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OPERATIONS EVALUATION GROUP

STUDY NO. 428

NUMBER OF TORPEDO HITS REQUIRED TO SINK A SHIP

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NUMBER OF TORPEDO HITS REQUIRED TO SINK A SHIP

Ref: (a) NavOrd Report No. 207-45, Probability of Sinking Medium Merchant Vessels as a Function of Torpedo Charge Weight, Conf 5 Sep 1945
(b) OPNAV-16-V, Striking Power of Air-Borne Weapons, Secret Jul 1944
(c) NavOrd Rpt No. 20-44 Secret Sep 1944

SUMMARY AND CONCLUSIONS

Based partly on statistical and partly on theoretical considerations, references (a) and (b) state the probability that a ship which has suffered a given number of torpedo hits will sink as a result. These probabilities are compared with the available statistics both on our own and on the German submarine results in World War II.

Taking P_n to be the probability that a ship with n hits will sink, it is found that the well-known expression for the probability associated with n independent events,

$$P_n = 1 - (1 - P_1)^n ,$$

fits the observed and derived data reasonably well for $P_1 = 0.5$ in the case of medium or large merchant vessels. In the case of small merchantmen the value of P_1 is larger, and probably lies somewhere between 0.65 and 0.75.

INTRODUCTION

Much work is currently underway with the objective of determining the probability that a submarine will be able to score a hit on his target, under various assumptions regarding the submarine, the target, and the torpedo. In order finally to use such figures to determine the danger to our shipping and to evaluate the various methods proposed for its protection, it is necessary to know the amount of damage that is done to a ship that has been hit by one or more torpedoes.

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MERCHANT SHIPS

The probabilities reported in reference (a) apply to a medium-size merchantman between 300 and 375 feet long, with gross tonnage between 2700 and 4800 tons.

The results are derived by considering the likelihood of the ships's being flooded and/or broken up sufficiently to sink it, through rupture of internal bulkheads.

The probabilities for torpedoes containing 600 pounds of Torpex are shown in Table I.

TABLE I			
Probability target will sink after receiving			
	one hit	two hits	three hits
Target in ballast	.38	.73	.92
Target loaded	.56	.87	.96

Tables II and III show the results of U.S. submarine attacks on Japanese merchant ships, as a function of type of target (cargo or tanker), target tonnage, and number of hits achieved.* Further details are given in reference (c).

The results for one, two, three, or four torpedo hits could, of course, be deduced directly from the tables. It is of greater interest here, however, to use these data to test the validity of some reasonable assumption as to the nature of a general expression for P_n, the probability that a ship with n hits will sink. Let us try the function

$$P_n = 1 - (1 - P_1)^n \quad . . . . (1)$$

where n is the number of torpedo hits in the target.

The assumption underlying this expression is that the damage done by a given hit is independent of the damage done by any and all other hits. This state of affairs appears to obtain for merchant vessels. Reference (a) indicates that independence is physically justifiable with respect to the

* Based on statistics compiled from U.S. Submarine War Patrol

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TABLE II

Results of U.S. Submarine Attacks on Cargo Vessels

Target Tonnage (Thous. Tons)	Torp. Hits n	Targets Sunk S	Targets Damaged D	Total S+D	Q_n $\frac{D}{S+D}$	Q_1 $=Q_n^{1/n}$	Est. of P_1 $1-Q_1$	Avg. Est. P_1
0-3	1	79	15	94	.16	.16	.84	
	2	30	3	33	.09	.30	.70	
	3	10	2	12	.17	.55	.45	
	4	--	--	--				
	5	--	--	--				
	Total	119	20	139	.14			.70
3-5	1	113	137	250	.55	.55	.45	
	2	137	42	179	.23	.48	.52	
	3	43	3	46	.07	.41	.59	
	4	6	2	8	.25	.74	.26	
	5	--	--	--				
	Total	299	184	483	.38			.46
5-7	1	108	117	225	.52	.52	.48	
	2	151	49	200	.24	.49	.51	
	3	44	5	49	.10	.46	.54	
	4	10	1	11	.09	.55	.45	
	5	--	--	--				
	Total	313	172	485	.36			.50
7-9	1	76	76	152	.51	.51	.49	
	2	149	55	204	.27	.52	.48	
	3	67	4	71	.06	.39	.61	
	4	19	1	20	.05	.47	.53	
	5	--	--	--				
	Total	311	136	447	.30			.51
9-12	1	22	12	34	.35	.35	.65	
	2	57	22	79	.28	.55	.45	
	3	38	6	44	.14	.52	.48	
	4	11	1	12	.08	.53	.47	
	5	--	--	--				
	Total	128	41	169	.25			.50
G. Total		1170	553	1723	.32			

DOWNGRADED TO UNCLASSIFIED SECRET CONFIDENTIAL breaking up of a ship. With regard to flooding, it is also conceivable that in some cases successive hits might be considered independent events; for example, a first hit near the bow or stern might cause so little flooding damage as not to affect significantly the extent of damage caused by a second hit in the more vital central portion of the ship.

TABLE III

Results of U.S. Submarine Attacks on Tankers

Target Tonnage (Thous. Tons)	Torp. Hits n	Targets Sunk S	Targets Damaged D	Total $S+D$	Q_n $\frac{D}{S+D}$	Q_1 $=Q_n^{1/n}$	Est. of P_1 $=1-Q_1$	Avg. Est. P_1
0-5	1	20	17	37	.46	.46	.54	
	2	27	11	38	.29	.54	.46	
	3	6	1	7	.14	.52	.48	
	4	1	1	2	.50	.84	.16	
	Total	54	30	84	.36			.49
5-10	1	20	34	54	.63	.63	.37	
	2	26	14	40	.35	.59	.41	
	3	18	4	22	.18	.56	.44	
	4	--	--	--				
	Total	64	52	116	.45			.40
10-15	1	15	25	40	.62	.62	.38	
	2	61	23	84	.27	.52	.48	
	3	29	3	32	.09	.45	.55	
	4	10	1	11	.09	.55	.45	
	5	12	0	12	0	0	1.00	
	Total	127	52	179	.29			.50
G. Total		245	134	379	.35			

The columns headed Q_n in Tables II and III give the observed estimate of the probability that a ship with n hits will not sink. If equation (1) holds, then

$$Q_1 = (Q_n)^{1/n}$$

should not show a trend with increasing n. Examination of

Tables II and III leads to the conclusion that this is true except for small cargo ships and possibly for the largest category of cargo ships, although the case for the second exception is not so strong as that for the first. Under the assumption that equation (1) does hold, the final column in Tables II and III gives the average (weighted according to the number of targets) of $P_1 = 1 - Q_1$, or the derived probability of sinking the target with one torpedo hit. Except for the small cargo vessels this average may be taken as 0.5; for the latter the value of P_1 is larger, lying probably between 0.65 and 0.75.

Figure 1, based on equation (1), gives for several values of P_1, the number of hits required to yield a given probability of sinking. Because the law expressed in equation (1) has been verified for only four and fewer torpedo hits it is felt that the curves in Figure 1 should not extend beyond five hits. Furthermore, the behavior of the function for probabilities between 0.95 and 1.00 is incompatible with physical reality; hence the curves should not be extended beyond $P_n = 0.95$.

Table IV shows the results of Axis submarine attacks against Allied and neutral merchant vessels, for several target tonnage classes. It is not possible to classify these attacks on the basis of the number of torpedo hits. However, the average value of Q_n, $\overline{Q}_n$, for each tonnage class and for all classes combined may be compared with the similar figures for the results of attacks by U.S. submarines, as given in Tables II and III. It appears that the values of $\overline{Q}_n$ realized by enemy submarines against our cargo ships are lower than those for our submarines against Japanese cargo ships. Against tankers they are about the same. The observed difference in the case of cargo ships might be made the subject of another study. If it is real, then the computed P_1 (based on the results from our submarines) is low. On the other hand, this computed P_1 agrees so well with the theoretical value as given in reference (a), that it is highly unlikely to be very much out of line.

COMBATANT VESSELS

The results for combatant ships (reference (b)) are also based partly on statistics and partly on a theory of flooding. Various degrees of compartmentation and other physical differences among the targets are considered. The probability values from reference (b) are brought together in Table V.

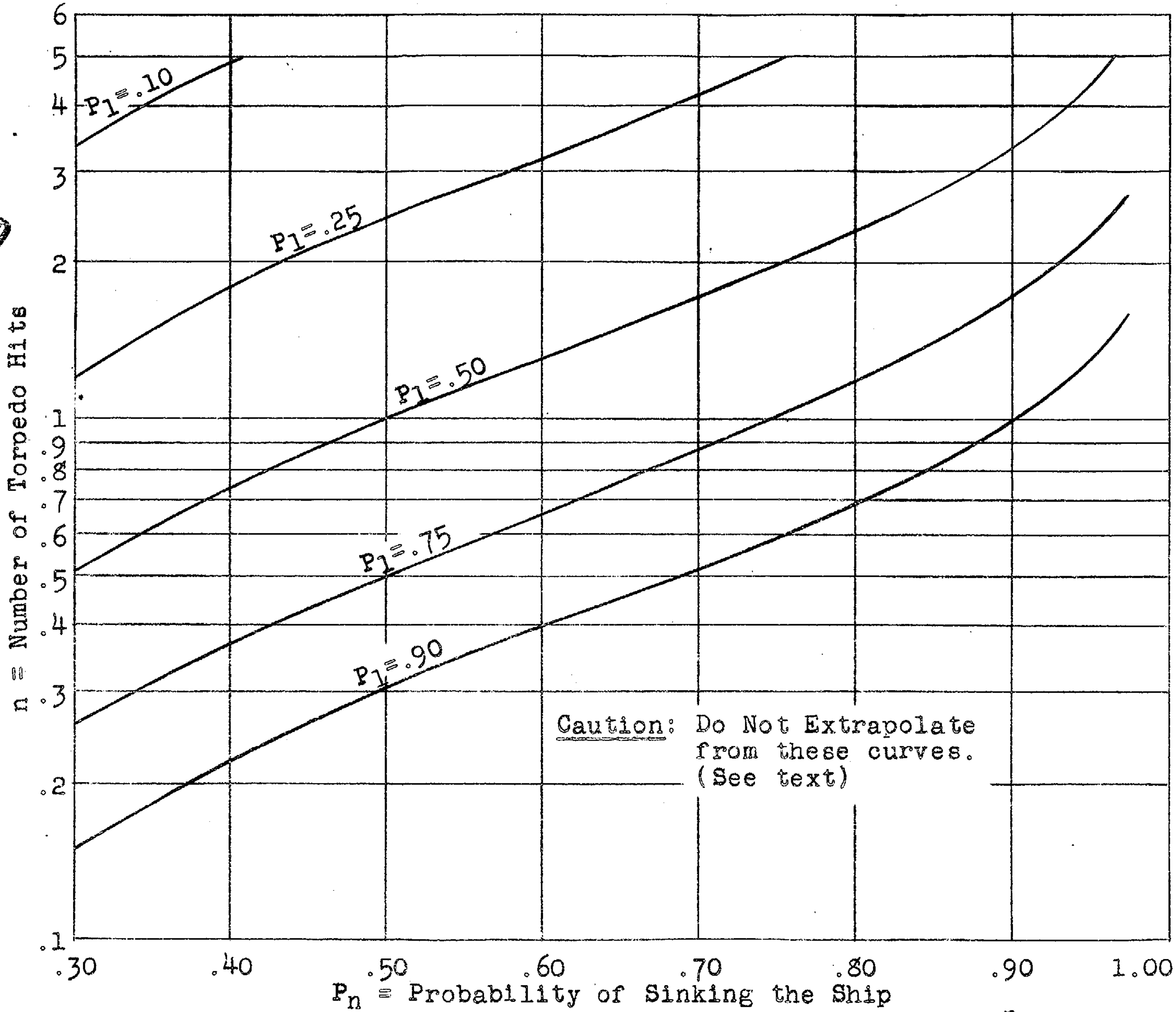

FIG. 1 GRAPH OF n VERSUS P_n WHERE $P_n = 1 - (1-P_1)^n$

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TABLE IVa				
Results of Enemy Submarine Attacks on Allied and Neutral Cargo Vessels				
Target Tonnage (Thous. Tons)	Targets Sunk S	Targets Damaged D	Total S + D	$\bar{Q}_n$ $\frac{D}{S + D}$
0-3	225	13	238	.05
3-5	299	22	321	.07
5-7	432	46	478	.09
7-9	281	91	372	.24
9-11	26	4	30	.13
11 a.o.	18	4	22	.18
Total	1281	180	1461	.12

TABLE IVb				
Results of Enemy Submarine Attacks on Allied and Neutral Tankers				
Target Tonnage (Thous. Tons)	Targets Sunk S	Targets Damaged D	Total S + D	$\bar{Q}_n$ $\frac{D}{S + D}$
0-3	10	1	11	.09
3-5	15	4	19	.21
5-7	76	34	110	.31
7-9	107	47	154	.30
9-11	66	40	106	.38
11 a.o.	11	3	14	.22
Total	285	129	414	.31

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TABLE V						
Probability of Sinking for Number of Torpedo Hits (from reference (b))						
Type Ship	No. of Hits					
	1	2	3	4	5	6
Destroyer (1500-1630 tons)	.75	.98	.99	.99		
Destroyer (1850-2100 tons)	.31	.90	.98	.99		
Cruiser (6000-7050 tons)	.05	.85	.95	.99		
Cruiser (10,000 tons and up)	.03	.40	.85	.98		
Carrier (CV)	.06	.12	.50	.90	.95	.99
Carrier (CVL)	.11	.48	.93	.99		
Carrier (CVE)	.12	.90	.99	.99		
Battleship (old)	.01	.05	.40	.90	.99	.99
Battleship (new)	.01	.02	.10	.40	.70	.90

Considerations of the physical characteristics of naval vessels — the relatively unstable small escort craft on the one hand, and the highly compartmented, many-skinned battleships on the other — suggest that the law expressed by equation (1) does not hold for such vessels.

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