(LO) 11-47
6 January

OPERATIONS EVALUATION GROUP
STUDY NO. 305

SUMMARY OF GERMAN TORPEDO FIRING IN WORLD WAR II, WITH COMPARATIVE FIGURES FOR U. S. SUBMARINES.

This Study represents the view of the Operations Evaluation Group at the time of issue, and is for information only; it does not necessarily reflect the official opinion of the Chief of Naval Operations. It includes information of an operational, rather than a technical nature, and should be made available only to those authorized to receive such information.

Reproduction of this document in any form by other than Naval activities is not authorized except by special approval of the Chief of Naval Operations.

This material contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C. Sections 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

Prepared by
OPERATIONS EVALUATION GROUP (formerly Operations Research Group)
Office of the Chief of Naval Operations

(LC) 11-47
6 January 1947

OPERATIONS EVALUATION GROUP
STUDY NO. 305

SUMMARY OF GERMAN TORPEDO FIRING IN WORLD WAR II, WITH COMPARATIVE FIGURES FOR U. S. SUBMARINES.

Reference (a) NavTechMisEu Technical Report No. 202-45: General Survey of German Torpedoes, September 1945, SECRET.

I. Summary

This report is based on a study of IBM cards relating to German torpedo war shots. The cards were prepared by the Germans and have not been checked against allied records except for a few comparisons reported herein. Furthermore, the card file does not contain data on submarines that were lost nor for any action after October 1944.

Tables 1 and 2 show an over-all picture of the U. S. and German submarine effort. However, it is very important to note that the data in these tables, as well as all other data in this report are the result of combining different ordnance and different tactical situations; therefore only conclusions of the most general nature should be drawn from the data presented. The figures for U. S. submarines are given for comparison.

Tables 3 and 4 show the use of, and results with, the several torpedo types used. On the basis of per cent hitting the target American and German torpedoes compare as follows:

	U. S.	German
Acoustic	32% hits	61% hits
Steam, straight	35% hits	52% hits
Electric, straight	29% hits	43% hits
Pattern	-	41% hits

This difference is primarily due to the fact that the U. S. used a salvo about twice as large as that used by the Germans. On the basis of per cent of salvos successful, the results are almost identical (55% for U. S., 52% for Germany).

II. Introduction

After the end of the war, the British Admiralty Delegation found in Germany a file of IBM cards describing the firing of torpedoes by German U/Boats.

Table 1. SUMMARY FIGURES

	U.S.	German
Torpedoes (total)	14398	8467
Torpedoes (acoustic)	122	338
Hits (total)	4831	3755
Hits (acoustic)	39	206
Salvos (total)	4981	6477
Salvos (acoustic)	122	338
Successful salvos	2755	3382
Submarine months at sea	2198	1765 (1)
Ships sunk by these submarines	1738 (5)	478 (1)
Ships sunk, total period covered	1738 (5)	1777 (6)
Submarines lost	49	781
Merchant vessels attacked	3087	2534 (2)
Merchant vessels hit	2138	1713 (2)
Merchant vessels sunk	1436	1236 (2)
Torpedoes fired at merchant vessels	10809	5362 (2)
Hits on merchant vessels	4005	2701 (2)
Targets attacked	4074	3986
Targets hit	2571	2445
Targets sunk	1335 (3)	1594 (4)

(1) U.S. Strategic area July 1942 through May 1943
Atlantic for June 1943 through September 1944
(2) Atlantic only
(3) O.N.I. records
(4) COMINCH RECORDS, Pearl Harbor to V.E. day.
(5) Submarine command
(6) U/Boat command, total period

Table 2. SUMMARY STATISTICS

	U.S.	German
Percent of torpedoes hitting	34	44
Percent of salvos successful	55	52
Torpedoes per salvo (except accoustic)	2.9	1.3
Ships sunk per 100 sub months at sea	78.6	27.1
Torpedoes fired per ship sunk	8.3	4.8
Merchant vessels hit per 100 attacked	69	68
Merchant vessels sunk per 100 hit	67	72
Percent hits among torps fired at M/V's	37	50
Number of hits per M/V hit	1.9	1.6
Average range of fire(except accoustic)	2063 yds.	2100 yds.
Percent under 1500 yards	37	50*

* Rough approximation, since range is given only to nearest kilometer.

Table 3. TORPEDOES FIRED BY U.S. SUBMARINES

Year & Quarter		Shots				Hits			
		Steam	Elec.	Acou.	TOTAL	Steam	Elec.	Acou.	TOTAL
1941	4	104			104	13			13
TOTAL		104			104	13			13
1942	1	369			369	104			104
	2	406			406	96			96
	3	476			476	151			151
	4	690			690	208			208
TOTAL		1943			1943	559			559
1943	1	740			740	256			256
	2	749			749	274			274
	3	1032	21		1053	317	4		321
	4	1170	80		1250	439	20		459
TOTAL		3691	101		3792	1286	24		1310
1944	1	1217	91		1308	475	39		514
	2	1079	183		1262	466	60		526
	3	1124	575	1	1700	453	202		655
	4	863	1021	4	1888	345	317	3	665
TOTAL		4283	1870	5	6158	1739	618	3	2360
1945	1	307	600	43	950	74	150	10	234
	2	352	612	48	1012	96	138	14	248
	3	127	288	26	441	29	66	12	107
TOTAL		786	1500	117	2403	199	354	36	589
TOTAL		10805*	3471	122	14398	3796	996	39	4831

The file was reproduced by B.A.D., and the reproduced file was forwarded to the Operations Evaluation Group. The card file covers, but not entirely, U/Boat activity from 3 September 1939 to the end of October 1944. It is incomplete with respect to the activities of U/Boats on the patrols on which they were lost, and a small amount of scattered information, believed by B.A.D. to have been omitted for no special reason. Since large numbers of German U/Boats were lost during 1943 and 1944, the data for those years are particularly incomplete.

The card file was never used by the Germans. It was still in the process of construction at the end of the war, and contained a large number of inconsistencies. It has been scrutinized and many errors eliminated, but some undoubtedly remain. A summary of the contents of the file appears in Appendix (A).

It must be emphasized that all figures and conclusions contained in this study are based on the claims of the Germans, as recorded in the punched cards described above, and that these data have not been compared with Allied records. A study which would be of interest would be a comparison of German claims, especially their descriptions of the target, with the Allied casualty records.

III. Discussion of Tables and Graphs

a. Torpedo Expenditure

Table 4a lists German torpedoes fired, by quarter and torpedo type. A summary of the frequency of the use of the various types, by year, is given below.

	1940	1941	1942	1943	1944
X electric.(impact)	79%	84%	84%	46%	*
Y electric.(proximity)	*	*	*	30%	20%
W steam	17%	14%	9%	3%	*
M electric.(pattern)	*	*	*	5%	30%
B accoustic	*	*	*	4%	40%
L steam (pattern	*	*	*	4%	5%
other	4%	2%	7%	8%	5%

* Either zero or extremely small percentage.

Table 4a. TORPEDOES FIRED BY GERMAN SUBMARINES

(See Appendix B for description of torpedo types)

Year & Quarter	Ac.	Pattern		Steam		Electric		Unk.	TOTAL
	B	L	M	V	W	X	Y	1	
1939 3	-	-	-	1	-	3	-	-	4
4	-	-	-	26	32	127	-	6	191
TOTAL	-	-	-	27	32	130	-	6	195
1940 1	-	-	-	7	35	146	-	3	191
2	-	-	-	8	54	219	-	3	284
3	-	-	-	7	49	275	-	1	332
4	-	-	-	11	55	256	-	2	324
TOTAL	-	-	-	33	193	896	-	9	1131
1941 1	-	-	-	3	40	182	2	1	228
2	1	-	-	10	111	301	-	1	424
3	-	-	-	4	8	232	-	1	245
4	-	-	-	8	13	338	-	-	359
TOTAL	1	-	-	25	172	1053	2	3	1256
1942 1	-	-	-	3	50	680	-	6	739
2	-	-	-	3	102	678	-	1	784
3	-	-	-	10	71	693	2	52	828
4	-	2	-	7	67	698	35	101	910
TOTAL	-	2	-	23	290	2749	37	160	3261
1943 1	2	30	-	6	15	543	187	43	826
2	4	7	3	8	22	254	117	39	450
3	15	20	36	14	23	100	160	31	399
4	67	51	54	-	6	25	137	8	318
TOTAL	88	108	93	28	66	922	601	121	1993
1944 1	114	14	73	-	7	7	58	3	281
2	80	4	47	-	-	1	55	4	191
3	56	8	65	-	1	-	14	4	148
4*	3	2	6	-	-	-	-	-	11
TOTAL	253	28	191	-	8	8	127	11	631
TOTAL	338	113	284	136	761	5758	767	310	8467

* Data very incomplete.

These data indicate that the types X, Y, and W were used most frequently until the end of 1943. In 1944, the type B (acoustic) and M (pattern) were used more frequently.

Table 4b lists German torpedo hits by quarter and torpedo type. The total percentage success for each type, for the entire period is as follows:

X	43.5% hits
Y	37 %
W	53 %
B	61 %
M	35 %
V	46 %
L	55 %
Total	44 % hits

Of all salvos fired, 52% were successful in obtaining one or more hits. On the basis of successful salvos the acoustic homing torpedo appears to have been about 15% better than the nonhoming torpedo. However, the acoustic homing torpedo was never fired in salvo, but only as a single shot. For the entire period, for the most frequently used German torpedo types, the ratios were:

Torpedo Type	Torps/Salvo
B - acoustic homing	1.0
X - electric (straight, impact)	1.3
Y - electric (straight, proximity)	1.7
W - steam (straight, 40 or 44 kts)	1.07
Total for all torpedoes	1.3

If economy is to be considered, the maximum advantage of the acoustic torpedo may best be estimated by comparing the percentage of hits against the percentage of successful salvos. These two percentages, by major torpedo type are as follows:

Torpedo Type	Percent salvos successful	Percent torpedoes hitting
Straight(X,W,Y,V)	52%	44%
Pattern (M,L)	54%	42%
Homing (B)	61%	61%
Total	52%	44%

Table 4b. GERMAN TORPEDO HITS

(See Appendix B for description of torpedo types)

Year & Quarter	Ac.	Pattern		Steam		Electric		Unk.	
	B	L	M	V	W	X	Y	1	TOTAL
1939 3	-	-	-	1	-	1	-	-	2
4	-	-	-	8	13	45	-	1	67
TOTAL	-	-	-	9	13	46	-	1	69
1940 1	-	-	-	3	20	69	-	-	92
2	-	-	-	3	20	78	-	-	101
3	-	-	-	3	21	159	-	-	183
4	-	-	-	7	31	150	-	-	188
TOTAL	-	-	-	16	92	456	-	-	564
1941 1	-	-	-	2	23	89	-	1	115
2	1	-	-	6	70	158	-	1	236
3	-	-	-	0	2	122	-	1	125
4	-	-	-	3	4	106	-	-	113
TOTAL	1	-	-	11	99	475	-	3	589
1942 1	-	-	-	0	28	271	-	2	301
2	-	-	-	2	55	267	-	1	325
3	-	-	-	2	36	309	1	33	381
4	-	2	-	3	39	290	10	45	389
TOTAL	-	2	-	7	158	1137	11	81	1396
1943 1	1	23	-	5	8	221	88	18	364
2	-	1	1	6	13	117	51	14	203
3	13	12	7	8	10	43	58	13	164
4	46	11	20	-	1	7	36	4	125
TOTAL	60	47	28	19	32	388	233	49	856
1944 1	72	8	29	-	7	4	16	-	136
2	52	2	17	-	-	1	15	2	89
3	21	3	24	-	1	-	5	1	55
4*	-	-	1	-	-	-	-	-	1
TOTAL	145	13	71	-	8	5	36	3	281
TOTAL	206	62	99	62	402	2507	280	137	3755

* Data very incomplete.

Total torpedo shots and hits are shown graphically in figure 1. The German records show fewer torpedoes fired than were fired by U.S. submarines, but this is largely due to the lack of data from the large number of missing U/Boats.

b. Size of salvo

Figure 2 shows that both Germany and the U.S. tended to increase the size of the salvo as the war progressed, but the average for Germany (1.3 torpedoes) was much lower than that for the U.S. (2.9 torpedoes). The percent of successful salvos was about the same for the two countries, but the U.S. increased to a maximum of 69% in the 2nd quarter of 1944, then decreased to the end of the war. It is interesting to note that the Germans were able to achieve about the same success as the U.S. subs with fewer torpedoes per salvo.

The total number of torpedoes fired per ship sunk increased almost constantly in the case of the German effort, as shown in Figure 3, while for the U.S. it remained fairly constant. If average range can be shown to affect success, this could be caused by the increase in range of German fire (see par. f).

Figures 4a and 4b show the number of ships sunk per 100 submarine months at sea and the total number of submarines lost. The Germans, in their own records show almost constantly decreasing productivity, and at the same time they had an almost constantly increasing loss rate. The GOMINCH figures on the results of the U/Boat war give them credit for an increased sinking rate beginning in the 2nd quarter of 1944. This could have resulted from the use of the acoustic torpedo.

In this connection, Figure 5 shows that both the U.S. and the German submarine commands probably were over-conservative in giving the submarine credit for sinking a target that was hit. It is interesting to note how this conservatism increased, for both countries, as the war progressed, then decreased. The final collapse of the German U/Boat war is reflected at the end of the curve.

Table 5 lists the average number of torpedoes fired at each target, by year and result of attack. For the entire period, the average number of torpedoes per target was:

per target attacked	2.12
per target sunk	2.18
per target damaged	2.32

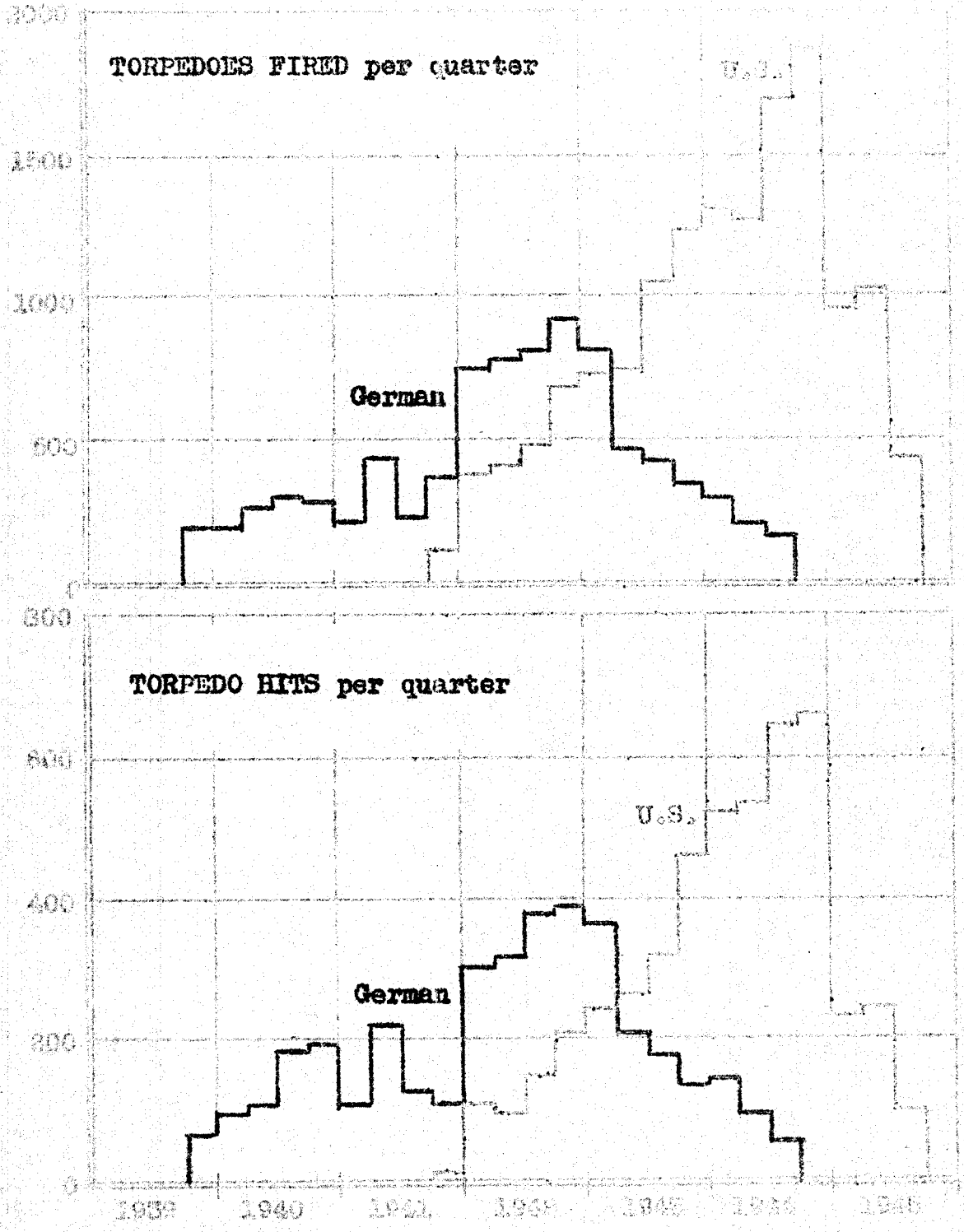
TORPEDOES FIRED per quarter
U.S.
German
TORPEDO HITS per quarter
U.S.
German
1939
1940

Figure 1.

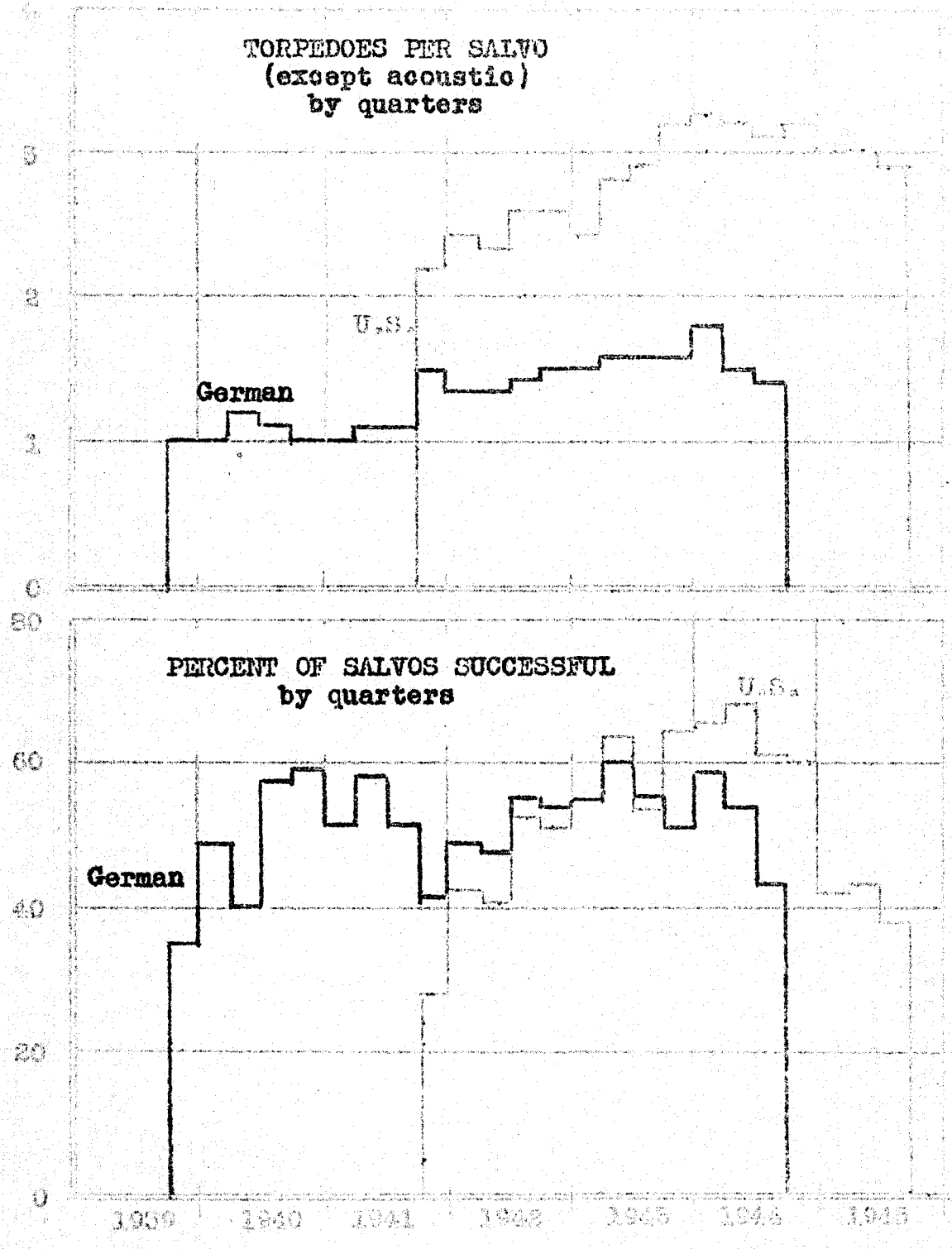
TORPEDOES PER SALVO
(except acoustic)
by quarters
3
2
1
0
U.S.
German
PERCENT OF SALVOS SUCCESSFUL
by quarters
80
60
40
20
0
U.S.
German
1939
1940
1941
1942
1943
1944
1945

Figure 2.

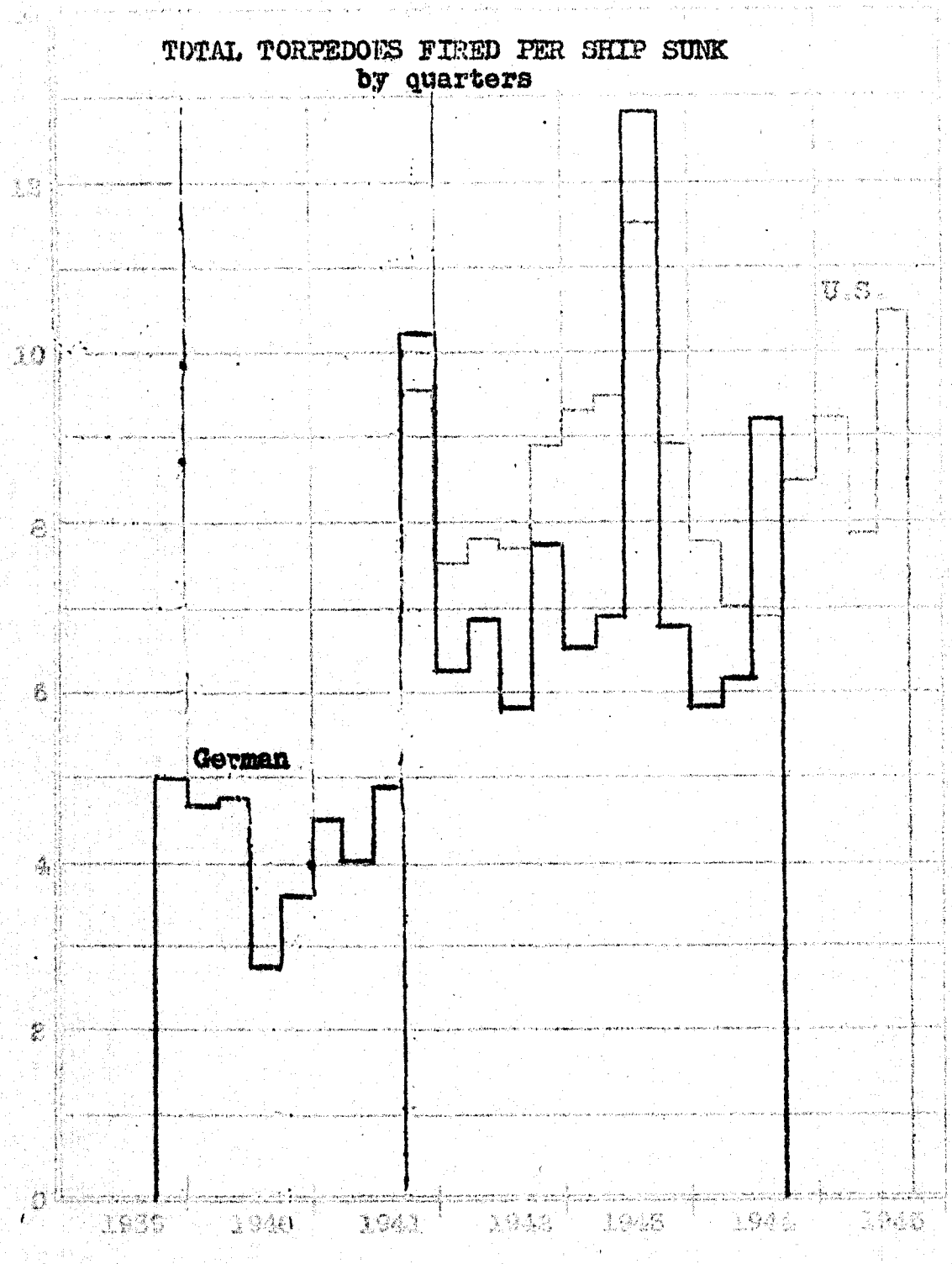
TOTAL TORPEDOES FIRED PER SHIP SUNK
by quarters
U.S.
German
12
10
8
6
4
2
0
1939
1940
1941
1942
1943
1944
1945

Figure 3.

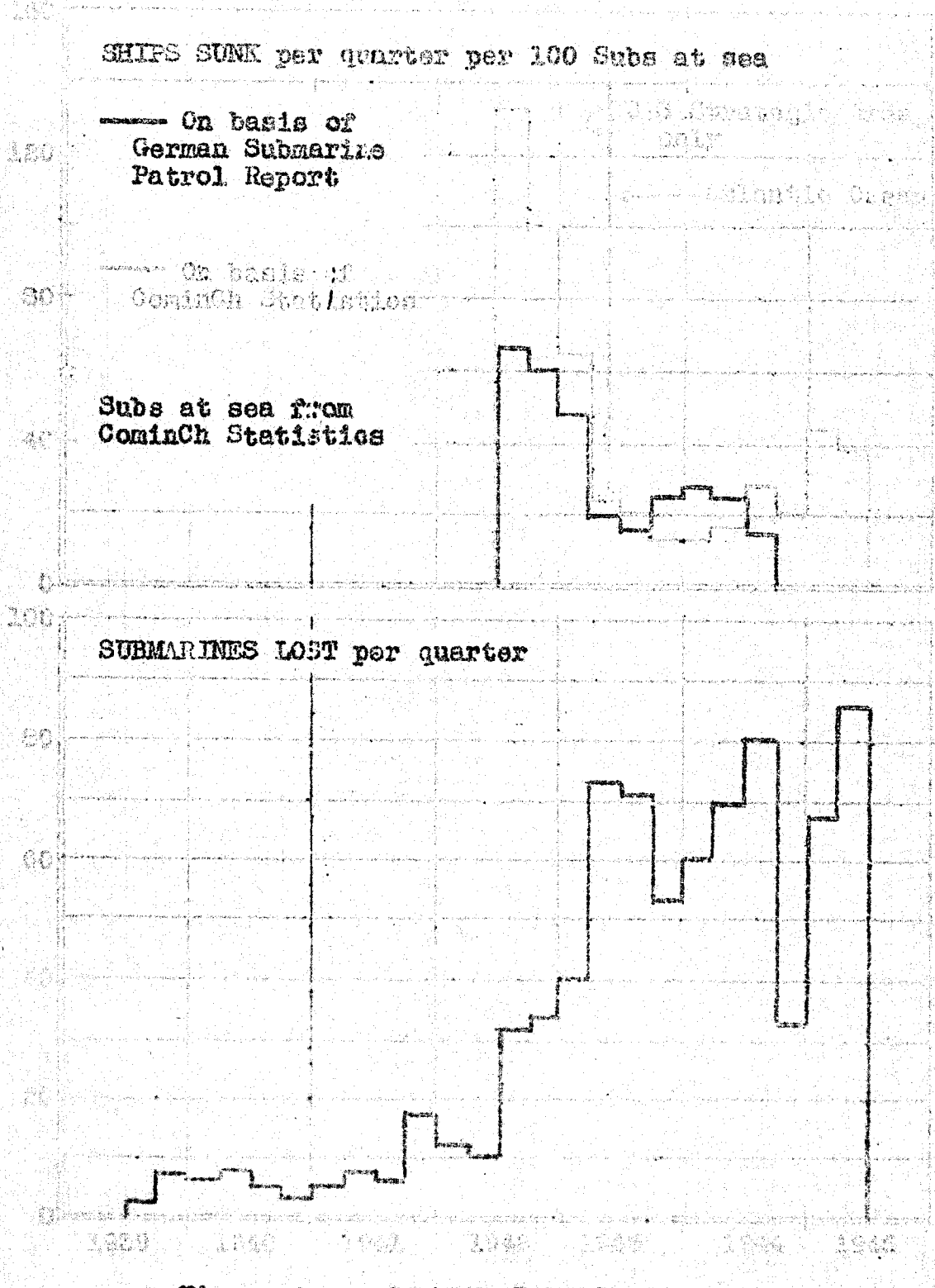

Figure 4a. GERMAN SUBMARINES.

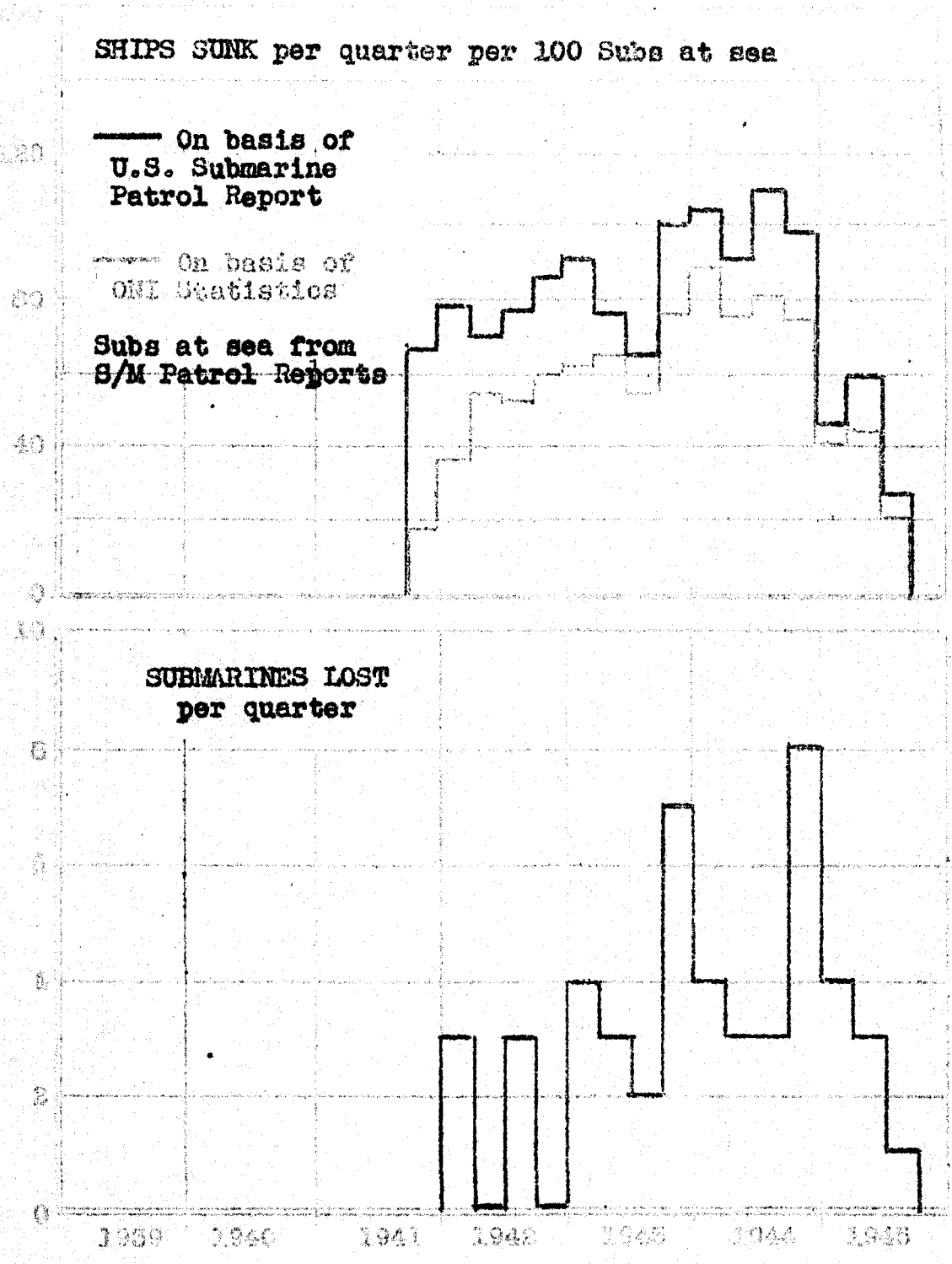

Figure 4b. U.S. SUBMARINES

PERCENT SHIPS SUNK OF SHIPS HIT by quarter

Figure 5.

It is interesting to note that an average of 2.32 torpedoes was fired to damage a target, while an average of only 2.18 was fired to sink a target. Damaged targets received fewer hits, however.

Table 6 shows the average number of salvos per target, by year and result of attack. These figures show that for the entire period, the average number of salvos per target was:

per target attacked	1.63
per target sunk	1.72
per target damaged	1.85

Again it is seen that more salvos were expended on damaged than on sunk ships.

Of the total number of salvos fired, 52% were successful in scoring one or more hits on the target. Of the number which were successful in scoring one or more hits on the target, 73% were effective in sinking ships, and 27% were effective in damaging ships. An index of effectiveness of German torpedo fire can be found in the number of ships which they sank per shot and per salvo. These indexes are:

	ships sunk	ships damaged	sunk or damaged
Per salvo	0.28	0.10	0.38
Per shot	0.21	0.08	0.29

Table 5. AVERAGE GERMAN TORPEDOES PER TARGET

Target	Year	Torpedoes fired at each target: Sunk	Dam-aged	No damage	Fired at	Torpedo hits on each target: Sunk	Dam-aged	Fired at	Total torpedoes fired per ship sunk
Single ships	1939	1.36	2.00	1.62	1.53	1.11	1.00	0.50	3.64
	1940	1.61	1.41	1.45	1.53	1.27	1.06	0.69	3.09
	1941	2.05	2.14	1.99	2.18	1.63	1.55	1.00	4.46
	1942	2.46	2.54	2.28	2.42	1.70	1.54	1.02	5.92
	1943	2.65	2.64	2.30	2.54	1.66	1.52	0.94	5.75
	1944	1.43	2.20	1.42	1.59	1.20	1.55	0.75	4.58
Ships in convoy	1939	2.00	2.00	2.00	2.00	1.60	1.00	1.00	3.60
	1940	1.53	1.70	1.31	1.51	1.25	1.41	0.94	3.12
	1941	2.09	2.11	1.47	1.90	1.77	1.44	1.17	4.45
	1942	2.50	2.00	2.29	2.30	1.75	1.45	0.98	6.15
	1943	2.20	2.08	2.04	2.14	1.64	1.50	1.26	3.58
	1944	1.73	2.16	2.43	2.02	1.18	1.50	0.83	3.86
All ships	1939	1.52	2.00	1.62	1.55	1.16	1.00	0.55	3.54
	1940	1.56	1.65	1.44	1.52	1.22	1.27	0.76	3.09
	1941	2.00	2.03	1.91	2.11	1.68	1.48	0.99	4.58
	1942	2.49	2.44	2.28	2.40	1.69	1.54	1.02	5.85
	1943	2.55	2.54	2.29	2.48	1.71	1.51	1.07	5.20
	1944	1.58	2.18	1.45	1.77	1.33	1.48	0.79	4.45

Table 6. AVERAGE [illegible] SALVOS PER TARGET

Target	Year	Salvos fired at each target: Sunk	Damaged	No damage	Fired at	Successful salvos on each target: Sunk	Damaged	Fired at	Total salvos fired per ship sunk	Total torps per salvo
All Ships	1939	1.40	2.00	1.55	1.50	1.15	1.00	0.54	3.44	1.03
	1940	1.48	1.53	1.30	1.42	1.23	1.25	0.74	2.88	1.08
	1941	1.94	2.08	1.53	1.81	1.54	1.47	0.95	3.92	1.17
	1942	1.85	1.92	1.52	1.74	1.47	1.40	0.90	4.25	1.38
	1943	1.72	1.76	1.39	1.61	1.42	1.30	0.89	3.38	1.54
	1944	1.38	1.66	1.27	1.38	1.20	1.39	0.72	3.47	1.28
	TOTAL	1.72	1.85	1.43	1.63	1.40	1.37	0.85	3.66	1.33

c. A picture of the war on Merchant Vessels

By eliminating other than merchant vessels, we obtain a more homogeneous picture of every-day submarine warfare, and one which can be used properly to compare the U. S. and German activities. The number of targets hit per target attacked is shown in Figure 6; Figure 7 shows the number sunk per target hit. Figure 8 shows the percent of torpedoes hitting and Figure 9 the average number of hits per target hit. The similarity, both in magnitude and behavior, of the graphs for the two nations is apparent.

d. Effect of convoy status

Table 7 shows the effect of torpedo shots, by year and convoy status of the target. For the entire period, the percent of torpedoes hitting is:

On single ships	42%
On unescorted groups	48%
On ships in convoy	53%

There is, of course, an increased risk to the submarine in an attack on a convoy, but he has a much greater chance of hitting a target not primarily aimed at. The distribution of total shots fired is as follows:

At single ships	69%
At unescorted groups	18%
At ships in convoy	12%
Unknown Status	1%

Independent ships which were damaged rather than sunk seemed to draw considerably more fire, but received about the same number of hits as ships that were sunk. On the other hand a ship damaged from a convoy drew about the same fire, but received fewer hits than one sunk from a convoy.

e. Accuracy and fire control

Table 8 shows the correlation between aim point and impact point, for single shots.

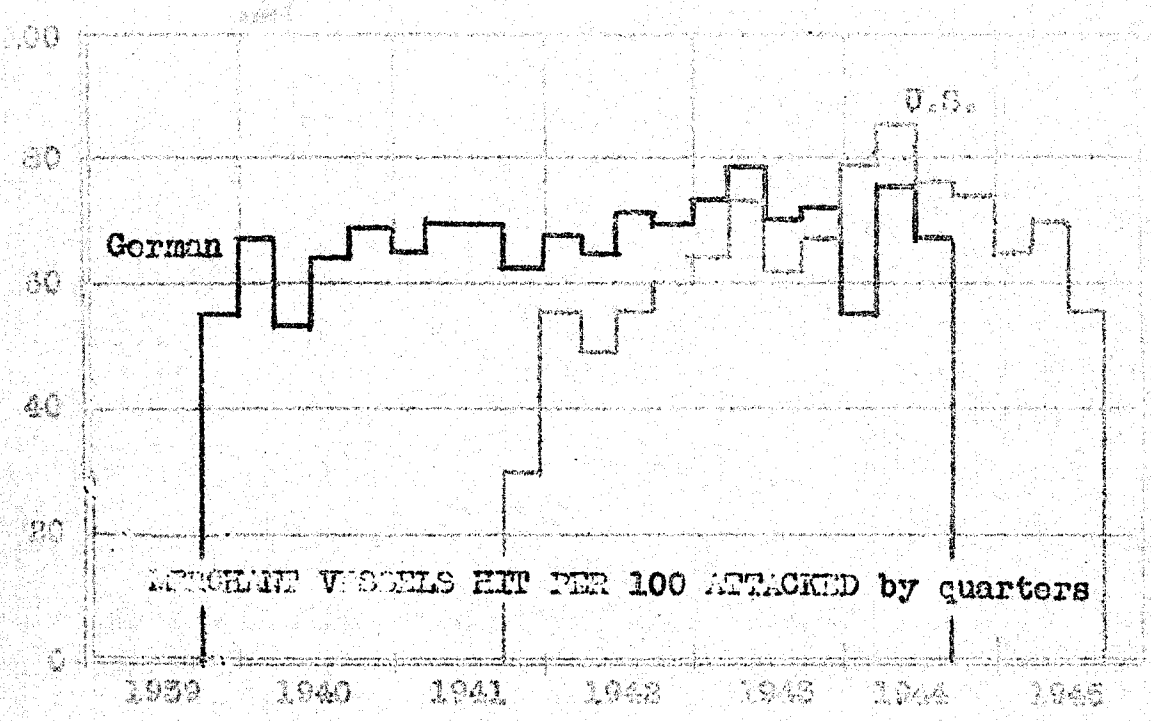

Figure 6.

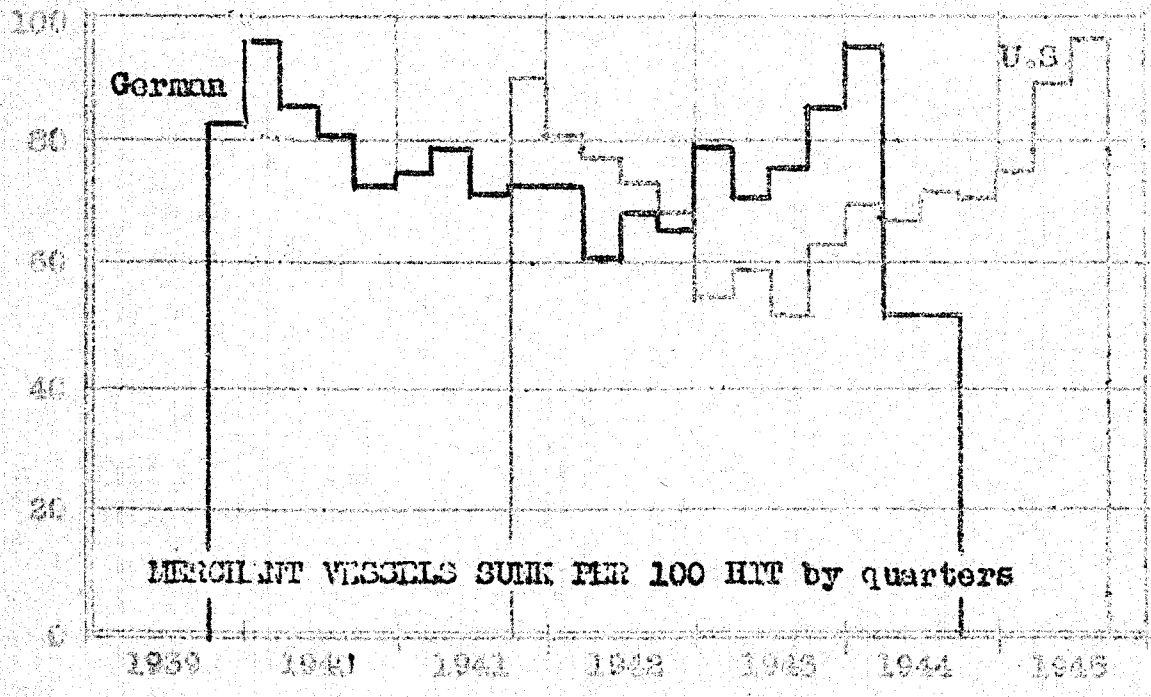

Figure 7.

PERCENT HITS AMONG TORPEDOES FIRED
AT MERCHANT VESSELS
by quarter

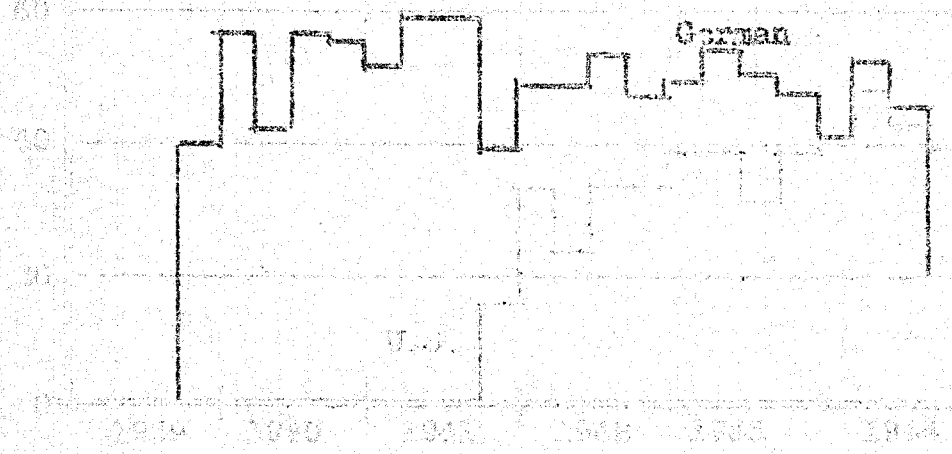

Figure 8.

AVERAGE HITS PER MERCHANT VESSEL HIT
by quarter

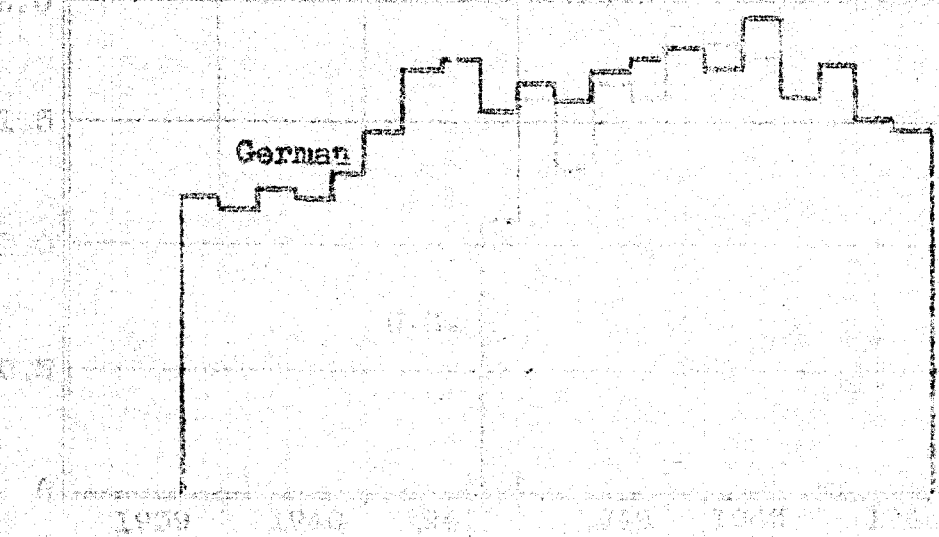

Figure 9.

Table 7. EFFECT OF GERMAN TORPEDO SHOTS
By Year and Convoy Status of Target

Year	Convoy status	Sunk			Damaged			No damage		Total		
		Targets	shots at	Hits on	Targets	shots at	Hits on	Targets	Shots at	Targets	Shots at	Hits on
1939	Single	47	64	52	4	8	4	61	99	112	171	56
	Unesc.Group	3	4	4	-	-	-	2	2	5	6	4
	Convoy	5	10	8	1	2	1	3	6	9	18	9
	Unknown	-	-	-	-	-	-	-	-	-	-	-
	TOTAL	55	78	64	5	10	5	66	107	126	195	69
1940	Single	282	454	357	34	48	36	254	369	570	871	393
	Unes.Group	29	41	38	18	28	26	12	19	59	88	64
	Convoy	55	84	69	27	46	38	32	42	114	172	107
	Unknown	-	-	-	-	-	-	-	-	-	-	-
	TOTAL	366	579	464	79	122	100	298	430	743	1131	564
1941	Single	199	448	324	55	134	85	155	308	409	890	409
	Unes. Group	31	65	46	11	25	14	37	74	79	164	66
	Convoy	44	92	78	27	57	39	32	47	103	196	117
	Unknown	-	-	-	2	3	3	2	3	4	6	3
	TOTAL	274	605	448	95	219	141	226	432	595	1256	595
1942	Single	387	965	657	198	504	306	361	823	946	2292	963
	Unes.Group	121	287	197	68	158	107	93	209	282	654	304
	Convoy	48	120	84	29	58	42	51	117	128	295	126
	Unknown	1	6	3	-	-	-	6	14	7	20	3
	TOTAL	557	1478	941	295	720	455	511	1163	1363	3261	1396

1943	Single	219	581	363	73	207	111	205	473	497	1261	474
	Unes.Group	83	232	162	34	78	52	47	118	164	428	214
	Convoy	77	169	126	24	50	36	28	57	129	276	162
	Unknown	4	12	5	1	1	1	9	15	14	28	6
	TOTAL	383	994	656	132	336	200	289	663	804	1993	856
1944	Single	74	106	89	45	99	70	94	134	213	339	159
	Unes.Group	45	98	72	11	23	13	34	66	90	187	85
	Convoy	22	38	26	6	13	9	14	34	42	85	35
	Unknown	1	2	2	-	-	-	11	18	12	20	2
	TOTAL	142	244	189	62	135	92	153	252	357	631	281
Total	Single	1288	2618	1842	409	1000	612	1130	2206	2747	5824	2454
	Unes.Group	312	727	519	142	312	212	225	488	679	1527	731
	Convoy	251	513	391	114	226	165	160	303	525	1042	556
	Unknown	6	20	10	3	4	4	28	50	37	74	14
	TOTAL	1857	3878	2762	668	1542	993	1543	3047	3948	8467	3755

Table 8. AIM POINT VS IMPACT POINT
Single German Torpedoes only

Torpedo type	Aim point	Point of impact 1	2	3	4	Total
All torpedoes	1	112	64	11	49	236
	2	182	553	86	301	1122
	3	1	1	6	2	10
	4	14	40	24	112	190
	TOTAL	309	658	127	464	1558
Type V	1	1	1	0	1	3
	2	6	13	3	6	28
	3	0	0	0	0	0
	4	0	0	1	5	6
	TOTAL	7	14	4	12	37
Type W	1	16	6	1	7	30
	2	27	112	20	56	215
	3	0	0	2	0	2
	4	0	6	5	24	35
	TOTAL	43	124	28	87	282
Type X	1	93	55	10	35	193
	2	144	402	63	220	829
	3	1	1	3	2	7
	4	13	32	18	82	145
	TOTAL	251	490	94	339	1174
Type Y	1	2	4	0	6	12
	2	5	26	0	19	50
	3	0	0	1	0	1
	4	1	2	0	1	4
	TOTAL	8	32	1	26	67

It is a severe test of fire control to require that the torpedo hit the point on the ship for which it is aimed. This test can be applied only to straight running torpedoes, and to single torpedo shots as tabulated in Table 8. The points of reference used are:

1 - Forward
2 - Amidships
3 - Engines (Although "Engines" have no fixed place, they will usually come at or between Class 2 or 4.)
4 - Aft

The following table gives the values of a modified rank-difference correlation coefficient which varies from the value "0" if the hits were equally distributed along the hull regardless of aim point, to "1" if the torpedoes all hit the point at which they were aimed. The development of the formula for "R" is given in Appendix C.

Torpedo type	R
V - (steam, 30 knots)	.42
W - (steam, 40 knots)	.44
X - (electric, contact)	.49
Y - (electric, proximity)	.64
All types	.48

The increase in R(W) over R(V) is to be expected on the basis of the greater speed of Type W. Type Y was used later in the war than X.

f. Range of fire

Figure 10, which indicates no appreciable variation of accuracy with range, is included because of the general current interest in the subject. However, range is correlated with many other variables and until it can be separated from them no really valid conclusions can be reached on the effect that it may have. (Note: a study of this nature is now in progress in the O.E.G.) Figure 11 shows how the Germans increased range of fire as the war progressed.

Submitted by:

Earl P. Gardiner

EARL B. GARDINER,
Operations Evaluation Group.

Approved by:

Glen D. Camp.

GLEN D. CAMP,
Operations Evaluation Group.

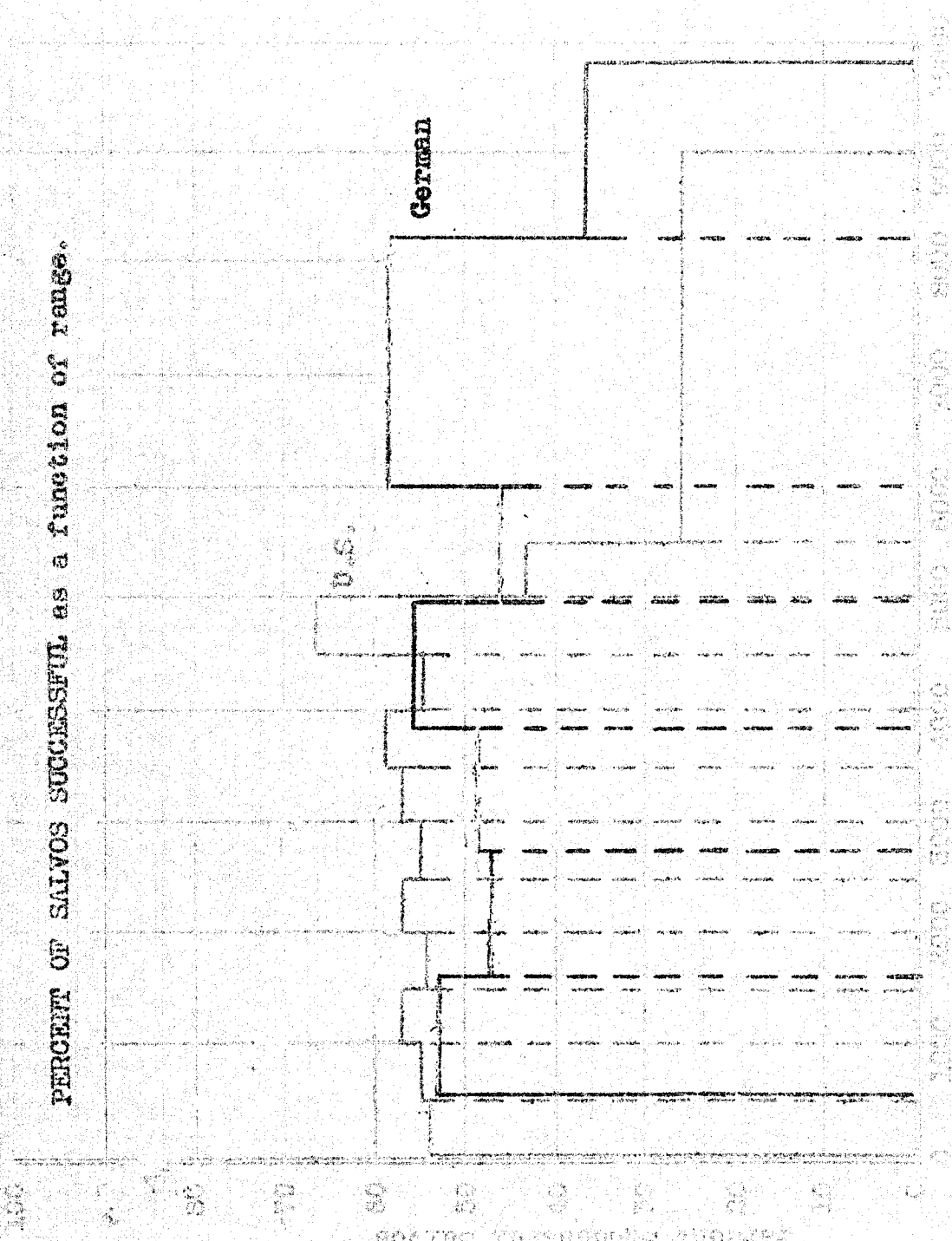
German
U.S.
PERCENT OF SALVOS SUCCESSFUL as a function of range.

Figure 10.

AVERAGE RANGE OF GERMAN TORPEDO FIRE by quarter

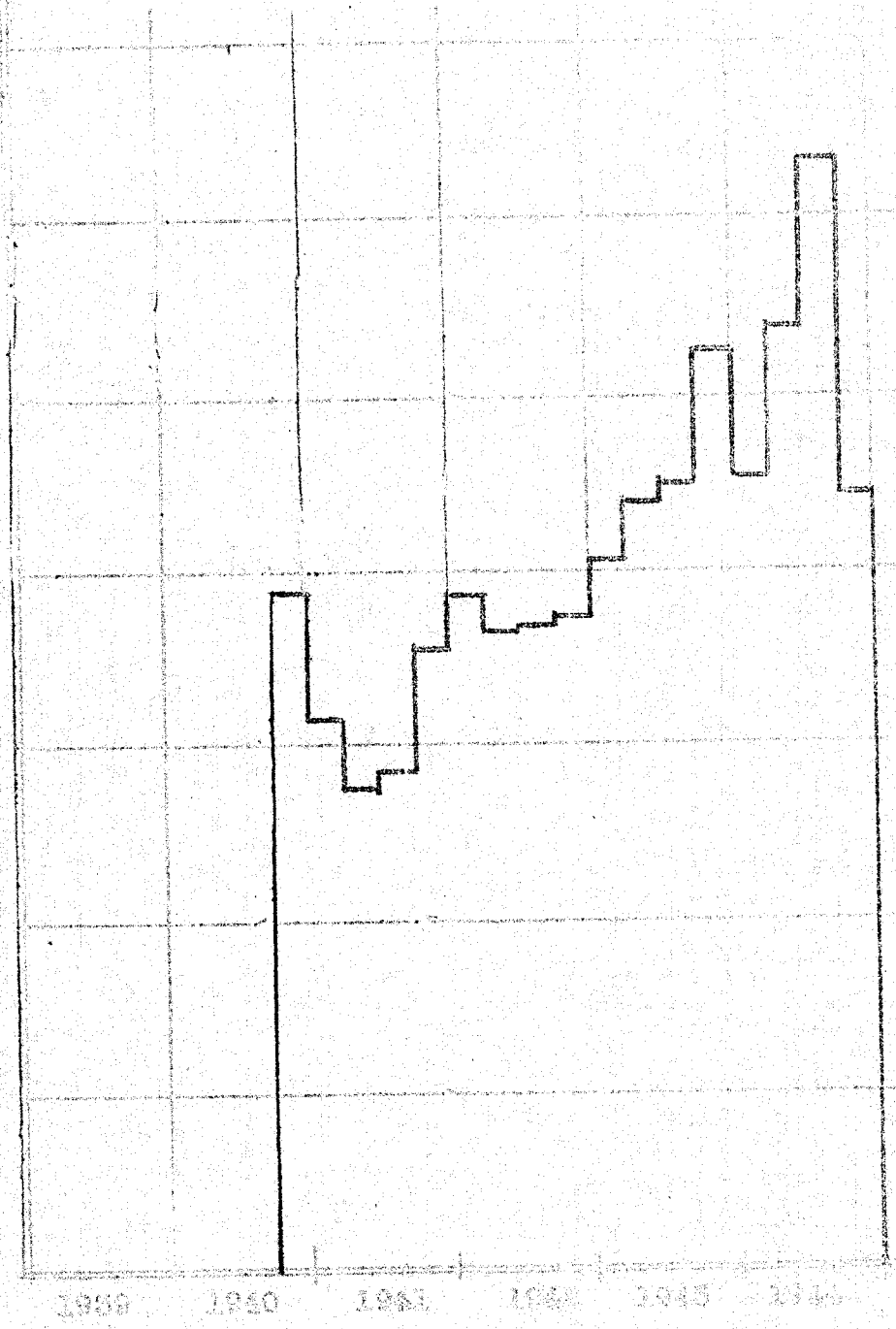

Figure 11

Appendix A: CONTENTS OF CARDS CAPTURED IN GERMANY

Card No. 1 (applies to one salvo).

1. Serial number
2. U/Boat
3. Date and time
4. Water depth
5. Area
6. Visibility, weather, overcast, day-night-twilight
7. Wind and sea
8. Water temperature
9. Target type, cargo, tonnage, convoy status, draft, length
10. Type of salvo, divergence, depth setting
11. Faulty torpedoes and fire control
12. Fire control and trim angle
13. Aim point
14. Dive and turn after fire
15. Hits
16. C/O of U/Boat
17. Torp. running time
18. Attack officer

Card No. 2 (applies to each torpedo).

1. Serial number
2. Running depth
3. U/Boat course and speed
4. Target bearing, course, speed
5. U/Boat angle on target bow
6. Range - First Est., firing, TDC
7. Initial torp. run, loop, Lut speed
8. Evidence of hit, type, and effect
9. Pistol type
10. Torp. type and speed
11. Failures and causes
12. Enemy counteraction
13. Point of impact
14. Torpedo gyro, course, angle on target bow
15. Angle between torpedo and swell
16. Time for target to sink
17. Loop in which hit occurred

Appendix B: DESCRIPTION OF GERMAN TORPEDOES

V T-I: A steam propelled torpedo, with wake. Speed 30 knots, range 12,500 meters, accuracy ±1% of range.

W T-I: Modified for a speed of 40 knots, range 7,500 meters; or a speed of 44 knots, range 5,000 meters.

L T-I Fat I: A 30 knot anti-convoy torpedo. After an initial straight run, the T-I Fat I turns 90° to port or starboard, and thereafter makes 180° turns. The setting of "long" (5 knot) legs or "short" (7.5 knot) legs determined the rate of advance. This torpedo was designed to be most efficient when fired at an angle of 90° to the course of the convoy.

X T-II: An electric, wakeless torpedo, powered by a 110V battery developing 90 hp. Speed 30 knots, range 5,000 meters if preheated to 30° C; 3,000 meters if not preheated.

Y T-III: An electric, wakeless torpedo. This type is the T-II adapted for use with the proximity pistol. Speed 30 knots, range 5,000 meters if preheated to 30° C; 3,000 meters if not preheated.

M T-IIIa: An electric, wakeless, torpedo fitted with proximity pistol. The T-III had too short a range to permit the use of figure-run devices; therefore to increase the range it was fitted with a larger battery. This modification, the T-IIIa, had a range of 7,500 meters at 30 knots with 30° C preheating. For a range of 5,000 meters the aiming error was 1.5% of the running distance; for larger distances 2%. Both Fat II and Lut I were combined with the T-IIIa.

M T-IIIa Lut I: An electric, wakeless torpedo fitted with proximity pistol and modified tracking pattern. The leg length could be adjusted to the speed of the target, and the torpedo could be fired at a target in a position of 0° to 360° from the submarine. By adjusting the position and rate of advance to the course and speed of the target, a higher probability of hitting was expected.

M T-IIIa Fat II: An electric, wakeless torpedo, [illegible] with a proximity pistol and modified Fat I. The [illegible] pattern could have either "long" (5 knot) legs, or could circle with a diameter of 240 meters to port. The circling torpedoes were designed to be fired at a target in a position of 0° to 180° from the submarine.

B T-IV and T-V: Accoustically controlled, homing torpedoes. Speed 24.5 knots, electrically driven.

Appendix C: THE MODIFIED RANK-DIFFERENCE CORRELATION COEFFICIENT.

We desire a measure of rank correlation in a square distribution where all cells may contain frequencies, the rank proceding from 1 to n by unit intervals. The measure should give "0" if all cells have the same frequency and "1" if all frequencies lie on the principal diagonal. By the nature of the problem negative correlation is inadmissible. The measure should be simple to compute.

Such a measure will be given by

$$R = 1 - \frac{\sum fXY \mid X-Y \mid}{K}$$

where K is to be determined so that the lower limit of R will be 0. The upper limit is fixed at "1", since the fraction will be 0 in the case of 1:1 correspondence in rank.

Now if each of the cells contains "a" items the numerator of the fraction will be, by reference to Figure 1,

$$2 \sum_{r=1}^{n-1} \sum_{u=1}^{n-r} au = a \frac{n(n^2-1)}{3} \text{ where } u = \mid x-y \mid$$

which is equal to

$$\frac{(n^2-1)\sum fXY}{3n}$$

since $\sum fXY = n^2a$.

Now since R = 0 for this case,

$$K = \frac{(n^2-1)\sum fXY}{3n}$$

and the formula for R is given by

$$R = 1 - \frac{3n \sum fXY \ |X-Y|}{(n^2-1) \sum fXY}$$

which reduces to

$$R = \frac{3}{5N} \sum fXY \ |X-Y|$$

for the case where n = 4. N is the total number of observations in the table.

		X				
	1	2	3	4	5	. . . . . n
1	0	1	2	3	4	
2	1	0	1	2	3	
3	2	1	0	1	2	
Y 4	3	2	1	0	1	
5	4	3	2	1	0	
. . . . . n						

Figure 1.
The figures in the cells are u = |X-Y|