EFFECTS ON U-BOAT PERFORMANCE OF INTELLIGENCE FROM DECRYPTION OF ALLIED COMMUNICATION

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ABSTRACT

Examination of the War Diary of the German ComSubs has made it possible to estimate the character and extent of intelligence obtained by the decryption of Allied radio messages pertaining to convoy operations in the North Atlantic during World War II, and to determine the effect of such intelligence on the capability of the U-Boats to contact convoys and sink ships. It is estimated that the availability of timely usable decryption intelligence increased the contact rate twofold over that which they would have obtained without it; probably over 60 sinkings in excess of the expected number if they had been deprived of decryption intelligence. These calculations help in estimating a valid measure of the effectiveness of current and future submarines in anti-convoy operations when decryption intelligence is not available.

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EFFECT ON U-BOAT PERFORMANCE OF INTELLIGENCE OBTAINED FROM DECRYPTION OF ALLIED COMMUNICATIONS

Ref: (a) The War Diary of the Commander of Submarines (Befehlshaber der Unterseeboote (BdU) From 1939 through December 1944 Conf
(b) CominCh Daily U-Boat Estimate Secret
(c) OEG Report No. 51 Antisubmarine Warfare in World War II Conf 1946
(d) OEG Report No. 56 Search and Screening Conf 1946
(e) ORG Memorandum No. 18 Frequency of Attacks on Convoys in Relation to U-Boat Predictions Secret 18 Nov 1942
(f) ORG Memorandum No. 25 A Probability Study of COMINCH Daily Submarine Estimates Secret 27 Feb 1943

1. INTRODUCTION

This study contains the findings of research carried out with the general objective of determining, if possible, in what manner and to what extent the availability of intelligence derived by the German U-Boat command* from the decryption of Allied radio messages affected the conduct of the U-Boat war against North Atlantic convoys during the Battle of the Atlantic from July 1942 to March 1944. The specific purpose of the research can be most clearly stated by giving the circumstances connected with the genesis of the project.

During World War II the Antisubmarine Operations Research Group (ASWORG) was organized for the purpose primarily of analyzing operational data as they were assembled in the course of the war against the German submarines, in order to provide information that would be of assistance to the command in adapting strategy and tactics so as to utilize the available antisubmarine forces with maximum effectiveness. In the course of this work, ASWORG found it necessary to devise and develop measures of effectiveness for the various aspects of the antisubmarine operations--as an example, in dealing with the detection of the enemy, subjects of study by ASWORG included the construction of systematic search plans for surface vessels and aircraft; the evaluation of the means of detection--visual, radar, sonar; studies of the most profitable areas of search, etc. At the end of the war, the most important results of the various studies carried out by ASWORG were assembled

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* In this paper, the German commander of the U-Boats is referred to by the letters BdU, for "Befehlshaber der Unterseeboote".

and published in two comprehensive reports: reference (c), dealing chiefly with the several aspects of the war against the U-Boats from a statistical viewpoint; and reference (d), presenting a complete and coherent theory of search and screening operations developed on the basis of the operational data assembled during the war.

With respect to the part played in the Battle of the Atlantic by intelligence, the operations analysts had available during the war only that obtained by the Allies.* Analysis of German U-Boat capabilities had to be made on the basis of over-all operational data, and conclusions derived from them would be valid only when applied to a set of conditions very similar to those under which the Germans operated. Not until after the close of hostilities was it discovered that the German U-Boats owed some portion of their effectiveness to the fact that for considerable periods the German cryptanalysts succeeded in reading the Allied convoy cipher more-or-less currently. The capabilities of the U-Boats in contacting and attacking convoys that had been evaluated in ignorance of this fact were weighted by the contribution of this type of intelligence and would not apply to an enemy who was not equally lucky in obtaining it.

The capture by the Allies of the War Diary of the German Submarine Command (reference (a)) made available data that has enabled the evaluation of the effect which intelligence, gained by decryption, had on the capability of the U-Boats to contact and attack convoys. Hence it is now possible to estimate how effective the German U-Boats would have been if they had been required to depend on ordinary sources of intelligence alone, without benefit of decryption intelligence. This information is potentially of great value as a base in determining force requirements for the future, when extrapolating from World War II U-Boat performance to that of possible future submarine forces, but assuming that a future enemy may not obtain decryption intelligence.

In order to limit the scope of this study, attention is confined to the convoys that traversed the North Atlantic between the United States-Canada and the United Kingdom--the east-bound HX and SC, and west-bound ON(S) convoys. The period considered is from July 1942 to March 1944, with the exception of the period from 1 June to 15 September 1943: during this period the U-Boats did not operate against the North Atlantic convoys (the Allies took the offensive with CVE hunter-killer groups and killed a large

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*Certain aspects of intelligence pertaining to the antisubmarine effort were subjected to analysis by ASWORG. For example, reference (e) contains an investigation of the relationship between attacks on convoys and the predicted positions of U-Boats shown in the COMINCH daily submarine estimate, thus providing means of estimating the accuracy of tracking the U-Boats. Reference (f) is a study of the accuracy of the daily estimate of enemy submarine positions based on all sources of intelligence combined.

number of U-Boats). Since the Allies changed the naval convoy cipher in June 1943, and the Germans were deprived of decryption intelligence, the over-all interval can be conveniently divided into three periods:

PERIOD I: From 1 July 1942 to 31 December 1942. During this time the War Diary indicates that the Germans had only slight success in reading the Allied convoy traffic.

PERIOD II: From 1 January 1943 to 31 May 1943. The Germans read the Allied convoy radio traffic much more effectively than during the previous period.

PERIOD III: From 16 September 1943 to 31 March 1944. During this period the Germans succeeded in reading only an unimportant part of the Allied convoy communications. The intelligence received from this source was of little use to them, although BdU tried to exploit it as fully as possible. In December 1943 this source dried up completely. (See the Review of the Radio Intelligence situation by BdU quoted in the War Diary after the entry of 30 September 1943.)

Details of the status of German intelligence during these periods are given in part 2. The conclusions of this study are based on a case history of each of the HX, SC, ON, and ONS convoys during the three periods just mentioned, with respect to the German intelligence on each; the use, if any, to which this was put by the German ComSubs, as evidenced by reference (a), contacts and attacks by the U-Boats.

2. HISTORICAL SURVEY

From 1940 on the Germans had used some of their comparatively few U-Boats to attack UK-US convoys, but immediately after Pearl Harbor de-emphasized this phase in order to exploit the opportunities offered by unescorted, independent U. S. coastal shipping, with practically no air defense and negligible surface combat ships to make it hazardous. The results during the first months of 1942 were disastrous for the Allies. By late spring, however, the campaign began to lose its effectiveness, and BdU renewed the attacks against the North Atlantic convoys. He was handicapped in this campaign by the lack of sufficient U-Boats until toward the end of the year; but by December he was able to operate, on the average, 35 U-Boats in the area traversed by the convoys, and the number rose to 70 by March 1943. The number of convoyed ships sunk became formidable. The landing of the Allies in Africa in November 1942 diverted BdU's attention somewhat from the North Atlantic, and from December 1942 on he placed U-Boat groups of fairly large size--up to 15 boats--west of Gibraltar to intercept convoys between that point and the United States and Caribbean.

In the North Atlantic, BdU maintained a fairly constant strategic pattern. By the end of 1941 he knew the general rhythm of the east-bound HX and SC and the west-bound ON convoy; he also knew the general routes they followed. In acquiring this knowledge he had been aided greatly by the decryptions of radio communications from Allied shore stations (reference (a), entry of 30 September 1942). Hence, lacking specific intelligence on

a given convoy, he was able to make a fair estimate of its probable position on a given date; easily within 500-600 miles in a generally north-and-south direction, and within one day's run--say 150-200 miles--along the great circle. If he had a pack of, say, 10 boats spaced 15 miles apart, they could sweep out the probable area in about 2 days if the weather permitted them to proceed at standard cruising speed. Given fair visibility, there was a good chance that they would sight the convoy. If the area was one where convoys from opposite directions passed each other, the probability of a contact was increased. The German intelligence branch had computed these areas of probable greatest convoy density, and, in general, throughout the convoy war, BdU had from four to six U-Boat groups patrolling these areas. They were disposed roughly in three lines, and the packs were shifted along these lines as intelligence (or the lack of it) suggested (figure 1). In the east, the boats were deployed in segments of a line running south from Iceland to the 50° parallel, somewhere near the 25° meridian. The packs on this line were intended to intercept ON (west-bound convoys), or to sweep southwestward to close east-bound (HX and SC) convoys that had been intercepted or, although fairly well located, missed by the western packs. In the west, a line was established in a NE-SW direction from north of Newfoundland to the Flemish Cap. A third line extended from the south-east tip of Greenland in a southerly direction to the 40° parallel. The pack on this line could be used against both east-bound and west-bound convoys, as occasion suggested. In addition, boats in transit traversed the regions not patrolled by the packs, and in several cases convoys were contacted by these transiting submarines.

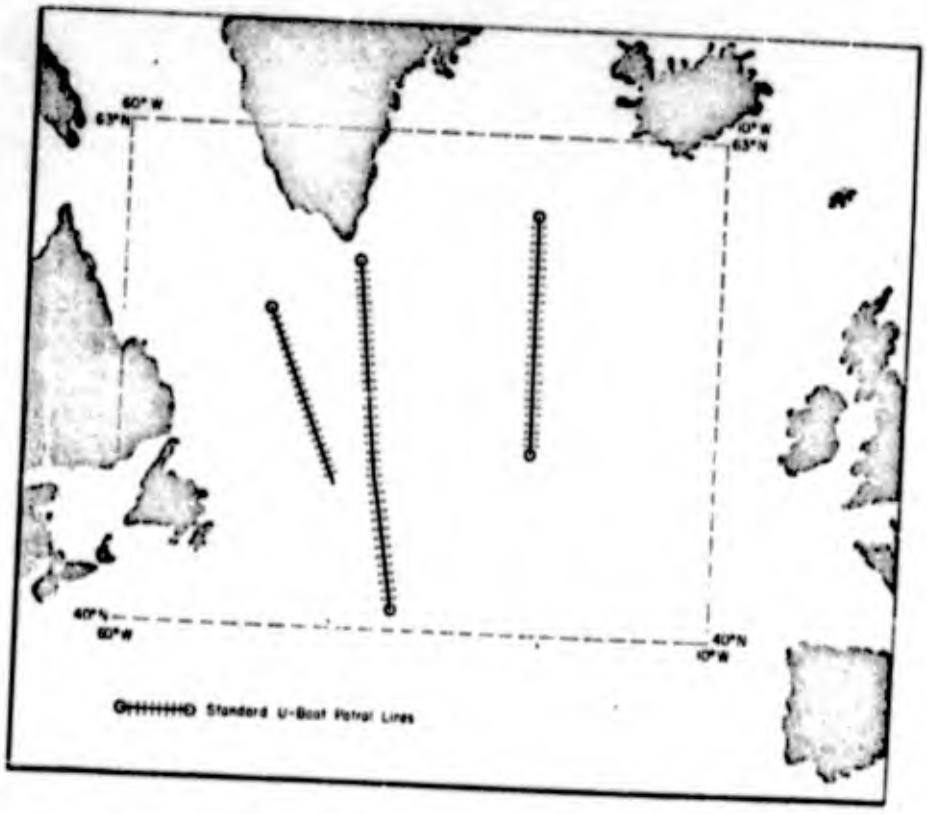

FIG. 1: AREA OF U-BOAT OPERATIONS AGAINST US-UK CONVOYS

It is possible that more contacts might have been obtained by spreading the U-Boats more thinly over the ocean and searching a larger area less intensively, especially when intelligence was plentiful and accurate, since the convoys were distributed more-or-less at random over the whole North Atlantic. BdU, however, aimed at getting the largest possible number of sinkings, rather than of contacts, and was convinced that in attacking convoys it was more profitable to have a large number of U-Boats concentrated on a single convoy, necessarily allowing others to pass unmolested or even undetected, than to attack a larger number of convoys with fewer boats each. Consequently, the value to him of decryption intelligence cannot always be judged by contact rates, especially since the patrol lines were long enough and dense enough to provide a high probability of contact.

This campaign was one of the most successful during the war, the average monthly shipping losses and the exchange rate of merchant ships sunk per U-Boat sunk reaching nearly their highest figures.

By the middle of May 1943, however, the U-Boat war against the North Atlantic convoy had become extremely unprofitable, as table I shows:

TABLE I

EXCHANGE RATE IN THE NORTH ATLANTIC, EARLY 1943

Month (1943)	Number of ships sunk by U-Boats	Number of U-Boats sunk	Exchange rate: merchant vessels sunk per U-Boat sunk
February	36	10	3.6
March	48	6	8.0
April	20	10	2.0
May	19	34	0.56

Of the 60 U-Boats sunk, about half (27) were sunk by surface craft, and half (30) by land-based aircraft; carrier aircraft accounted for three.

To get his boats beyond the range of land-based air, BdU withdrew them from the North Atlantic to an area southwest of the Azores, in order to intercept US-Gibraltar convoys. They were entirely unsuccessful during June and July, and BdU then dropped anti-convoy operations and concentrated on coastal shipping and independents in more distant areas---the Caribbean, off Brazil, Freetown, the Cape of Good Hope, and the Indian Ocean.

The U-Boats stationed in the Mid-Atlantic did avoid land-based aircraft, since bases in the Azores were not available to the Allies until August. However, they ran into the CVE groups--BOGUE, CARD, CORE, SANTEE, CROATAN--who, during the summer of 1943, made a total of 44 attacks on German submarines, sinking 15 and damaging nine, in the area bounded by 25° N to 45° N and 20° W to 50° W.

Aside from the losses inflicted on the U-Boats in the Mid-Atlantic, the Allied antisubmarine forces gave the German submarine fleet a severe drubbing wherever they encountered them. During these 3 months, the Biscay offensive accounted for 31 U-Boats sunk; 10 more were sunk in the Atlantic south of the area considered here and nine north of the area; 6 were lost in the Caribbean area and 9 in the Mediterranean and the Indian Ocean. To offset the loss of these 80 U-Boats, only 86 ships were sunk by submarines all over the world.

It was doubtless the failure of the summer campaign which convinced BdU that the only region where a profitable exchange rate could be looked for was the North Atlantic. He confidently expected to meet effectively the threat of the surface escorts, which had taken such a heavy toll of U-Boats in May, by means of a new accoustic torpedo; the threat of antisubmarine aircraft was to be countered by improved search receivers and a new quadruple-mount 20-mm. AA gun. Thus, the last half of September saw the U-Boats heading again in considerable numbers for the lanes of the UK-US convoys; by October their numbers in the North Atlantic were comparable with those of the spring. This new anti-convoy campaign resulted in dismal failure; the exchange rate in October in this area was one merchant vessel sunk per seven U-Boats sunk, and in November the U-Boats sank no ships at all in the North Atlantic, although over 30 U-Boats were concentrated there. This state of affairs continued through the winter. In March 1944 the last wolf-pack to operate in the North Atlantic was disbanded. The world-wide situation was very little better. The exchange rate for the period from July 1943 to the end of the war was 0.5 merchant vessels sunk per U-Boat sunk, which was one-eighth the exchange rate during the 9-month period from October 1942 to June 1943, and only one-thirty-sixth the rate for the 9 months preceding that.

The invasion of Normandy in June 1944 caused BdU to concentrate his boats in the Channel. By this time it meant practical certainty of kill for a U-Boat to surface anywhere near their enemy; hence the only boats operating were those equipped with schnorchel. From this time on to the end of the war, the German submarine effort was directed against coastal shipping near the UK. It was not successful, as the low exchange rate indicates.

3. THE CHARACTER AND EXTENT OF DECRYPTION INTELLIGENCE AVAILABLE TO THE GERMAN U-BOAT COMMAND

3.1. GENERAL CHARACTER OF THE DECRYPTION INTELLIGENCE

The War Diary of the German ComSubs provides a fairly comprehensive picture of the extent and character of the decryption intelligence available to the BdU, and also of the degree and manner of its tactical and strategic exploitation. The daily entries of the diary contain a very complete detailed survey of all phases of the U-Boat war, including details of intelligence on the movements of the Allied forces and the sources of this intelligence. The format has a category entitled "Reports on the Enemy" which included an item on "Radio Intelligence" obtained by means of decrypting messages transmitted

via radio by Allied forces. In another category headed "Operations" the specific use to which some of the radio intelligence was put is described. In most cases the diary designates the convoy in question quite clearly; in those instances in which it does not, it is comparatively easy to identify the given convoy by means of data on position and course.

In this study a given convoy is considered to have been "compromised" by radio intelligence if the War Diary mentions such intelligence in connection with it. It is obvious that this selection does not include all the convoys of which BdU had radio intelligence that conceivably was useful to him in planning his operations; for if the communications traffic was read promptly at any given time, it was probably read fairly completely and doubtless provided information on most, if not all, of the convoys at sea at the time. However, the War Diary gives no clue to those convoys of which usable decryption intelligence was presumably available, but was not explicitly exploited. While such convoys can be considered "compromised" within a less restricted definition of that term, the fact that they were not designated particularly by BdU implies that he did not plan operations against them; hence, if in some cases they were contacted and attacked, the operation might reasonably be ascribed rather to exploitation of the fortunes of war than to the planned utilization of the forces at his disposal on the basis of intelligence.

A study of the War Diary indicates that the intelligence provided by decryption included the following items:

(a) Information enabling BdU to compute the rhythm of the several classes of convoys (see, for example reference (a) entries of 7 March 1943, 12 March 1943, among others);
(b) Sailing dates, rendezvous times, and positions.
(c) Position, course, and speed of convoys while enroute. The source of this is not clear, since convoys customarily observed radio silence; it is possible that escorts betrayed the position when arranging for rendezvous with the convoy.
(d) Diversions ordered by a shore command after the convoy had left the rendezvous point.
(e) Information of Allied estimates of U-Boat positions.
(f) Occasional information of the composition of convoys.

3.2 QUANTITY OF DECRYPTION INTELLIGENCE AVAILABLE FOR U-BOAT OPERATIONS

The War Diary indicates that the contribution of the German cryptanalysts to the over-all intelligence picture of the U-Boat command was substantial from the beginning of the war until the summer of 1943. Its importance was enhanced by the fact that other sources of intelligence on convoy movements were meager. The War Diary makes one conclude that radio direction finding played a very minor part in furnishing intelligence on Atlantic convoys. Reconnaissance by aircraft was possible only for short periods and at limited ranges from the European coast, owing to the inability of the Air Force command to allocate long-range patrol planes to the submarine campaign.

By the time the Unites States entered the war, the German U-Boat command was able to predict the probable areas of greatest density of the UK-US convoys, having obtained enough information from decryptions to establish the rhythm of sailing and the probable courses they would take. These areas were three in number (figure 1):

(1) a strip northeast of Newfoundland,
(2) one just northeast of the former, stretching south from Greenland,
(3) one stretching south from between Greenland and Iceland.

The value placed on this analysis by BdU is indicated by the fact that for nearly 2 years, in every campaign against North Atlantic Convoys, he placed his patrol groups chiefly in these areas, lengthening the strips to the southward when Allies began using a southern route along the 40° N parallel in January 1943. It is difficult to understand why the Allies continued to route the convoys along the same routes for such long periods (reference (a), entry at end of September 1942.)*

The contribution of the decryption service was stopped in June 1943 by a change in the cipher on the part of the Allies (reference (a), review after entry of 30 September 1943 and 31 March 1944.) By 16 September 1943 the Germans had succeeded in breaking a part of the new cipher. However, they were able to read only messages giving straggler routes and early rendezvous points. This information appears to have been of value to ComSubs in only a few cases; in general, it may even perhaps have been more confusing than helpful. In December 1943 the Allies removed this last scanty source of information by giving straggler routes and rendezvous points relative to certain reference points, the location of which the Germans were unable to determine. During the remainder of the submarine campaign against Atlantic convoys the U-Boats were obliged to depend on their own scouting and that of the few long-range aircraft available. The Allies, on their part, made scouting by the U-Boats themselves very difficult: to achieve a satisfactory search-rate, the U-Boat had to search on the surface, depending on visual

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*The effect of retaining the same routes is discussed by BdU in the entry of 15 January 1943 of the War Diary as follows:

"It must be assumed that the enemy has left the convoy routes that he has been sailing for nearly 6 months and is again scattering his convoy routes. This development is a great drawback to attacks by our boats, but was only to be expected. As has already been emphasized in this War Diary, it was quite inexplicable why the English stuck so stubbornly to almost the same convoy routes for six months, which greatly simplified finding the convoys. Probably the convoy routes to the North have been moved into the patrol areas of the Greenland and Iceland units. The next step for us to take is to make long dispositions with numerous boats so as to find out exactly what detours the enemy is making."

This was written at the end of a 3-week period during which decryption intelligence on North Atlantic convoys appears to have been lacking.

sightings since it lacked an adequate search radar. When submerged, its speed and endurance were so limited that very little dependence was placed on sonar search. Aircraft patrols forced the U-Boats to operate submerged a large part of the time, and thus reduced their contact capabilities as well as their ability to close the contacts that were obtained.

The amount of intelligence supplied to BdU by decryption was radically different in each of the periods listed in the Introduction.

TABLE II

QUANTITY OF AVAILABLE INTELLIGENCE OF CONVOYS

Period	Number of convoys	Number of convoys compromised	Percent compromised
I: Jul-Dec 42	100	3	3
II: Jan-May 43	79	21	27
III: Sep 43-Mar 44	87	15	17
All periods	266	39	15

4. THE UTILIZATION BY THE GERMANS OF DECRYPTION INTELLIGENCE ON NORTH ATLANTIC CONVOYS

A cursory glance at the problems associated with a U-Boat campaign against North Atlantic convoys immediately reveals the need for good intelligence. An average of seven convoys were distributed more or less uniformly (once the Allies ceased to follow the great circle route persistently) over the region shown in figure 1, an area of about 3,000,000 square miles. The Germans maintained an average of 35 submarines in this area over the periods considered.* [To concentrate these submarines near the ends of the routes, where the convoy density was greatest, was not practicable because the presence of land-based patrol aircraft hampered their operations] Granted an optimistic sweepwidth of 20 miles at a relative searching speed of 10 knots, the whole submarine force operating as single units without decryption intelligence could expect to make about 12 sightings per month; however, these would be sightings by a single submarine, with small chance that others would contact the sighted convoy.

*The averages for the three periods were: period I, 31 U-Boats; period II, 52 U-Boats; period III, 26 U-Boats.

The limitations of the small 500-ton Type VII-C U-Boat, of which the German submarine force in great part consisted, made this kind of campaign impracticable. Unless it was refueled at sea, its average time on patrol was 16 to 20 days; the number of submarines required to keep 35 on stations at all times throughout the whole area involved would have been beyond the German capabilities. Refueling widely distributed individual boats on their stations was out of the question; it could be, and was, done by concentrating the boats in 3 or 4 groups, patrolling some portions of the whole area while neglecting other portions. This consideration alone forced the Germans to adopt pack tactics; moreover, the German command was convinced that concentrating the largest possible number of boats on fewer contacts would yield more sinkings than single attacks on a greater number of contacts.

Lacking aircraft reconnaissance, the great need for intelligence of the type provided by decryption is obvious. Its value lay in reducing the area that had to be searched in order to assure contacts. Throughout the North Atlantic convoy war, BdU placed his U-Boat packs in patrol lines at the positions which, according to calculations based in large part on decrypted Allied messages, were consistently most likely to be those of greatest convoy density. When the Allies changed their routing, the Germans were apprised of this by decryption intelligence and could react effectively. (See the War Diary for January 1943, for example.)

Precise evaluation of the operational effect of decryption intelligence requires consideration both of the successes obtained with its use, and also of the success that would have been obtained without it. Section 4.1 deals with the effect of decryption on the ability of the U-Boats to contact convoys; section 3.2 with its effect on the ability to convert contacts into attacks and sinkings.

4.1 THE EFFECT OF DECRYPTION INTELLIGENCE ON THE CAPABILITY OF U-BOATS CONTACTING CONVOYS

a) The Operational Sweeprate of the U-Boat

The most meaningful measure of U-Boat performance in the search effort is the "operational sweeprate". The following is a brief discussion of this quantity and of its application to the situation under discussion.

The number of contacts, C, that a force of U-Boats could be expected to make during T U-Boat days should be proportional to T and to the average density of shipping in the area. Thus one can write:

$$C = Q\,T\,(N/A) \qquad (1)$$

where A is the size of the area, N is the average number of targets in the area, and Q is the proportionality coefficient found by substituting operational values for the other quantities into equation (1).

This Q was adopted in World War II (page 93 of reference (c)) as an appropriate measure of the average submarine's search capabilities and was termed the "operational sweeprate." (It has the proper dimensions of area/time). Of importance to this study is the fact that this Q will measure the usefulness of decryption intelligence to the submarine force; this intelligence should permit a better dispostion of the submarines and consequently an increased C and Q, when T, N, and A in equation (1) remain approximately constant. Q is preferred to C as the final measure since its values are independent of variations in T, N, or A.

The operational sweeprate, Q above, becomes equivalent to a "theoretical sweeprate", Q', i.e., the area (relative to the targets) searched ("swept out") by a single submarine in one day, when the following conditions hold:

(a) the targets are distributed uniformly over the area; the area in the North Atlantic considered herein, see figure I, was chosen so that this condition was approximately true;
(b) the enemy has no intelligence information or other means of determining shipping concentrations;
(c) the submarines are disposed so that there is a negligible chance that a given convoy will be contacted by more than one submarine; this would include disposition on a barrier line when the spacing between submarines is great enough, but it would not include wolf-pack tactics.

Under these conditions the target density in the neighborhood of each submarine can on the average be taken as N/A. By the above definition of Q' each submarine should contact Q' (N/A) convoy targets each day on the average. The total contacts for T submarine days would then be given by equation (1) with Q' substituted for Q.

The theoretical sweeprate could be further factored into the product of a sweepwidth characteristic of the detection means employed and the relative speed with which a submarine and a convoy come within detection range of each other. An alternative derivation of equation (1) could then be made again under the conditions of the last paragraph, but based on the number of convoys entering the area each day and the fraction of these convoys which come within the theoretical sweepwidth of a submarine.

"Contact" is used here in the sense that a given convoy is contacted only once per transit, regardless of the number of U-Boats that actually contacted it. Hence it must not be confused with "sighting" or "detection".

Used in the sense indicated above, the operational sweeprate gives an accurate measure of the search capabilities of the U-Boats in the Battle of the North Atlantic convoys, under varying conditions of the status of German intelligence, U-Boat aggressiveness, Allied antisubmarine effectiveness (including intelligence on U-Boat movements), and the usual environmental factors such as weather. It is therefore an important component parameter in developing planning factors.

The values of the operational sweeprate for the three periods considered are shown in table III. Three cases are shown:

(a) The over-all value of Q applied to all convoys, compromised or not;
(b) The value of Q considering only those convoys mentioned by BdU (in reference (a)) as being compromised by decryption intelligence (this defines a "compromised" convoy;
(c) The value of Q as it applies to those convoys not compromised; this is the closest approximation to the true "operational sweeprate" from the available data.

TABLE III

OPERATIONAL SWEEPWIDTH OF U-BOATS AGAINST NORTH ATLANTIC CONVOYS*

Period	Number of convoys	Average number of convoys in area	U-Boat days in area	Number of transits contacted	Operational sweeprate square miles per day
ALL CONVOYS					
I (Jul 42-Dec 42)	100	7.6	5,675	37	2,650
II (Jan 43-May 43)	79	7.1	7,845	38	2,050
III (Sep 43-Mar 44)	87	5.6	5,146	16	1,700
All periods	266	6.6	18,666	91	2,350
COMPROMISED CONVOYS					
I	3(3%)	0.2	5,675	3	8,000
II	21(27%)	1.9	7,845	17	3,400
III	15(17%)	0.8	5,146	3	2,050
All periods	39(15%)	0.9	18,666	23	3,950
NONCOMPROMISED CONVOYS					
I	97	7.2	5,675	34	2,500
II	58	5.2	7,845	21	1,600
III	72	4.8	5,146	13	1,600
All periods	227	5.7	18,666	68	1,900

*The area considered is 3,000,000 square miles.

b) Discussion of the Results

(1) The true operational sweeprate

On non-compromised convoys, the U-Boats achieved an operational sweeprate of 1,900 square miles per day, averaged over the three periods. This is the most accurate approximation to the true operational sweeprate of the U-Boat against convoys in this area; however, the following points need consideration:

In calculating the value of the sweeprate for "non-compromised" convoys all convoys were included that are not specifically mentioned in the War Diary as being compromised. A certain (unknown) number of these convoys may well have been compromised by decryption, and even though the information on these is not specifically mentioned by BdU as having been exploited tactically, it obviously would have been useful in providing a clearer picture of the convoy situation and thus would have helped BdU, in disposing his U-Boats and planning his operations. This consideration implies that the 1,900-square-miles-per-day value is higher rather than lower, than the true figure.

On the other hand:

(a) This average is heavily affected by the low average sweeprate of period II. During this period 27 percent of all convoys were compromised; a condition which enabled BdU to concentrate the U-Boats most of the time against compromised convoys, thereby reducing the normal frequency of operations and the expected number of contacts against others. This is borne out by the fact that during this period 45 percent of all contacts were made on compromised convoys, compared with only 8 percent in period I and 20 percent in period III. This would tend to reduce the value of Q for non-compromised convoys.

(b) With respect to period III, the lower value of Q reflects the decided improvement in Allied antisubmarine effectiveness (including intelligence on U-Boat movements) resulting from experience gained in the long U-Boat war, together with the consequent low state of morale of the U-Boat crews.

(c) The higher value for period I (2,500 square miles per day) for non-compromised convoys should carry greater weight, because only 3 percent of all the convoys during this period were compromised.

A reliable practical value may be above 2,000 square miles per day.

(2) Effect of compromise by decryption on the operational sweeprate

The average value of Q for all three periods against compromised convoys is seen from table III to be 3,950 square miles per day, compared with 1,900 square miles per day against non-compromised convoys. Hence, when usable decryption intelligence was available to the German U-Boat command, the contact effectiveness of the U-Boats, measured, purely conventionally, as a sweeprate, was increased twofold.* (The effect on their ability to sink ships is discussed in section 3.2)

(3) Correlation of the over-all operational sweeprate (against all convoys) with the amount of decryption intelligence

The over-all operational sweeprate measures the general contact effectiveness of the U-Boats, including all factors that affect it. Hence it might be expected that its value would reflect the variation in the quantity of usable decryption intelligence, since, as has been pointed out, this was such an important factor in the successful operation of the U-Boats. The figures of table III do not show the expected correlation. In period II decryption intelligence compromised 27 percent of all convoys as compared with only 3 percent during period I; nevertheless the over-all operational sweeprate in period II was smaller: 2,050 square miles per day as against 2,650 for period I. In period III, when the Germans were deprived of decryption intelligence the operational sweeprate is reduced, as expected; it drops to 1,750 square miles per day.

Some of the possible reasons for this lack of correlation are as follows:

(a) The high value for period I may be due partly to the fact that the Allied convoys used the great circle route consistently; this simplified the U-Boat search problem materially and to some extent compensated for the comparative scarcity of specific intelligence. In period II the North Atlantic convoys routes were spread between 40° and 60° N, and the convoys appear to have been diverted more than before; hence the U-Boats had to search a larger area even when they had good intelligence; reference (a) shows that on various occasions during this period it was necessary to guess the route of the convoys even when an accurate earlier DR position and course were known from decryption intelligence.

(b) In period II the Allies had more effective antisubmarine measures; in particular, increasing air patrol and, from the spring of 1943, air protection from escort carriers, reduced the ability of the U-boats to contact convoys.

(c) In period II, unfavorable weather appears to have interfered with U-Boat operations to a considerable extent. The War Diary in several cases attributes the failure to contact a compromised convoy to this cause.

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*If period III is not included in the calculation of Q, because of the reduction in the reliability of the decryption intelligence and in the enemy's aggressiveness, the average value of Q against compromised convoys is 4,600 square miles per day, compared with 1,900 square miles per day for non-compromised convoys; an increase by a factor of 2.4.

(d) In period II, it is probable that a saturation effect with respect to compromised convoys occurred. That is to say, in some cases BdU had to choose one convoy among several (that are included as compromised ones in the calculation of Q) if he wished to apply the principle of concentration of forces and mass attacks.*

In spite of the small size of samples of compromised convoys in periods I and III, the differences between the values of the operational sweeprate for the three periods and for the average of all three periods are significant within 90-percent confidence limits; that is, there is at the most a 10-percent chance that the differences shown are due to chance fluctuation. Thus it appears evident from the data that the value of decryption intelligence to the U-Boat command can be summed up as follows: The information obtained by means of decryption intelligence on specific convoys enabled BdU to select certain ones for pack operations, either ignoring others or leaving their detection to chance. As a result, the effectiveness of the U-Boats in contacting convoys was increased by a factor of 2 or more over their effectiveness when the convoys were not compromised by decryption intelligence.

4.2 The Effect of Decryption Intelligence on the Attack Factor and the Sinking Rate

In general, in evaluating the effect of intelligence, the contact rate is a more significant quantity than the sinking rate, since there is no direct connection between intelligence and sinking rate. The sinking rate depends directly upon the contact rate, as well as upon other factors which have no connection with intelligence, such as fire control, armament, aggressiveness, etc. on part of the U-Boat, and on the effectiveness of tactical anti-submarine measures on the part of the defense.

However, in view of the tactics, employed by the German U-Boat command, of vectoring every available U-Boat to the attack on an intercepted convoy, it seems reasonable to presume that the possession of good decryption intelligence would make it possible for BdU to dispose his boats in a manner that would not only enhance their chance of contacting a convoy, but also of converting the contact into an attack by as many submarines as possible and thus obtaining a greater sinking rate.

Table IV presents data showing the effect of decryption intelligence on the attack factor and the sinking rate. Only those attacks that yielded at least one sinking are considered.

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*An example of this condition is the case of ONS-5 in early May 1943: 40 U-Boats--practically the whole North Atlantic force--chased the convoy from Iceland to the neighborhood of Newfoundland, thus leaving any other compromised convoy unmolested for possibly more than a week, since the ONS-5 boats had to be refueled or replaced after the battle.

TABLE IV

ATTACKS AND SINKINGS

Period	Convoy transits	Convoy transits contacted	Transits attacked with at least one sinking			Transits attacked with 3 or more sinkings		
			Transits attacked	Ships sunk	Ships sunk per transit attacked	Transits attacked	Ships sunk	Ships sunk per transit attaked
ALL CONVOYS								
I	100	37	31	123	4.0	15	102	6.8
II	79	38	27	126	4.7	14	109	7.8
III	87	16	7	14	2.0	2	8	4.0
All periods	266	91	65(71.5%)	263	4.0	31	219	7.1
COMPROMISED CONVOYS								
I	3	3	1	16	16.0	1	16	16.0
II	21	17	13	69	5.7	7	62	8.9
III	15	3	21	4	2.0	1	3	3.0
All Periods	39(14%)	23	16(70%)	89(31%)	5.6	9(39%)	81	9.0
NON-COMPROMISED CONVOYS								
I	97	34	30	107	3.6	14	86	6.1
II	58	21	14	57	4.1	7	47	6.7
III	72	13	5	10	2.0	1	5	5.0
All periods	227(80%)	68	49(72%)	174(69%)	3.6	22(32%)	138	6.3

It might be argued that a more realistic approach would be to consider only the attacks of major proportions; i.e., those which resulted in multiple kills, in view of the argument cited above for the use of the sinking rate as a measure; for of the 65 successful attacks, half resulted in only one or two sinkings, and these include some cases in which only one or two U-Boats contacted a convoy, as well as two cases which the Germans considered independents. The figures for attacks that resulted in three or more sinkings are included separately in table IV.

Considering all the attacks (with at least one sinking), it appears that the availability of decryption intelligence had no appreciable effect on the attack factor (percent of contacts converted to attacks), which was near 70 percent in all categories. In the case of major attacks (3 or more sinkings), the attack factor was only slightly larger (39 percent as against 32 percent) for compromised convoys than for non-compromised ones.

With respect to sinkings, 31 percent of all sinkings, as against only 14 percent of all contacts, were from compromised convoys. This results in a significantly higher average number of ships sunk per attack--5.6 from compromised convoys compared with 3.6 from non-compromised ones.

Because the state of affairs with respect to decryption intelligence differed so greatly during periods I, II, and III, it is of interest to compare the effectiveness of the average U-Boat for the three periods, as measured in terms of ships sunk per U-Boat-day per convoy-day. In table V the values of the operational sweeprate and the sinking rate per U-Boat-day per convoy-day are expressed as ratios of the over-all values for period I.

TABLE V

COMPARISON OF OVER-ALL CONTACT AND SINKING RATES

Period	Relative operational sweeprate	Relative sinking rate per U-Boat-day per convoy-day
I	1.00	1.00
II	0.78	1.09
III	0.64	0.18

It is seen that, whereas the ability of the average U-Boat to sink ships from convoys was reduced to nearly one-sixth during period III compared with periods I and II, its ability to contact the convoys was reduced to only about two-thirds of the previous figure, in spite of the almost complete lack of decryption intelligence during this period.

Caution must be observed in interpreting these figures. On the one hand, it is not correct to conclude that the reduction in the contact rate was due entirely to the status of the intelligence during period III. It is equally incorrect to conclude that the reduction in the sinking rate must be ascribed entirely to the increased efficacy of other antisubmarine measures, aside from the reduction caused by the decrease in the contact rate. These are oversimplifications. It has been pointed out above why the contact rate itself does not reflect the full value to the Germans of the decryption intelligence available to them especially since the data does not permit evaluation of the effect of Allied intelligence in countering the U-Boats.

A rough estimate of the cost to the Allies in ships sunk by U-Boats can be made as follows: assuming that the operational sweeprate of 1,900 square miles per day achieved against non-compromised convoys represents the contact capabilities of the U-Boats without the aid of decryption intelligence, the number of contacts that would have been made (from equation (1) and table I) $(1{,}900 \times 6.6 \times 18{,}666)/(3 \times 10^6) = 78$, compared with 91 actual contacts.

The number of ships sunk from the 68 non-compromised convoys contacted was 174, an average of 2.56 ships per contact. Hence 78 contacts would result, on the average, in 199 sinkings. This is 64 less than the number of ships actually sunk from the convoys under consideration. It seems very probable that if the Germans had not been aided by decryption intelligence, more than 60 ships sunk from these convoys might have survived.

5. SUMMARY AND CONCLUSIONS

The findings of the study of the effectiveness of German decryption intelligence in U-Boat performance in the campaign against North Atlantic convoys are summarized as follows:

(a) The War Diary of the German Submarine Command mentions decryption of Allied radio messages as providing usable intelligence of 39, or 15 percent, of the 266 HX, SC, and ON(S) convoys that crossed the North Atlantic from 1 July 1942 to 31 May 1943, and from 15 September 1943 to 31 March 1944. During the period from 1 January 1943 to 31 May 1943, the fraction of convoys listed in the War Diary as being compromised by decryption is nearly twice the average, or 27 percent.

(b) The availability of good radio intelligence on specific convoys enabled the German U-Boat command to select certain ones for pack operations with greatly enhanced chances of successful attack, either ignoring others or leaving their detection to chance. As a result, the effectiveness of the U-Boats in contacting such selected convoys was increased to more than twice the contact rate when convoys not compromised in this manner are considered by themselves.

(c) Regarded from the opposite point of view, the discovery of this effect and estimation of its magnitude permit us for the first time to determine the true capabilities of World-War-II U-Boats, operated as the Germans operated, to find and attack convoys without benefit of decryption intelligence. This information is potentially of the greatest value as a base in determining force requirements for the future, and extrapolating to the magnitude of future threats by boats having the same or different characteristics.

(d) U-Boats operating against convoys not specifically selected (according to the War Diary) by BdU for operations on the basis of decryption intelligence, were apparently capable of searching 2,000 square miles per day. Their apparent search rate when all convoys are included (even those whose movements were compromised by decryption) was about 2,350 square miles per day. Their ability to find those convoys alone that are listed in the War Diary as being compromised by decryption was significantly higher; if it is expressed, purely conventionally, as a search rate corresponding to them it is equivalent to 3,900 square miles per day; a twofold increase over the search rate on non-compromised convoys.

(e) The apparent search rate of U-Boats on all convoys (including those compromised) of 2,350 square miles per day is nearly equal to the value of 100 square miles per hour given in reference (c), page 94, as typical of the submarine search rate for merchant ships not sailing in convoy. This value was computed from ranges of first contact on independents reported by U.S. submarines. Similar data for ranges on convoys are not available; from theoretical considerations (reference (c), page 100) it is estimated that the sweeprate should be greater on convoys by a factor roughly equivalent to the cube root of the number of ships in the convoy. On this basis one would expect a search rate

from 3 to 4 times as great as was achieved against independents, or from 7,000 to 10,000 square miles per day. The much smaller search rates actually achieved by the U-Boats as given in (d), are not easily accounted for. It is possible that U.S. submarines, in general, had significantly better visibility conditions than those encountered in the North Atlantic by the U-Boats.

(f) Comparison of ship sinkings from North Atlantic convoys designated by BdU for operations on the basis of decryption intelligence, with those not so designated, leads to an estimate that, during the period from July 1942 to March 1944 about 60 fewer ships would have been sunk from these convoys alone if the German Command had not been in a position to so designate them. This is nearly one-fourth of all the sinkings. Actually the reduction in sinkings would have been greater than this, because only convoys mentioned specifically by BdU are used in the calculation of the estimate. It is quite possible that the Allied failure to prevent the Germans from decrypting their convoy cipher was accountable for the loss of 100 ships, considering only the North Atlantic convoys for the period examined. This is nearly 40 percent of all the ships sunk in these convoys during that period.

(g) The experience of the U-Boats, as exhibited in the War Diary, emphasized the fact that the submarine's effectiveness against convoys can be materially reduced if he is denied good intelligence on convoy movements; this is achieved by preventing the enemy from exploiting the necessary convoy radio traffic, and by using multiple routing in a more-or-less random manner. If to these precautions are added effective tactical antisubmarine measures and intelligence on submarine movements as good as that during the last 2 years of World War II, the state of affairs of the period from September 1943 to March 1944 might be approximated: 14 ships sunk from 87 convoys, with (world-wide) submarine kills averaging 23 per month.

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