results. After Reference [9]

The case in which the Germans had X-B, but did not use it, arises because they sometimes had so much X-B information that there were not enough U-boats to search for and attack all the compromised convoys. Yet sometimes an unsought convoy would be sighted anyway: hence the third data column in the table. [9]

This was a noble effort, but it ran into severe difficulties. The worst of these was that there were really not very many months' worth of comparable data, considering that four different search rates were to be estimated. The analysts counteracted this difficulty by considering the presence or absence of X-B on a convoy-by-convoy basis (there being no pure cases of a full month with neither X-B or Ultra, but they erred in their treatment of repeat sightings of the same convoy, counting already-sighted convoys into the density, while giving the U-boats no credit for re-sighting them. Finally, the results are unaccompanied by any statement of the statistical uncertainty surrounding them. [9]

Arguably, the fundamental problem was that the OEG had made an incorrect choice of measure of effectiveness (MOE). Their analysis concentrated on estimating the search rate of the individual U-boat, hence detections, and on how this was raised by X-B and/or lowered by Ultra. But detection did not always lead to an attack, and, conversely, detection by a single member of a wolfpack often led to multiple U-boat attacks. These attacks might be repeated over several days. Therefore, the effectiveness of the U-boat fleet is not the sum of the individual U-boat's detections. Rather than analyze U-boat search rates, therefore, a more appropriate measure of effectiveness should be utilized.

Brian McCue created a chessboard model of the U-boat Battle of the Atlantic and examined the campaign using U-boat attack-days, the overall success of the U-boat force in attacking convoys, as the MOE.

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III. THE MCCUE CHESSBOARD MODEL

A. DEVELOPMENT

The McCue chessboard model developed from attempts to investigate the influence of SIGINT on the Battle of the Atlantic. These attempts included: 1) a circulation model similar to that used in his previous work, *U-boats in the Bay of Biscay*, 2) an operations research-style study reprising work conducted by the OEG, 3) an extensive statistical investigation that considered the sightings of convoys utilizing well-developed mathematical mortality calculations, and 4) a detailed Monte Carlo model that operated on the individual U-boat level. [9] However, in the end, McCue found each approach wanting or overly complex. To get around this complexity, McCue created a chessboard "model of a model" and found that it worked as well as the more complex models developed earlier.[1]

McCue derived the data in Table 2 from the OEG reports to be used as parameters for his chessboard model.

MONTH	U-BOATS	CONVOYS	X-B	ULTRA	ATTACKDAYS
Jul42	17	8	0.4	0	59
Aug42	27	7.3	0.5	0	139
Sep42	39	8.7	0.4	0	196
Oct42	47	7.2	0.1	0	202
Nov42	28	7	0.4	0	151
Dec42	31	8	0.4	0	274
Jan43	41	7.3	0.6	1	47
Feb43	51	6	0.5	1	191
Mar43	58	7.3	0.9	1	226
Apr43	53	6.5	0.7	1	174
May43	58	8.8	0.9	1	300

Table 2. Basic Data from OEG Reports. After Reference [9]

[1] The following discussion of the McCue chessboard model and data analysis is a direct description from Reference [9], sometimes verbatim and elsewhere paraphrased, shortened or clarified with guidance from the Thesis Advisor.

The number of U-boats and convoys are monthly averages at sea. The figure for X-B is the proportion of convoys that were compromised in a given month whereas the compromise of U-boats by Ultra is estimated as one message per month (the total number of messages was much greater but the majority were not directly useful in redirecting convoys).

The original chessboard model was designed as a board game. To run this model, the player needs a chessboard, a pair of dice, pencil and paper, and some copies of the playing pieces shown in Figure 1.

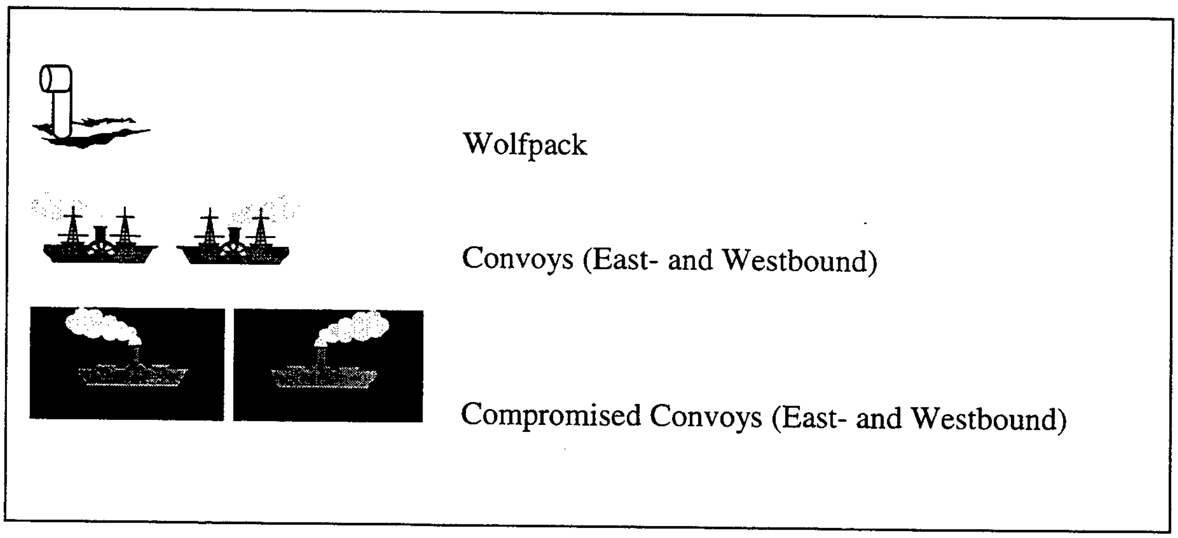

Figure 1. Playing Pieces for the Chessboard Model. After Reference [9]

By ignoring the top three rows of the chessboard the player is left with a very approximate chart of the North Atlantic region of operations. Number the rows and columns as shown in Figure 2.

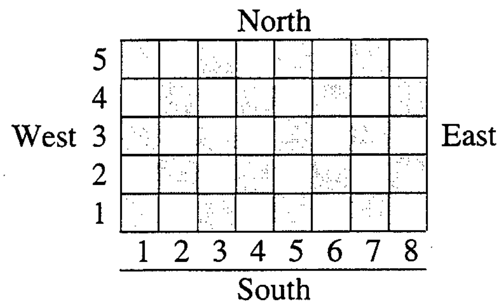

Figure 2. Chessboard Representation of the North Atlantic. After Reference [9]

To simulate the phases of the battle, different numbers of wolfpacks and convoys, and probabilities of X-B are used in the game. Table 3 shows how many are appropriate to each month including the dice results needed to simulate the probabilities of X-B compromise from Table 2.

MONTH	WOLFPACKS	CONVOYS	DICE FOR X-B
Jul42	1	8	3-6
Aug42	2	7	2-6,11
Sep42	3	9	2-5,10
Oct42	4	7	6
Nov42	2	7	2-6
Dec42	3	8	6-8
Jan43	3	7	6-10
Feb43	4	6	6-8
Mar43	5	7	3,5-12
Apr43	5	7	3-8
May43	5	8	2,5-12

Table 3. Data for the Chessboard Model. After Reference [9]

To make the initial set-up of the wolfpacks, roll a single die for each wolfpack: this is the row number (re-roll it if it is a 6). Roll a second die, and add 1: this is the column number. Locate the convoys using dice in the same way, and then flip a coin for each to determine which direction it is going: heads is eastbound, tails is westbound.

Note that in this set-up procedure, a convoy and a wolfpack can end up in the same square - if so, the unlucky convoy has just been sighted. To see if a convoy is compromised by X-B, roll two dice for it when it sets out and consult Table 3. Do this at the beginning of the game, and also anytime a convoy reaches the east or west edge and turns around, in effect becoming a new convoy. A convoy is compromised if the total showing on the dice is as in Table 3.

Running the model is accomplished by enacting a number of steps in order. Together, the steps represent the passage of one day.

1. The first step is to keep score. The score is zero at the beginning of the first day, but on all other days count the number of wolfpacks that are attacking convoys and add this number to the wolfpack score for the month.
2. The next step is to see if sightings turn into attacks. Roll the die for each wolfpack that is in the same square as a non-attacked convoy. If the result is a 1 or a 2, the wolfpack takes the convoy under attack and is marked to denote this fact.
3. Then see about converting sighted convoys, and those under attack, back into unsighted status. Roll a die and if the result is a 1 or a 2, the convoy becomes unsighted. The wolfpacks attacking these convoys return to patrol, and if it just started the attack in the previous step, it does not get credit for it at the next iteration of step 1. This circumstance corresponds to attacks that were repulsed immediately, or broken off because of the timely arrive of reinforcements.
4. This step deals with the effects of X-B and Ultra, in that order. If there are any compromised convoys that are not threatened by wolfpacks, turn them into threatened ones by assigning a wolfpack to intercept them. Now the convoy is threatened, and

the wolfpack is converging. Use judgment to find the best possible assignments at this time - doing so may entail un-assigning a wolfpack that is converging on a distant convoy, if a nearer convoy (or one that is headed towards the wolfpack) becomes compromised, but do not interrupt a wolfpack attack that has already started. If Ultra is in use during the month being simulated, then apply its effects. Roll a die for each wolfpack that has sighted a convoy or is converging upon one. If the result is a 1 or a 2, the convoy ceases to be threatened or sighted and becomes unsighted, and the wolfpack returns to patrolling. Note that in the case of a sighted convoy, the wolfpack and the convoy will be temporarily be left in the same square, a situation that will in all likelihood change before the next sightings are made.

5. Move all the convoys. Convoys move only on odd-numbered days, starting with day one. Convoys are eastbound or westbound. To move a convoy, roll a single die - if the convoy is eastbound, it moves northeast on a 1 or a 2, due east on a 3 or a 4, and southeast on a 5, or a 6. Similarly, if the convoy is westbound, it moves northwest on a 1 or a 2, due west on a 3 or a 4, and southwest on a 5 or a 6. Convoys directed to move off the north or south edges of the board bounce off them, moving south if directed north off the board, or vice versa. It is all right if a convoy moves to a square occupied by another convoy. Sighted convoys and their sighting wolfpacks are moved together, but just because a convoy and a wolfpack are in the same square does not mean that the wolfpack has sighted the convoy - they may be left over from an un-sighting in step 4, in which case the convoy moves without the wolfpack. If the convoy is under attack, do not roll for the north-south movement: zig-zagging at this point is useless, so the convoy heads due east or west. When a convoy moves off the

east or west edge of the board, it is replaced by rolling a die and placing a new (and un-sighted) convoy in the indicated row (1-5) on the same side (east or west) or, in the event that a 6 is rolled, try again. New convoys must be checked for X-B compromise, following the same procedure as was used when doing the initial set-up.

6. Now move all the wolfpacks that do not have convoys in sight and are not responding to X-B. Such wolfpack movement is governed by Table 4. Roll two dice. If the result is 7, the wolfpack remains in the square it occupies, otherwise, it moves to the neighboring square that corresponds to the number rolled. If there is no such square, because of the edges of the board, then the wolfpack bounces as if it were a billiard ball. For example, if a wolfpack is in the first row and rolls a 12, it moves up instead of down; if it rolls an 11, it takes a glancing bounce off the bottom edge and moves as if it had rolled a 10. In this simple model, wolfpacks remain at sea permanently. It is all right if a wolfpack moves into a square occupied by another wolfpack.

10	2,6	3
5	7	9
11	12,8	4

Table 4. Die Rolls for Wolfpack Movement. After Reference [9]

7. Check for new sightings. Convoys in the same square as wolfpacks at this time become sighted, and the wolfpacks become sighting.

When these steps are completed, record the passage of a day and begin again at the first step. Continue in this fashion, remembering that convoys can only move on odd-numbered days, through all the days of the month. When finished, multiply the number of wolfpack attack-days by 12 to get the number of U-boat attack-days. Notice that the U-boats progress through the pattern of searching, then possibly converging, stalking sighted convoys, and finally attacking the convoys.

B. MCCUE MODEL VS HISTORICAL CASES

Before the chessboard model can be used to make observations about the influence of signals intelligence, it must be determined that the model replicates the actual Battle of the Atlantic. Moving from the board game described above, McCue wrote a computer program of the chessboard model and ran the simulation 24 times for each month. The results are shown in Figure 3. The dashed lines contain the middle two quartiles: half the model results lie between these two lines, another quarter above, and the last quarter below. If the random dispersion of the historical results mirrors that of the model, half the historical results, too, will lie between the dashed lines. This is nearly the case - 7 of the 11 historical cases lie inside the middle two quartiles of their respective months' model results, with another three cases lying just about on the inter-quartile lines. Nor is the model especially biased -the historical results lie on both sides of the model's median result. With the exception of January, the cases that lie outside the inter-quartile range do not lie far outside, and are not beyond the range delineated by the 24 trials.

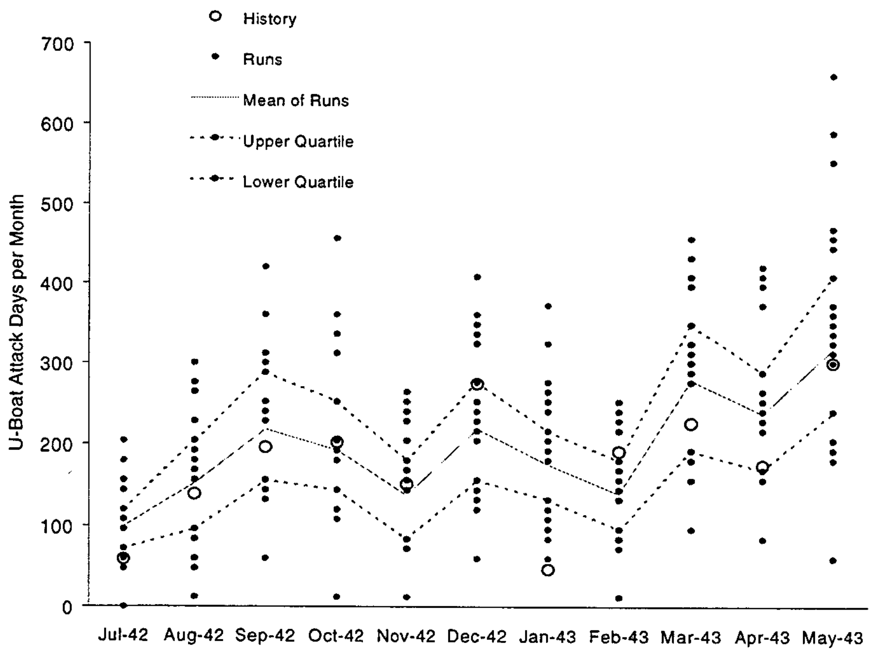

Figure 3. The Chessboard Model Compared to Historical Data. After Reference [9]

These notions can be formalized statistically. For each month, Table 5 shows the historical number of attack-days, the mean and standard deviation of the 24 runs, the z-score of the historical attack-days (the difference between the historical attack-days and the mean, divided by the standard deviation), and the square of the z-score. The results of the runs are normally distributed, therefore, the sum of the squares of the z-scores will be chi-squared distributed with 11 degrees of freedom. The chi-square test amounts to noting that the observed sum of the squares is not an improbable result under this assumption. In this case, the observed sum of the squares of the z-scores would be at least as good as 7.02 some 79.8% of the time.

MONTH	HISTORICAL ATTACKDAYS	SIMULATION MEAN	SIMULATION STDEV	SIMULATION Z-SCORE Z	Z^2
Jul42	59	100	45	-0.90	0.80
Aug42	139	152	76	-0.17	0.03
Sep42	196	218	77	-0.29	0.08
Oct42	202	193	87	0.11	0.01
Nov42	151	138	63	0.21	0.04
Dec42	274	219	80	0.70	0.49
Jan43	47	176	66	-1.95	3.81
Feb43	191	140	56	0.92	0.84
Mar43	226	279	93	-0.57	0.32
Apr43	174	237	83	-0.76	0.57
May43	300	318	124	-0.14	0.02
				Z-SCORE SUM	7.02
				CHI-SQUARED P-VALUE	0.798

Table 5. Statistical Validation of the Chessboard Model. After Reference [9]

C. EXCURSIONS

Having tested the chessboard model against historical input variables and found it to be in accord with the actual Battle of the Atlantic, McCue next varied the data from the historical values to examine the effects of signals intelligence. Table 6 shows the historical levels of attack-days, the results of the historical base case and the various excursions considered below.

First, McCue re-ran the model without X-B. Unsurprisingly, the number of attack-days goes down, usually by about a third of the average modeled value. Adding the monthly averages and comparing the non-X-B case to the historical base case, McCue found 1,481 attack-days as compared to 2,167 - a difference of 686. Taking each wolfpack to contain exactly 12 U-boats, the whole simulated campaign had 444 U-boat months, so each U-boat is responsible for about five and a half attack-days per month.

Thus the extra 686 attack-days conferred by X-B is about 141 additional U-boat months' of attacks. A given U-boat might be able to get to sea for at most 2 or 3 months in this 11-month period, so this is at least 45-70 U-boats' worth of assistance.

	U-BOAT ATTACKDAYS (AVERAGE)					
MONTH	HISTORICAL	SIMULATION	NO X-B	NO ULTRA	ULTRA ONLY	NO SIGINT
Jul42	59	100	44	100	104	44
Aug42	139	152	91	152	154	91
Sep42	196	218	142	218	206	142
Oct42	202	193	164	193	195	164
Nov42	151	138	100	138	143	100
Dec42	274	219	135	219	213	135
Jan43	47	176	97	224	175	132
Feb43	191	140	124	195	162	139
Mar43	226	279	172	312	329	221
Apr43	174	237	178	288	276	208
May43	300	318	235	354	335	247
TOTAL	1959	2167	1481	2392	2289	1623
DIFFERENCE			-686	225	122	-545

Table 6. Summary of Excursion Results. After Reference [9]

Running the model without Ultra, McCue found that the U-boats gain 225 attack-days - by which U-boats might get 32 extra sinkings. Though it is less than the effect of X-B, about 200 attack-days instead of almost 700, one must keep in mind that Ultra was available less than half of the time.

One of McCue's questions concerned the degree to which Ultra (when available at all) allowed convoys to escape from wolfpacks that had sighted them, but not yet attacked. By altering the rules of the model so that Ultra does not help in this way, McCue gauged the contribution of this form of help. Without it, the U-boats score 122 extra attack-days, corresponding to the sinking of 20 extra merchant vessels - a substantial fraction of the overall benefit of Ultra, but a relatively small change overall.

Finally, McCue considered the case in which there is simply no SIGINT at all. This will allowed him to investigate the idea of "feedback," namely that Ultra's primary utility lay in combating X-B, and/or vice versa. Consistent with what was examined above, removing SIGINT altogether acts to the detriment of the Germans, costing them 545 attack-days, or 67 merchant vessel sinkings. It is not as drastic for the Germans as the uncompensated loss of X-B would be, of course, because in the no-SIGINT case the Allies are losing the benefits of Ultra as well, but even in the periods with Ultra, the net effect of SIGINT is in favor of the Germans.

But these findings are tied to the co-varying historical numbers of wolf packs and convoys from month to month. So far, McCue considered only cases that are, in effect, alternative histories: the historical base case, the no-XB case, the no-Ultra case, and the no-SIGINT case. These are valuable points of reference, but they do not support an investigation of the role of signals intelligence in a fully satisfactory way because they remain attached to historical accidents such as the amount of X-B available in given months, and the overall trend towards increasing levels of X-B and U-boats at sea.

Therefore it seems reasonable to work in terms of an "average month," varying only the SIGINT and keeping the number of wolf packs and convoys fixed at some reasonable level. Four wolf packs on station and eight convoys at sea is reasonable and about average. Given these levels, it is easy to vary the proportion of convoys compromised by X-B across the entire spectrum from zero to one hundred percent, with or without Ultra. The presence of Ultra means that each wolfpack has a one-third chance per day of being compromised. Figure 4 shows the results of these experiments.

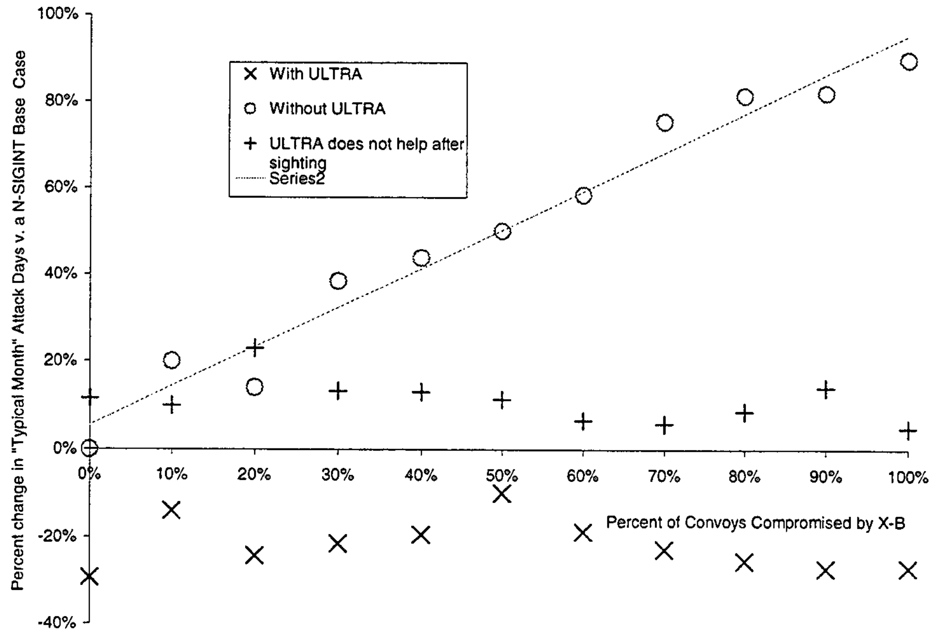

Figure 4. Effect of X-B and Ultra on "Average Month" Attack-days. After Reference [9]

As was suggested by the historical cases, there is no evidence of any saturation effect, and (as the historical cases suggested) complete X-B compromise leads to about a 95% increase in the number of attack-days - but only in a no-Ultra environment. As can be seen by the flatness of the graphs of the two Ultra cases, Ultra is able to nullify the effect of any level of X-B. Because of the role of Ultra in facilitating the escape of convoys once they are sighted, two cases have to be considered. With Ultra able to do this, it will save some convoys that were sighted without help from X-B, and will therefore reduce the number of attack-days to below the no-X-B level. Just to be sure that nothing untoward is happening, McCue altered the model as mentioned above so that Ultra does not help sighted convoys to escape. In this mode, Ultra negates X-B as exactly as can be discerned on the basis of 24 runs. The fact that the points associated with these runs tend to lie slightly above the horizontal axis is not a cause for alarm: it simply means that the average of the 0% X-B runs—used to position the horizontal axis—came in a little low, as is also suggested by the fact that the trendline value for 0% X-B is somewhat higher than the 0% X-B point.

In the McCue simulation, the computer controlled convoys and wolfpacks behave fairly sensibly but there is room to wonder if a wargame that utilized human players would provide significantly different results.

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IV. THE WARGAME

A. DESCRIPTION

A wargame is a combination of game, history and science – combining a game space, playing pieces representing military units and a set of rules – which enables the player(s) to recreate specific events and to explore "what if" questions. [2]

Developed in Java, this wargame benefits from low-cost, modeling flexibility, and platform independence features associated with this programming language. [6] The Java virtual machine, the only software required to run the program, is available for download from Sun Microsystems' worldwide website, **www.sun.com**, at no cost. The inherent modeling flexibility of the object-oriented programming language allows the user to easily add forces or improve the current modeling algorithms without changing the entire program. Since Java is platform independent, the operators and players in wargames have the flexibility to run the program on a variety of hardware located on a ship or in the office.

The wargame designed and used in this thesis has the same instructions and parameters as the McCue simulation described in the previous chapter. However, the McCue simulation was programmed in QuickBasic, and as is common when writing in another programming language (in this case Java) the programs will not match exactly. As described in the next chapter, phase one of testing compared results of the wargame with the McCue simulation to ensure that the wargame remains true to the simulation. Figure 5 depicts the wargame as a flow diagram.

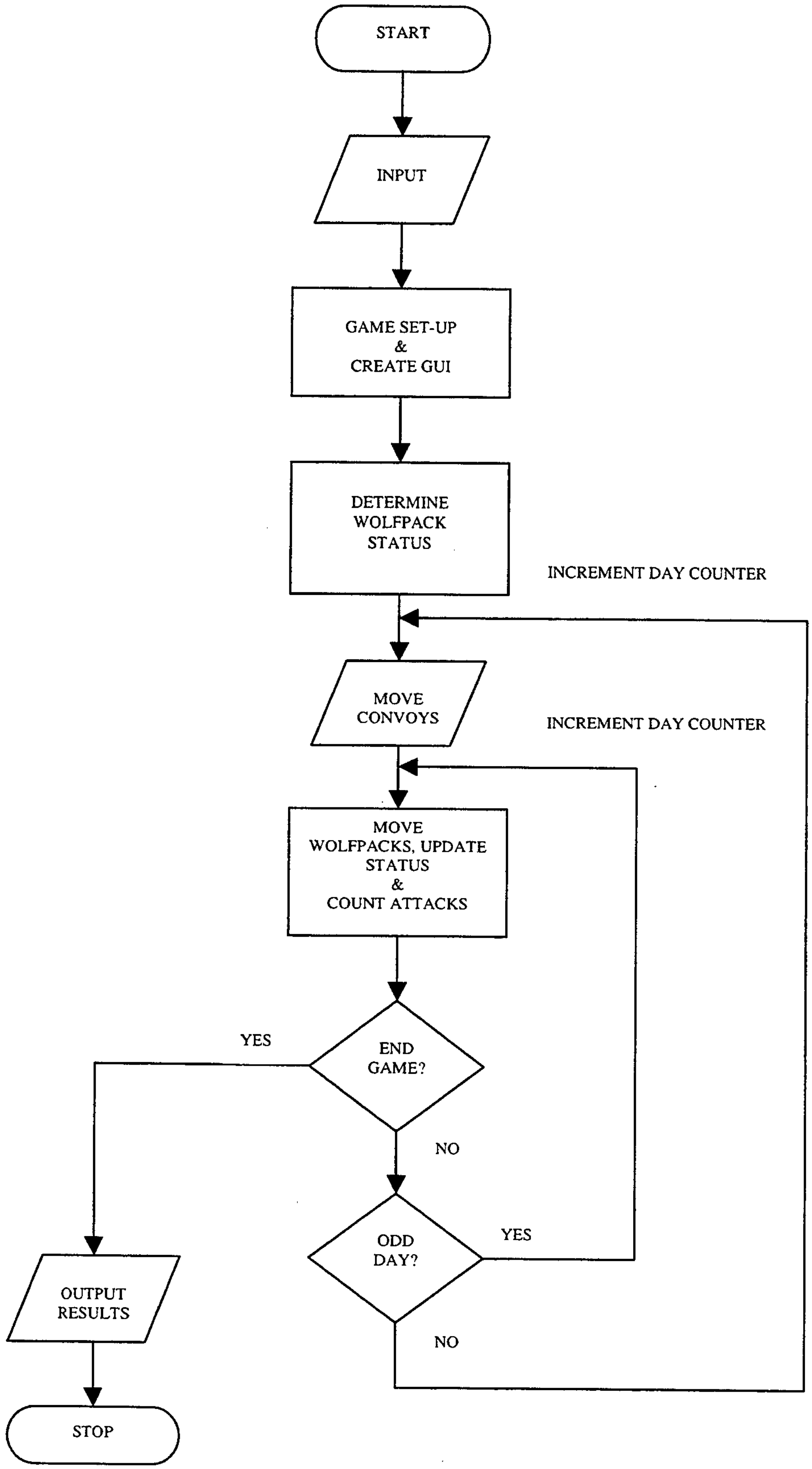

Figure 5. Flow Diagram Representation of the Wargame.

In this version of the wargame, the convoys are controlled by the human player while the wolfpacks are controlled by the game. The wargame is initiated when the game parameters are entered at the DOS command line. These parameters include: 1) number of turns (equivalent to the number of days in the month being played), 2) the month being played, 3) the number of convoys, 4) the number of wolfpacks, 5) X-B available (true/false), 6) Ultra available (true/false), 7) subject number (parameter added for phase two testing), and 8) output filename to which data will be written.

The wargame randomly generates the convoys' starting location and direction of movement (eastbound and westbound). If X-B intelligence is available (set to true), the wargame determines convoys' compromised state based on the probabilities listed in the X-B column of Table 2. Next, the wargame randomly generates the wolfpacks' starting locations. The number of wolfpack attack-days at the beginning of day one is zero. The game then determines the state of each wolfpack in the same manner as described in the McCue simulation. Using the generated locations and states, the wargame generates the graphical user interface. Only attacking wolfpacks are displayed to the player.

The goal of the human player is to get the convoys across the chessboard representation of the North Atlantic. Convoys move on odd days only beginning with day one and move only one square per turn. Wolfpacks move on both odd and even days (one square per day) and are controlled by the wargame. To move the convoys, the player selects any convoy highlighted in red (indicating an unmoved convoy). When a convoy has been selected to move, the remaining convoys are disabled and the squares into which the selected convoy is allowed to move is highlighted in red. When the player selects the square that he/she wishes to move the convoy, the convoy image is transferred to that square, is disabled for the remainder of the turn and the remaining unmoved convoys are again highlighted and enabled. The player repeats this process with all of the convoys. The COMMIT button (which allows to player to commit his/her turn) is enabled only after all convoys have been moved. The player may undo any or all moves at any time until they commit that turn. The UNDO button resets moves in reverse order from which they were made. Figure 6 shows the wargame graphical user interface. Once a turn is committed, the wargame moves the wolfpacks, updates their status (patrolling, sighting, converging or attacking) and updates the number of wolfpack attacks for each of two turns.

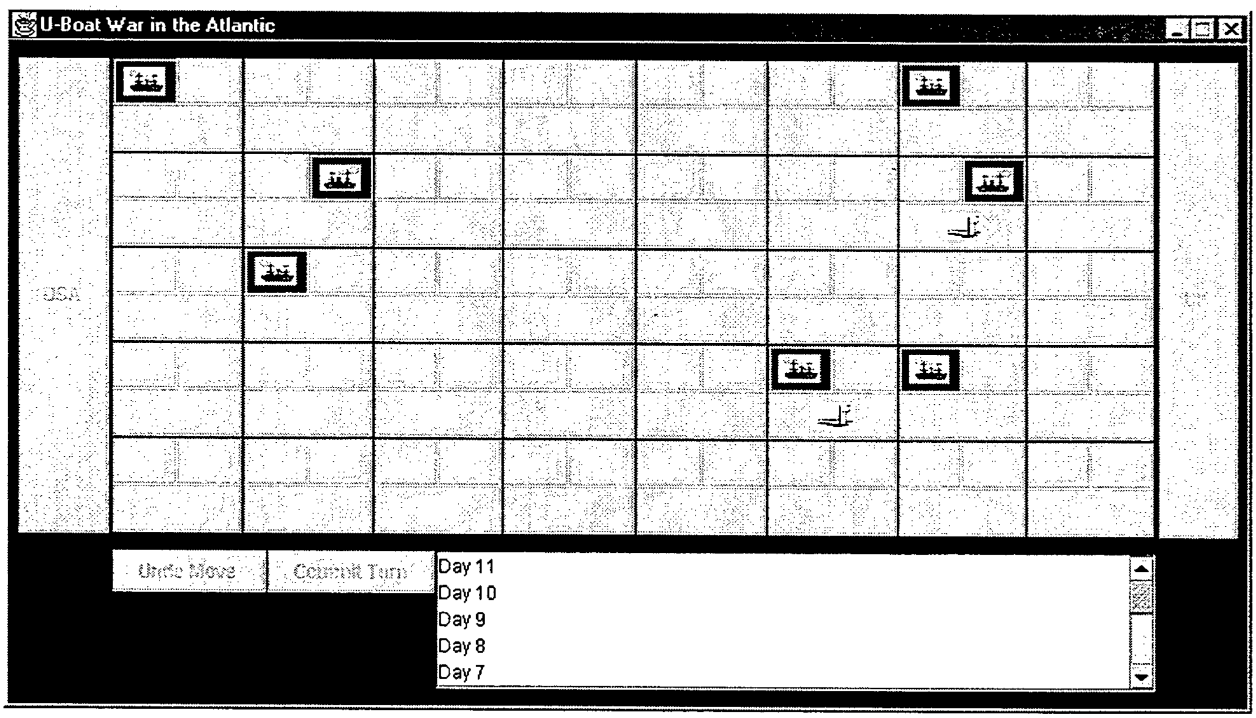

Figure 6. Wargame Graphical User Interface.

At the end of each turn, the wargame verifies whether the end game condition has been met. An end game condition occurs when the turn number equals the number of days entered as a parameter at the start of the game. If the end of the game is not reached, the wargame determines who makes the next move. If the turn number is odd, the wolfpacks move again and new attacks are counted. If the turn is even, the human player moves convoys and then the computer moves the wolfpacks. The turn count is incremented by one at the end of each turn.

Movement of convoys and wolfpacks, and counting of attacks continues as described until end game conditions are met. At that point, the game board is disabled, the player is notified that the game is over and game data is written to the specified file. The number of U-boat attack-days is calculated by multiplying the total number of attacks by 12 (the average number of U-boats in a wolfpack).

The data collected is used in two phases of data analysis as described in the next chapter.

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V. WARGAME ANALYSIS

Data collection was accomplished in two phases. Phase one consisted of verifying that the wargame models reality well and is true to the original McCue chessboard model. The second phase of data collection consisted of experimenting within the wargame to explore the effects of SIGINT by examining the four possible conditions of signals intelligence (neither side having SIGINT, one side or the other having it and both sides having it) with all other variables held constant.

A. PHASE ONE DATA ANALYSIS

Before the wargame can be used to make observations about the influence of signals intelligence, it must be determined that it replicates the historical cases well. For this, the wargame was played 30 times by the researcher for each month, utilizing the data in Table 3. The results are shown in Figure 7 and Figure 8.

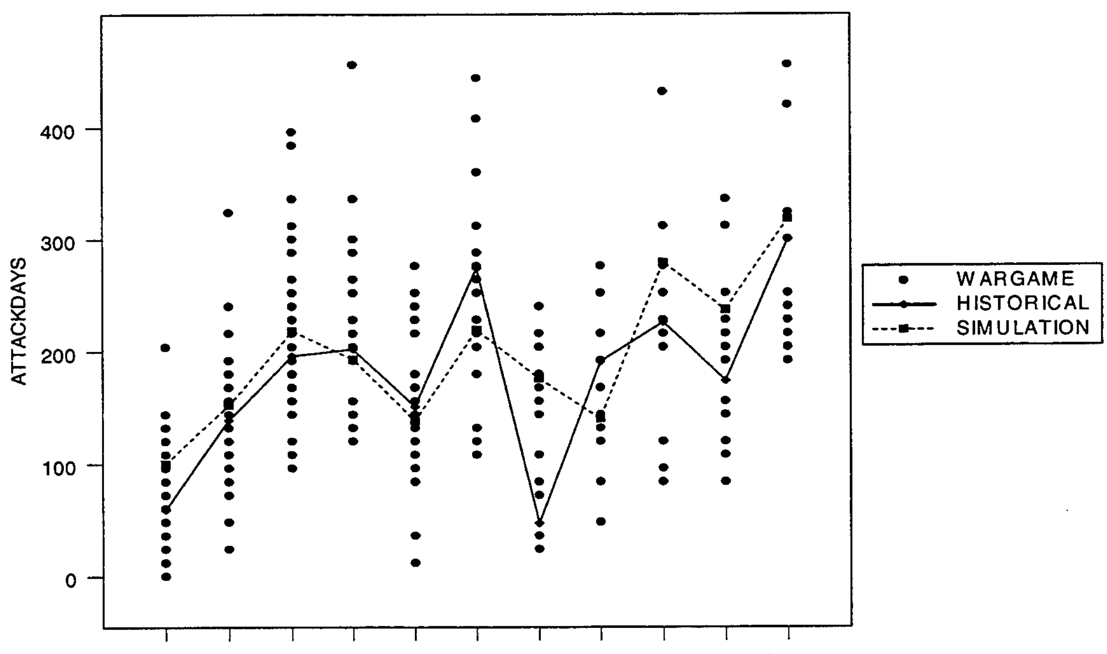

Figure 7. Comparison of Wargame Data with Historical and Simulation Data.

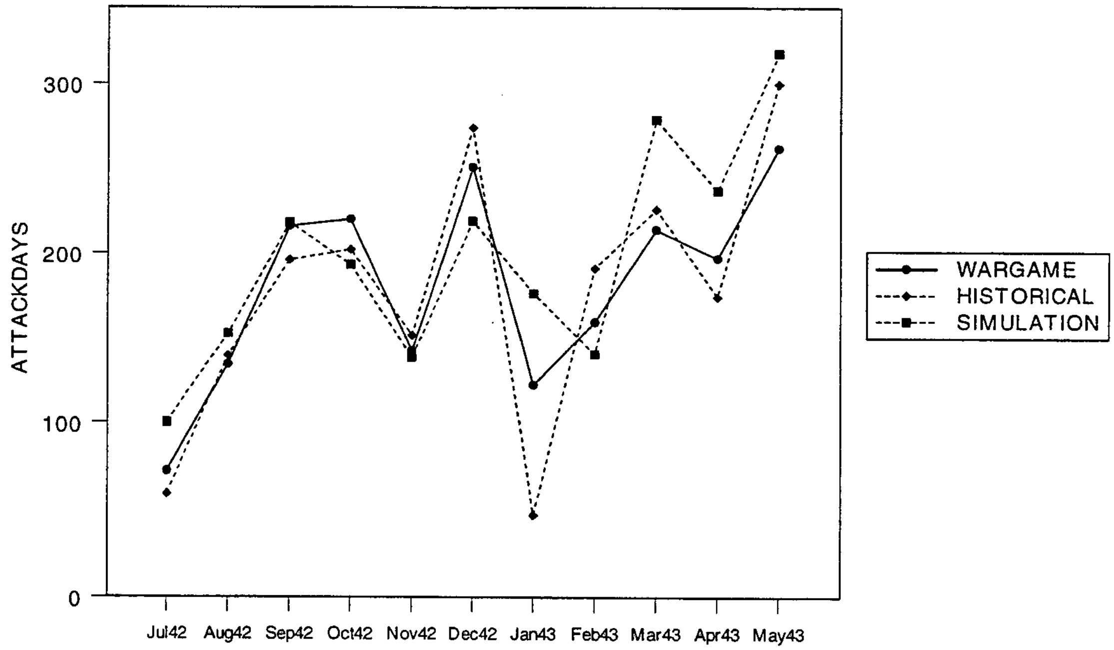

Figure 8. Comparison of Wargame Mean with Historical and Simulation Data.

Figure 7 shows the data spread for each month in comparison to the historical data and the simulation mean. As with the McCue simulation, nearly all of the historical cases fall amid the middle two quartiles of the respective months' wargame results. Figure 8 shows that, in 7 of 11 cases, the wargame mean falls between the historical results and the simulation mean.

The results are also analyzed statistically in Table 7. For each month, Table 7 shows the wargame mean and standard deviation along with the historical and McCue simulation data. The z-score and chi-squared p-value are calculated for the wargame data to facilitate comparison with the McCue simulation. For the wargame data, the chi-squared p-value (assuming 11 degrees of freedom) is .998 compared to .798 with the McCue simulation.

MONTH	HISTORICAL ATTACKDAYS	SIMULATION MEAN	SIMULATION STDEV	WARGAME MEAN	WARGAME STDEV	WARGAME Z-SCORE Z	WARGAME Z-SCORE Z^2
Jul42	59	100	45	72	46	-0.28	0.08
Aug42	139	152	76	134	60	0.09	0.01
Sep42	196	218	77	216	78	-0.26	0.07
Oct42	202	193	87	220	80	-0.23	0.05
Nov42	151	138	63	142	66	0.14	0.02
Dec42	274	219	80	251	86	0.26	0.07
Jan43	47	176	66	122	69	-1.08	1.17
Feb43	191	140	56	159	68	0.47	0.22
Mar43	226	279	93	214	88	0.14	0.02
Apr43	174	237	83	197	70	-0.33	0.11
May43	300	318	124	262	80	0.48	0.23
						Z-SCORE SUM	2.04
						CHI-SQUARED P-VALUE	0.998

Table 7. Statistical Validation of the Wargame.

B. PHASE TWO DATA ANALYSIS

Having evaluated the wargame against the historical data, and found it in accord with the Atlantic campaign and true to the McCue simulation, the second phase of analysis evaluates the influence of SIGINT on an "average month". The month of January 1943 was chosen since the data for that month (the number of convoys and wolfpacks as well as the probability of X-B compromise) represents the averages for the period under examination.

Thirty players (a random mix of NPS students, faculty and staff members) each played four iterations of the wargame representing the four possible SIGINT conditions. The order in which the games were played differed from player to player to eliminate any possible "learning" effects. Table 8 summarizes the results of the 30 players giving the mean and standard deviation broken out by each of the four cases.

XB	ULTRA	ATTACKDAYS MEAN	ATTACKDAYS STDEV	PERCENT DIFFERENCE
NO	NO	148.80	64.86	0.00
NO	YES	122.80	74.75	-17.47
YES	NO	196.80	103.35	+32.26
YES	YES	142.40	58.68	-4.30

Table 8. Wargame Player Results per SIGINT Condition.

The percent difference is calculated by subtracting the mean of the base case (neither side having SIGINT) from the mean for each case and dividing by the base case mean. Not surprising, the data shows that SIGINT aids the side that has it and is effectively neutralized when both sides have it.

Table 9 examines the data from the convoy and wolfpack perspectives.

	ATTACKDAYS				
	ULTRA		W/O ULTRA		
	MEAN	STDEV	MEAN	STDEV	PERCENT DIFFERENCE
CONVOYS	132.60	67.36	172.80	88.90	-23.26
	XB		W/O XB		
	MEAN	STDEV	MEAN	STDEV	
WOLFPACKS	169.60	87.72	135.80	70.61	+24.89

Table 9. Summary of Wargame Results.

Convoys experienced a 23.26% reduction in attack-days when examining the case of having Ultra (the combined average of both sides having SIGINT and only the convoys having it) against the case of no Ultra (the combined average of neither side having SIGINT and wolfpacks having it when convoys do not) irrespective of wolfpack SIGINT. Similarly, wolfpacks experienced a 24.89% increase in attack-days with SIGINT.

The results show that signals intelligence had nearly equal value for both sides, albeit with entirely different consequences. X-B assists the wolfpacks in attacking convoys whereas Ultra assists the convoys negate the effects of X-B. While the influence of SIGINT is significant in this analysis, it is not the "make or break" factor in warfare that has sometimes been postulated. Additionally, these results concur with previous work by LT John McGunnigle on the value of information vs. force advantage. In his thesis examining the values of information and force advantage, McGunnigle concluded that it may be difficult to realize the benefits of information superiority and that enthusiasm for information technologies should be tempered when arriving at the best balance between more information and more forces. [10]

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VI. CONCLUSIONS

Future military visions are based on a battlespace in which information superiority is a prime tenet. Signals intelligence is a means to gaining information superiority and has long been viewed as a significant factor in modern warfare. The goal is to develop a method to place "value" on SIGINT so that it can be evaluated along with other battlespace assets.

The field of operations research specializes in using models of the real world to solve problems, and providing information and insight to decision makers. Building on research by Brian McCue, this thesis creates an interactive wargame representation of the Second World War's Atlantic campaign that provides a reasonable measure of the value of SIGINT. The results show that signals intelligence has nearly equal value for either side, and, while significant in this analysis, SIGINT is not the "make or break" factor in warfare that has sometimes been postulated. Additionally, these results concur with previous work by LT John McGunnigle. In examining the values of information and force advantage, McGunnigle concluded that it may be difficult to realize the benefits of information superiority and that enthusiasm for information technologies should be tempered when arriving at the best balance between more information and more forces. [10]

Development of this model into a two-player wargame is the next logical step. A networked wargame (with one player controlling the wolfpacks, a second controlling the convoys, and the wargame serving as referee) would be the ideal venue. Such a model might then be modified and applied to the future battlespace so that military leaders can see the effect of own-forces signals intelligence and the potential threat to American forces from an adversary's SIGINT activities.

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4. Professor Gordon H. Bradley 3
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   Naval Postgraduate School
   Monterey, California 93943-5000

5. Brian McCue 2
   4915 Cherokee Avenue
   Alexandria, VA 22312

6. LT Charles W. McCaffrey 2
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