J.W. Devanney III
S. Protopapa
R. Klock

Tanker Spills, Collisions and Groundings

MIT Sea Grant
College Program

Massachusetts
Institute of Technology
Cambridge
Massachusetts 02139

Report Number
MITSG 79-14
June 1979

Tanker Spills, Collisions and Groundings

J.W. Devanney III

S. Protopapa

R. Klock

Sea Grant College Program
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Report No. MITSG 79-14
Index No. 78-314-Nft
June 1979

ACKNOWLEDGMENTS

The MIT Sea Grant College Program is publishing this report with the support of the Office of Sea Grant in the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, through grant number 04-158-44979, and the Massachusetts Institute of Technology. The U.S. government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear hereon.

AUTHORS

J.W. Devanney III, Associate Professor, Massachusetts Institute of Technology, Department of Ocean Engineering

S. Protopapa, Transportation Systems Engineer, Transportation Systems Center, U.S. Department of Transportation

R. Klock, Research Assistant, Massachusetts Institute of Technology, Department of Ocean Engineering

The Sea Grant Marine Resource Information Center maintains an inventory of all technical and advisory publications. We invite orders and inquiries to:

MIT Sea Grant Program
Marine Resource Information Center
77 Massachusetts Avenue
Building E38-302
Cambridge, Massachusetts 02139

TABLE OF CONTENTS

FORWARD

This work was undertaken in support of the Transportation Systems Center's (TSC) study of Offshore Vessel Traffic Management. The TSC study was directed by the U.S. Coast Guard Port Safety and Law Enforcement Division, Office of Marine Environment and Systems, Washington, D.C.

The purpose was to collect relevant data on tanker traffic and casualties and to organize this data in a manner that would contribute to TSC's analysis of alternative offshore vessel management systems. This effort did not include the formal analysis of potential systems, but, from time to time, we have pointed out certain patterns in the data which appeared to us to have obvious and important implications for such systems. Whenever we did so, the opinions so expressed are the personal judgements of the authors and do not represent the position of either MIT or the Department of Transportation.

EXECUTIVE SUMMARY

Our basic finding with respect to collisions is that it is a communication and coordination problem rather than a detection problem. The core of the issue is that in nearly head-on encounters, with the ships displaced slightly to starboard, the Rules of the Road are ambiguous and the ships are maneuvering into a collision. We find that neither the standard prescription of earlier and more violent maneuvers nor the more modern solution of computerized straight-line projection of other ship's courses (the so called Collision Avoidance Systems) addresses the coordination problem. In fact, we offer evidence that following such advice may well lead to more rather than fewer collisions.

The proper approach, in our opinion, would involve:

a) Less ambiguous Rules of the Road stipulating safe CPA's above which no maneuver is indicated.

b) Recognition both in the rules and in court decisions that full ahead throttle is almost always the proper manuever when a collision is imminent.

c) Most importantly, a strictly enforced bridge-to-bridge communication system.

With regard to groundings, we find that almost all past groundings occured either entering harbor or bays within a very few miles offshore and that offshore American groundings were highly localized in just two areas: Guayanilla Bay and Delaware Bay. The data indicates that conning or guidance errors are as important as navigational errors in causing groundings and that many of the conning-related groundings are connected with pilot transfers. Basically, we find that the <u>Argo Merchant</u> type of grounding (mid-route, well offshore) is an extremely unlikely scenario. The data does not suggest a vessel management system built around this scenario. Rather it indicates that a highly specialized study of two entrances (Delaware Bay and Guayanilla Bay) should be undertaken to discover what topographical peculiarity or local operating practices are causing these groundings. After that is determined, the proper corrective measures should be obvious.

As part of this study, we made an estimate of the tanker traffic pattern in U.S. continental shelf waters. A com-

parison of this traffic pattern with our collision and grounding data showed no correlation between the level of tanker traffic and tanker casualties. Simplistic arguments relating tanker traffic and tanker casualties are not supported by the casualty data which indicate that local factors appear to dominate. Therefore, whatever vessel traffic management scheme is adapted should recognize this fact.

CHAPTER 1. THE NATURE OF TANKER SPILLS

1.1 The Statistical Character of Oil Spill Volumes

Anything more than a cursory glance at tanker spill statistics reveals three striking features of the data which together pose an unusually difficult problem for statistical analysis:

a. The size range of an individual spill is extremely large. Spill magnitudes range from a few gallons to tens of millions of gallons. The largest spill reported to date (March, 1978), the Sea Star collision, discharged about 34 million gallons and, with present tanker sizes, spills three and four times this size are inevitable. With respect to spill size, we are dealing with a variable which can range over eight orders of magnitude.

b. The vast majority of all spills are at the lower end of this range. For example, 96% of all American petroleum industry related spills reported by the Coast Guard in 1972 were less than 1000 gallons and 85% of these spills were reported to be less than 100 gallons.

c. Most of the oil is spilled in a very few, very large spills. In a single collision in the Persian Gulf, the Sea Star in 1972 spilled more oil than all the oil that was reported spilled in USA waters from all sources in that year. And in 1972 in the United States, three spills accounted for over half the total American volume; the largest 18 spills accounted for over 85% of this volume. This pattern has been consistent throughout the period over which oil spillage data has been collected. In every year, a handful of spills account for the great bulk of the total volume spilled by tankers. (1)

The fact that most oil is spilled in a few very large, but relatively rare spills implies that all statements based on volumes must be very carefully qualified. For example, the oil industry used to point with pride to the operations at Milford Haven, a carefully monitored, well-run Welsh port

---

(1) In this usage of the word 'spilled', we are excluding planned discharges of oil such as overboard discharge of dirty ballast, bilge pumping and the like.

which now handles over 200,000 tons of oil per day. In the first ten years of operation, Milford Haven averaged about 30 tons spilled per year, a spillage rate of less than .0002%. Industry officials pointed to such figures as 'typical' of what could be expected from a well-run operation. Then in August of 1973, the Dona Marika went aground in the entrance to Milford Haven, in heavy weather, losing over 3000 tons of leaded petrol. With one, not particularly large spill, the ten year Milford Haven spillage rate increased by a factor of ten. The same thing happened at Bantry Bay which was claiming a spillage rate 1000 times lower than that of Milford Haven pre-Dona Marika until two spills in late 1974 and early 1975 dumped 3000 tons into the Bay increasing its average spillage rate by better than a factor of 1000.

More to the point, consider the oft discussed groundings versus collisions issue. Table 1.1 summarizes an analysis of the Coast Guard Worldwide Tanker Casualty Database for the years 1969 to 1973 inclusive. There are 3698 casualties in this file representing the results of a manual extraction from insurance reports, primarily Lloyd's Daily List. We believe this file is a reasonably complete compendium of all large tanker spills during this period for it is extremely difficult to have a large tanker spill and no insurance claim. In 568 of these casualties, the Coast Guard established that pollution actually did occur. (1) The total amount reported spilled is 968,501 tons. This total does not include spillage which has been estimated using an average of other spills of the same type; i.e. spills which have a 'C' as the method of determining outflow, column 55. This method is double counting of the worst sort. Firstly, if the amount spilled cannot be estimated by the other methods, it's quite likely that the spill was much smaller than the average. Secondly, due to the very wide dispersion in spill sizes, even if this bias did not exist,

---

(1) These and subsequent results are based on a PL/1 program written by MIT for accessing this file. This program obtains the number of spills, total amount spilled, and the sum of the squared amount spilled for approximately 400 spill cause, spill size, spill locale and spill flag categories. The program also prints out the particulars of each spill over 125 tons (about 1000 barrels or 42,000 gallons). Due to mispunches in a few of the fields the MIT progam was unable to operate on 16 spills totaling 2000 tons. Thus, our overall totals may not match Coast Guard totals exactly.

TABLE 1.1 SUMMARY OF ALL SPILLS IN COAST GUARD WORLDWIDE TANKER CASUALTY DATABASE, 1969 thru 1973

	Structural Failure	Grounding	Collisions and Ramming	Explosion and Fire	Other	Total
All spills over 10,000 tons	13 308,303	6 143,509	1 120,300	3 61,716	4 84,019	27 717,847
All spills over 1,000 tons	19 336,074	31 212,532	27 181,633	15 98,350	4 84,019	96 912,612
All spills over 125 tons	23 337,054	64 229,235	61 196,781	23 101,760	7 85,306	178 950,136
All incidents in file	320 339,394	463 234,311	893 207,144	200 104,464	74 86,083	1,950 953,446

the likelihood that the spill would be anywhere near the average is very small. Most importantly, if one is interested in estimating this dispersion as well as the mean, one way of completely fouling up one's sample is to arbitrarily add elements at the mean. Fortunately, the Coast Guard has wisely made very little use of the 'C' entries. They total less than 18,000 tons.

With respect to the results themselves, it will come as no surprise to anyone familiar with spill characteristics that the total volumes spilled are dominated by a very small minority, in fact a handful of the spills. Table 1.1 breaks down all spills in the file by major cause category and size class. There are 178 spills in the file over 125 tons; these 178 spills represent 99.67% of all the spillage reported. There are 96 spills over 1000 tons. These spills represent 96% of all the spillage. There are only 27 spills over 10,000 tons in the file, yet these spills represent over 75% of the spillage.

Recently, the Coast Guard has updated this file to include the calendar years 1974 through 1976. Through the courtesy of the Marine Technical Division, we obtained a preliminary version of this additional data and subjected it to the same analyses. The additional entries totaled 1175 casualties in 76 of which positive spillage was definitely reported. The total spillage contained in these reports was 351,118 tons. It's pretty clear that the 74 through 76 data in its present form is seriously incomplete. The number of definite spills reported per year in the 74 to 76 data is less than one-fourth the annual average for the preceding five years. Secondly, the volumes for several large spills on which M.I.T. has independent information is way off. Finally, perhaps the most famous spill of the last five years, the Argo Merchant, is not listed. We have informed the Coast Guard of the apparent weaknesses.

However, accepting the data as given, Table 1.2 breaks down all offshore, definite spills reported in the combined, eight year database. Table 1.2 contains only those spills whose locale was listed as Coastal Zone (less than 50 miles offshore) and At Sea (more than 50 miles offshore). Spills listed as At Pier, In Harbor, or In Estuary or Entranceway are not included.

In this summary, the number of collisions, groundings, and structural failures is approximately equal. Accepting the data at face value, over the last eight years we have

TABLE 1.2
ALL OFFSHORE SPILLS IN COAST GUARD 1969-1976 WORLDWIDE DATA BASE[a]

	Collisions and Ramming	Groundings	Structural Failure	Explosion and Fire	Breakdown	Capsizes
Number	90	77	86	33	11	7
Volume in Tons	175,730	184,428	401,748	109,784	73,583	55,408

[a]Includes only locale "C" and "S" spills for which positive spill amount was reported.

averaged roughly 10 of each, offshore, worldwide per year. This sample of open water, polluting groundings and collisions is fairly sizable. A very interesting exercize would be to attempt to track down the particulars of these 167 casualties through industry sources or court records.

Table 1.3 lists the 19 largest spills in the combined file in order. These 19 spills represent 57% of all the volume reported spilled. The largest spill in the file, the Sea Star collision, represents one-eighth of all the volume reported spilled from tankers worldwide in the eight year period from 1969 to 1976. The reason for the overwhelming importance of the big spills is simple. The size range of possible spillage ranges from a few gallons to 100 million gallons. In terms of total volume spilled, one really big spill is worth literally thousands of small spills. This massive range of spill sizes has important implications for any attempt at statistical inference based on historical spill data. In terms of the all-important big spills, we are dealing with a very small sample size. To put it another way, if one is interested in total volume spilled, one must focus on a few very rare, but very important events. This in turn implies that any statement made about total volume which will be spilled in the future is subject to very wide confidence limits. A single very large spill can triple annual worldwide totals. In such a situation, one can make only very weak predictions about the total amount of oil which will be spilled in the future.

These statements hold a fortiori for predictions about the amount of oil which will be spilled by any given cause. If, for example, one is willing to make the assumptions underlying classical statistical analysis, to wit: spillage is being generated by a Gaussian process with unknown mean and variance, and then attempts to estimate the mean of the process generating collision and grounding spills over 1,000 tons, one finds that one can make the following statement.

TABLE 1.3

ALL SPILLS OVER 20,000 TONS LISTED IN COMBINED 1969-1976 DATABASE

VESSEL	AMOUNT(Long tons)	CAUSE
SEA STAR	120,000	COL
JACOB MAERSK	88,000	EXP
METULA	57,000	GRD
ENNERDALE	49,000	GRD
BRITISH AMBASSADOR	44,000	BKD
WAFRA	40,000	STF
NAPIER	35,000	GRD
TRADER	34,000	CAP
GOLDEN DRAKE	32,000	EXP
CHRYSSI	31,000	STF
PACOCEAN	30,000	STF
KEO	30,000	STF
CRETAN STAR	28,000	STF
GIUSEPPE G.	21,000	CAP
ALBACRUZ	20,000	STF
GOLAR PATRICIA	20,000	EXP
THEODOROS V.	20,000	STF
NANYANG	20,000	
PRINCESS KAUANI	20,000	GRD

KNOWN SPILLS OVER 20,000 TONS WITHIN PERIOD NOT IN FILE

URQUIOLA	88,000	
OTHELLO-KATELYSIA	60,000	COL
TEXACO OKLAHOMA	30,000	
ARGO MERCHANT	27,000	GRD
GRAND ZENITH	27,000	STF
SPARTAN LADY*	20,000	STF

*Listed at 2,857 tons in Coast Guard file.

Primary source for spills not in the Coast Guard file is R. Golob, Center for Short-Lived Phenomena, Cambridge, Mass.

	Collision	Grounding
Sample Mean	7878 tons	6855 tons
T-test Statistic	5366 tons	1911 tons
95% Confidence Interval	(-2856, 18610)	(3033, 10677)

That is, under these assumptions, all one can say is that there is a 95% chance that the mean of the process generating collision spills is between -2854 tons and 18,610 tons. Not a very strong statement. The confidence interval for the grounding spills over 1000 tons is somewhat narrower for we had more such spills with less variance.

These results are for the mean of the process. The mean of a process is a much better behaved parameter than an individual sample. If we were to take a quasi-Bayesian viewpoint and generate the density of the next spill, or even the next N spills, from either of these causes, the densities so obtained would have very large variances indeed. This is not the fault of the methodology but reflects the fundamental uncertainty inherent in dealing with a random variable which has an extremely wide range and a relatively small sample. Actually, the patently false assumption of a Normal process (note the possibly negative mean) tends to understate this uncertainty. Stewart and Kennedy have shown that spillage does not obey a Normal process, that it has a much fatter right tail than a Normal, and that at least certain categories of spill volumes are reasonably well-described by Log-Normal or Inverted Gamma processes. (Stewart 78).

Statistical jargon aside, it's clear what's happening. Take the collision category. The total amount reported spilled by collisions in the entire file is 193,254 tons. 120,300 tons of this amount or 62% was spilled in one spill, the Sea Star collision. Examining Table 1.3, one notes that this spill is the only collision in the top 14 and, in fact, the next largest collision in the file is 7,500 tons. This very definitely does not mean that one should discard the Sea Star spill as being 'non-representative'. In terms of total volume, one would do better to throw away all the other collisions. What it does mean is that the total volumes in any cause category can be completely dominated by a single event. If the recent collision between the two 330,000 ton tankers, Venoil and Venpet, had resulted in the loss of the fully loaded Venpet, then the total amount spilled by collisions would have more than doubled. In short, one would have to be completely foolhardy to predict, with any degree of accuracy, how much oil is going to be spilled from any particular cause in the next year or the next five years or even the next 20 years. Similarly, any particular spill prevention policy whose success depends on a specific prediction about how much oil is going to be spilled by cause, will with high probability be ineffective. Rather, given our uncertainty, what we should look for are policies which will be effective against a range of possible outcomes--policies which will be about as effective if it turns out that 30% of all oil is spilled in collisions as if it turns out that 70% of all oil is spilled in collisions.

1.2 Spill Incidence: The State of the Art with Respect to the Analysis of Spill Numbers

In the oil spill game, spill numbers are much more stable than spill volumes. Consider Table 1.4 which compares Coast Guard American spill reports (PIRS) for 1971 and 1972. The first category is for all oil spills; the second category involves only those coastal and offshore spills emanating from oil industry-related activities. Inland spills are not included in this category, nor are oil spills which occur after the oil is in the hands of the final users; for example, spills from a utility's fuel tank. The final three categories break the non-inland, oil industry spills down by offshore tanker, terminal, offshore production facilities (platforms and pipelines), and onshore pipelines. The offshore tanker spills include only those tanker spills which did not occur in harbors or near terminals. Since the Coast Guard's reporting authority extends only out to the three-mile limit with respect to foreign flag vessels, this category may not be indicative.

For now, the important thing to notice about this table is that while total oil production and consumption in the United States in 1972 was not much different from that in 1971, the volumes spilled, both total and in most of the categories, are quite different. This is because these totals are completely dominated by a few very large spills. In 1971, there was only one spill over 1 million gallons (2 million gallons) reported; in 1972, there were three such spills totalling 15 million gallons. Given the dependence of the total amount spilled on a very few, very large spills, there is little reason to expect the volumes to agree. Our sample of very large spills is simply too small

TABLE 1.4
COMPARISON OF 1971 AND 1972 USCG DATA (VOLUME IN GALLONS)

		1971	1972
All spills	Number	7,461	8,287
	Volume	8,611,173	21,742,320
Non-inland, petroleum industry spills	Number	4,023	4,078
	Volume	6,322,459	5,934,478
Terminal	Number	1,475	1,632
	Volume	5,283,915	2,296,828
Ships-offshore	Number	22	32
	Volume	16,315	2,168,811
Offshore production facilities	Number	2,452	2,252
	Volume	655,117	239,515
Onshore pipeline	Number	74	162
	Volume	367,112	1,229,324

to expect any statistical regularity with respect to these particular spills.

On the other hand, the number of spills, both total and by major category, exhibits a definite pattern. With respect to incidence as opposed to amount, each individual spill counts equally and the sample of all spills is large enough so that if the processes generating spillage in 1971 and 1972 were similar, one would be quite surprised if the number of spills did not exhibit statistical regularity.

Table 1.5 breaks the 1971 and 1972 non-inland, oil industry-related spills down by region. Once again, there is much better agreement with respect to number of spills than there is to spill volume.

Table 1.6 shows a more detailed breakdown of the non-inland, oil industry-related Coast Guard data by spill category. The terminal spills follow the same basic pattern--definite correspondence between number, little correspondence in total volumes. However, the offshore facilities' spills when broken down into pipeline and production platform offer a glaring exception. This anomaly was presented to the relevant Coast Guard personnel, who commented that it was often a purely judgmental decision upon the part of the data coder whether to place a spill in the offshore production category or the offshore pipeline category, and that due to personnel changes it was quite possible that coding habits had changed. In view of the other data presented and in view of the agreement between the sum of the offshore pipeline and offshore production spills, we believe it is reasonable to assume that this was the case.

Table 1.7 compares the size distribution of non-inland, oil industry-related spill volumes for 1971 and 1972. Once again a definite pattern is demonstrated. It appears quite reasonable to assume that the same basic process is generating spill sizes in 1971 as in 1972. Note, however, that because there are so few spills in the very large categories, it is not particularly surprising that, for example, there were three spills over 1 million gallons in 1972 as opposed to one in 1971.

In summary, the characteristics of oil spillage are such that dealing with total volume spilled directly leads to very little insight. Using classical techniques, confidence intervals are sometimes orders of magnitude larger than the estimator and only very weak statements can be

TABLE 1.5
COMPARISON OF REGIONAL STATISTICS (VOLUME IN GALLONS)

	1971	1972
New England		
Number	311	365
Volume	852,763	397,731
Mid-Atlantic		
Number	894	1,034
Volume	465,087	9,431,839
Gulf		
Number	3,927	3,632
Volume	1,426,186	6,444,977
Southern California		
Number	552	507
Volume	301,362	43,141

TABLE 1.6
BREAKDOWN OF TERMINAL AND OFFSHORE PRODUCTION SPILLS (VOLUME IN GALLONS)

		1971	1972
Breakdown of terminal spills			
Tanker and barge	Number	917	912
	Volume	2,586,993	816,396
Refinery	Number	167	172
	Volume	2,197,417	34,624
Bulk storage and transfer	Number	391	548
	Volume	499,506	1,494,808
Breakdown of offshore production spills			
Offshore tower	Number	1,087	2,211
	Volume	117,661	231,738
Offshore pipelines within 3-mile limit	Number	1,204	36
	Volume	515,913	7,326
Offshore pipelines outside 3-mile limit	Number	156	5
	Volume	14,540	451

TABLE 1.7
VOLUME DISTRIBUTION, ALL SPILLS (GALLONS)

Volume	1971	1972
0-1	2,497	2,387
1-10	1,526	2,020
10-100	2,146	2,509
100-1,000	1,000	1,068
1K-10K	222	232
10K-100K	53	54
100K-1M	16	14
1M-10M	1	3
>10M	0	0
	7,461	8,287

made. However, both the number of spills and the spill size distributions exhibit definite regularity given the sample sizes available. This strongly suggests that any attempt by the Coast Guard to relate spillage to such system variables as traffic density or port calls or tanker route volume should focus on number of spills rather than volume spilled. If the Coast Guard attempts to relate spilled volume to such parameters using historical data, they will almost certainly come up with extremely weak conclusions even if such dependencies do exist. A statistical analysis based on spill numbers is much more likely to reveal such a dependency or its lack.

CHAPTER 2. THE NATURE OF COLLISIONS

2.1 Introduction

If we are to effectively address the question of the relationship between oil pollution and offshore vessel control, it is essential that we obtain a causal understanding of collisions and groundings. A great deal can be learned from statistical summaries, but real understanding can come only from in-depth analysis of actual collisions and groundings. In so doing, since we are dealing with a relatively rare event, it is only prudent to use as wide a database as possible. Otherwise our sample may be too small to reveal even the most important causal patterns.

In this chapter, we will review what is known about vessel collisions, all sorts of collisions whether tanker or not, whether in American waters or not, and whether under pilotage or not. The only limitation which we will place on our summary is that the collision must involve a sea-going vessel in open water. In the following chapter, we will consider groundings.

2.2 The Importance of Visibility

The single most complete and useful post-mortem of vessel collisions of which we are aware is that of Wheatley (1972). Wheatley studied 174 collisions occurring in the Straits of Dover and approaches in the period 1958 to 1971. The single most striking finding of his study was the importance of visibility. Eighty-two percent of all the collisions in his sample occurred in periods of poor visibility (less than 4000 meters). Two-thirds of the collisions occurred in thick fog (visibility less than 200 meters). In contrast, the average percentage incidence of poor visibility in the area was 6% and the average time of thick fog about 1%. To put it another way, collision incidence per hour of thick fog was 440 times that per hour of good visibility. Only 14% of the collisions occurred under clear conditions and 80% of these collisions occurred at night. Only 3% of the collisions in Wheatley's sample occurred during the day in clear conditions.

In a much more comprehensive but considerably less detailed effort, Cockroft studied a worldwide sample of collisions which occurred over the period 1958 through 1974. Data was taken from casualty returns with the restriction that at least one vessel had to be over 100 grt. The resulting sample contains 2000 collisions for the 17 year period. Based on his survey, Cockroft estimated that over 70% of the collisions occurred in visibilities of less than one mile (Cockroft, 1976).

In short, visibility is by far the single most important factor influencing collision incidence.

2.3 Encounter Geometry and Range at Initial Detection

Not surprisingly, most of the collisions in Wheatley's sample involved vessels approaching approximately end-on. Before traffic separation in the Channel, 73% of the Wheatley collisions were described as vessels meeting, 6% were described as crossing, 6% as overtaking, and in 15% of these collisions, the form of the encounter could not be determined. After institution of traffic separation, the percentage of end-on collisions dropped to 62%. The U.S. National Transportation Safety Board (1969) in a study of 96 collisions found that all of the cases which occurred in open water developed from meeting end-on or nearly so (NTSB, 1969). In Cockroft's worldwide sample of 2000 collisions, encounter data were available in 70% of the cases. In 72% of these collisions, the initial approach was end-on or nearly so, 9% were listed as crossing, 9% as overtaking, and 10% were listed as doubtful.

A still more interesting finding of Wheatley's is that the colliding ships were usually aware of each other's presence well before the collision. Separation distance at first observation was determinable from the reports for 62% of his collisions. When first observation was by radar, the separation averaged 9000 meters. When first observation was visual (29 of the 66 reporting), the separation averaged 900 meters. Time to collision from first observation was determinable in 40 cases. For radar initiated observations, the average time was 17 minutes; for visual observations 4 minutes. The average initial speed for ships using radar was reported at 9 knots and those for visual control 4 knots.

M.I.T. among others has performed extensive analyses of vessel maneuverability. (Patell, 1974). This work, based on a combination of model tests, full scale trials, and computer modeling clearly indicates that the above cited radar detection ranges are much larger than the minimum required to avoid collision in open waters for even the largest tankers. For example, our results indicate that the minimum detection range for two 250,000 ton tankers meeting end-on at ten knots each is less than 2000 meters. Even if both vessels postpone their maneuver until they are within 2000 meters of each other, they can still avoid a collision if they react properly.

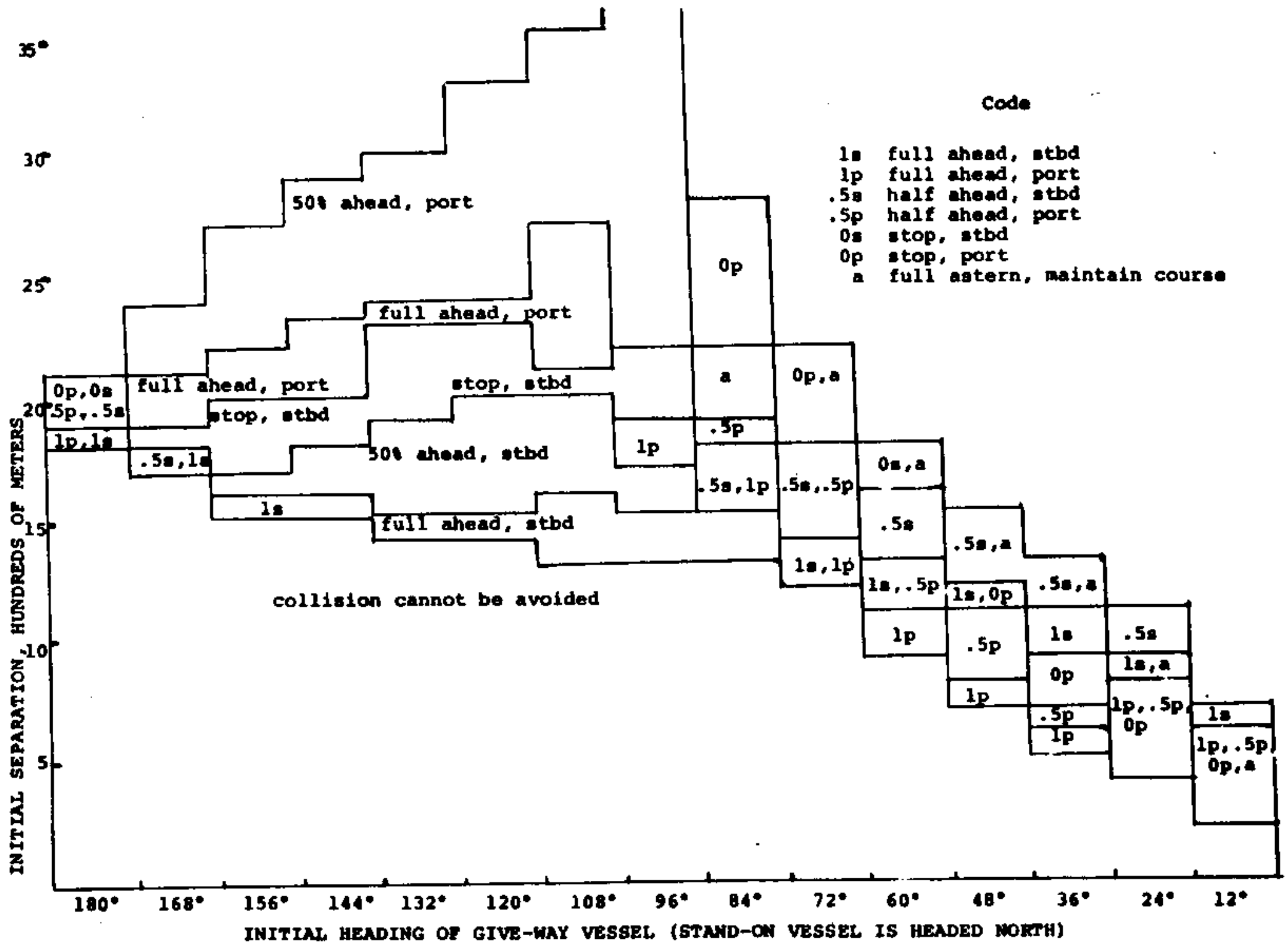
Figure 2.3.1 taken from the M.I.T. report displays some of these results. This figure shows minimum separation distance at initiation of maneuver as a function of approach angle and choice of maneuver for a situation in which one tanker is moving at 10 knots and does not alter course or speed (the stand-on vessel) while the other, the give-way vessel, is also initially at ten knots. The ship used in this exercise was the 193,000 ton tanker Esso Bernicia for which extensive maneuvering trial results are available.

The minimum separations ranged from 1800 meters (bow-on) to 0 meters (overtaking). In general, the minimum separations were achieved by non-book maneuvers: throttle full ahead and hard turn to starboard when initial relative bearings are less than 50 degrees (bow-on to slightly overtaking) and throttle full ahead and hard turn to port when relative bearings were greater than 50 degrees. The advantage of the unusual turn to port over the more obvious turn to starboard under the privileged vessel's stern when "overtaking" is a product of stern swing. Turning into the privileged vessel rather than away prevents the stern from swinging into the privileged vessel. The minimum separation in these overtaking cases is quite small, one or two ship lengths.

Note the increase in minimum separation for the crossing cases with decrease in throttle. This is a product of the fact that large ships, especially large tankers, will not only turn much more sharply but will also slow down more quickly if the throttle is advanced rather than retarded during the maneuver. In general, crash astern appears to be an extremely ineffective means of avoiding collisions.

This result is illustrated by Figures 2.3.2, 2.3.3, and 2.3.4 which display track, speed, and heading for the Esso Bernicia under eight hard-over maneuvers with a range

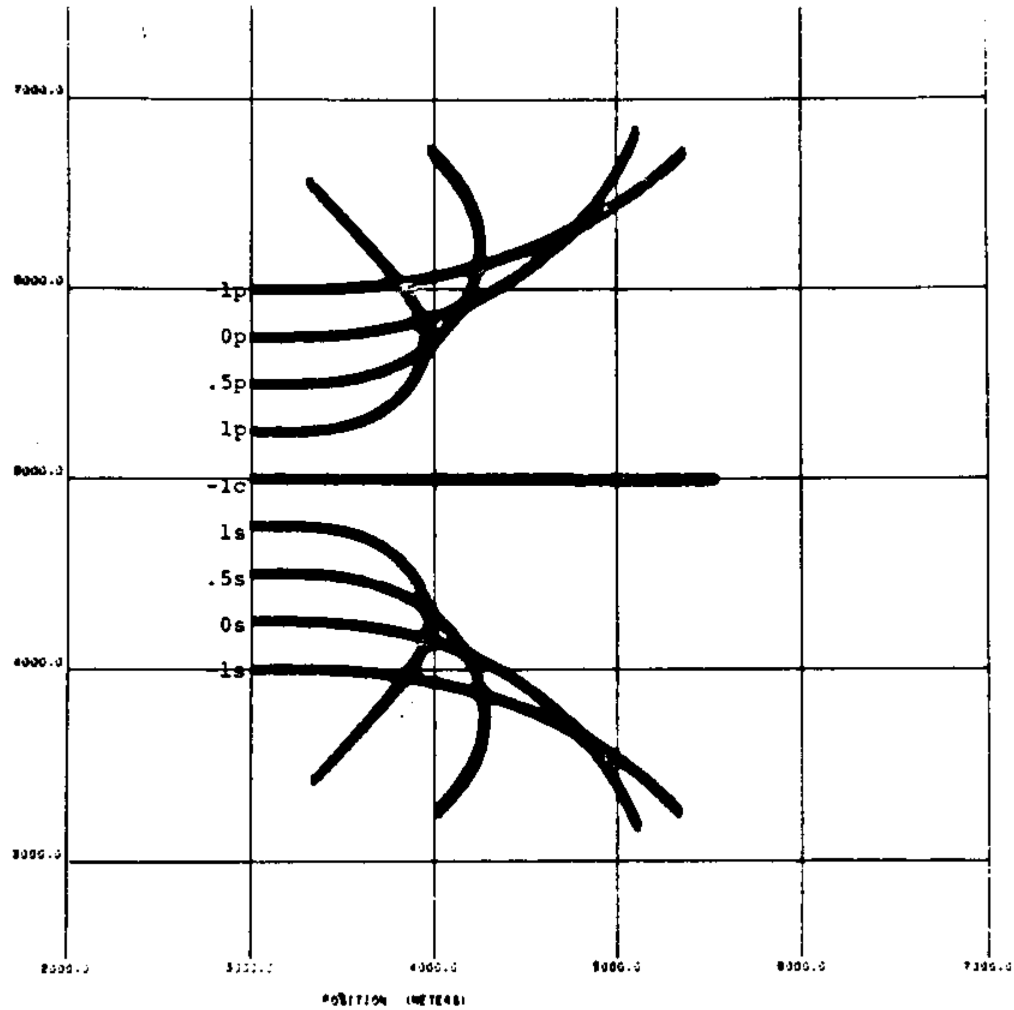
TABLE 2.3.1 Minimum Separation Distances as a Function of Maneuver, Initial Speed Both Tankers 10 Knots, One Ship Maneuvers



SOURCE: Patell, J. Norrbin, N., Devanney, J., and Szasz, N., Ibid

FIGURE 2.3.2

Track as a Function of Maneuver, "Esso Bernicia" Initially at 10 Knots
Simulation Ended After 10 Minutes

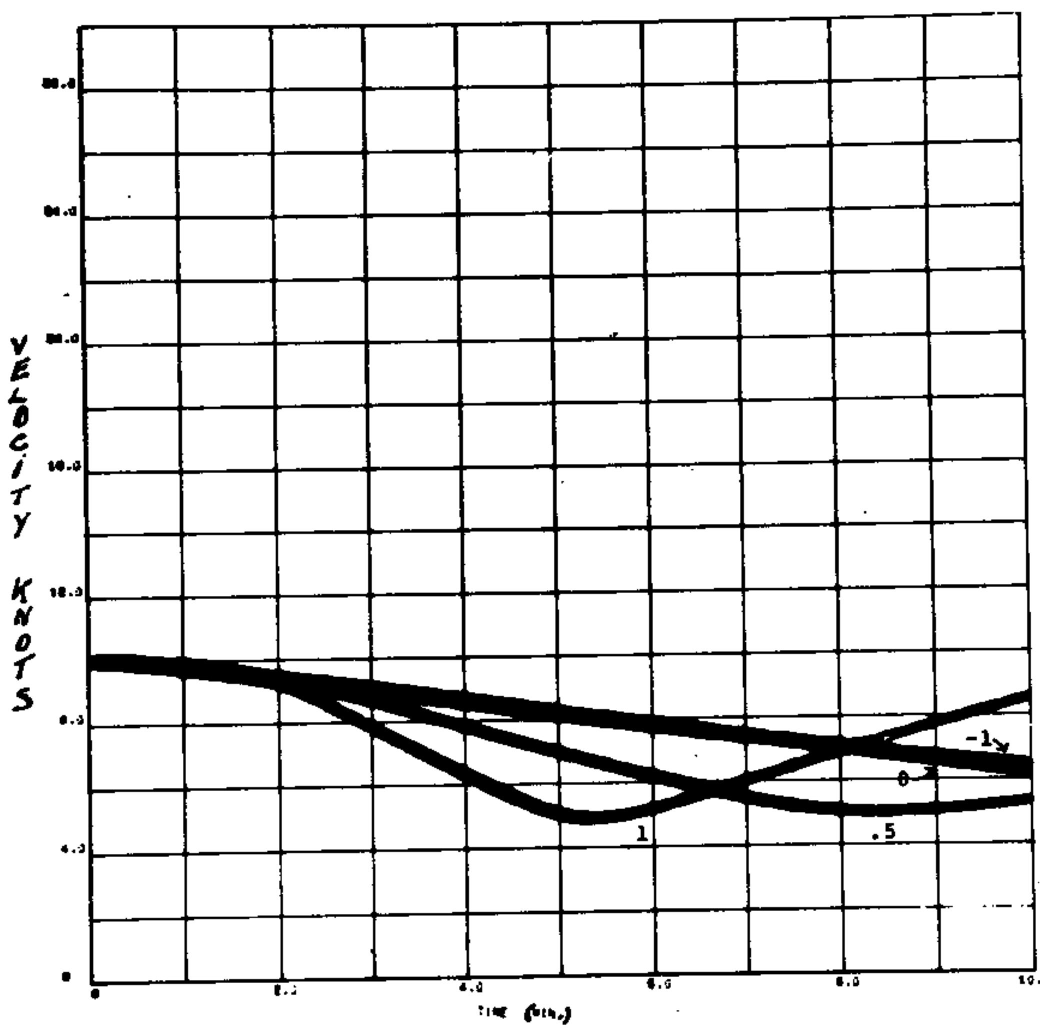


Throttle Code		**Helm Code**	
1	full ahead	p	helm hard to port
.5	half ahead	s	helm hard to stbd
0	stop	c	maintain course
-1	full astern		

Source: Patell et al, ibid

FIGURE 2.3.3

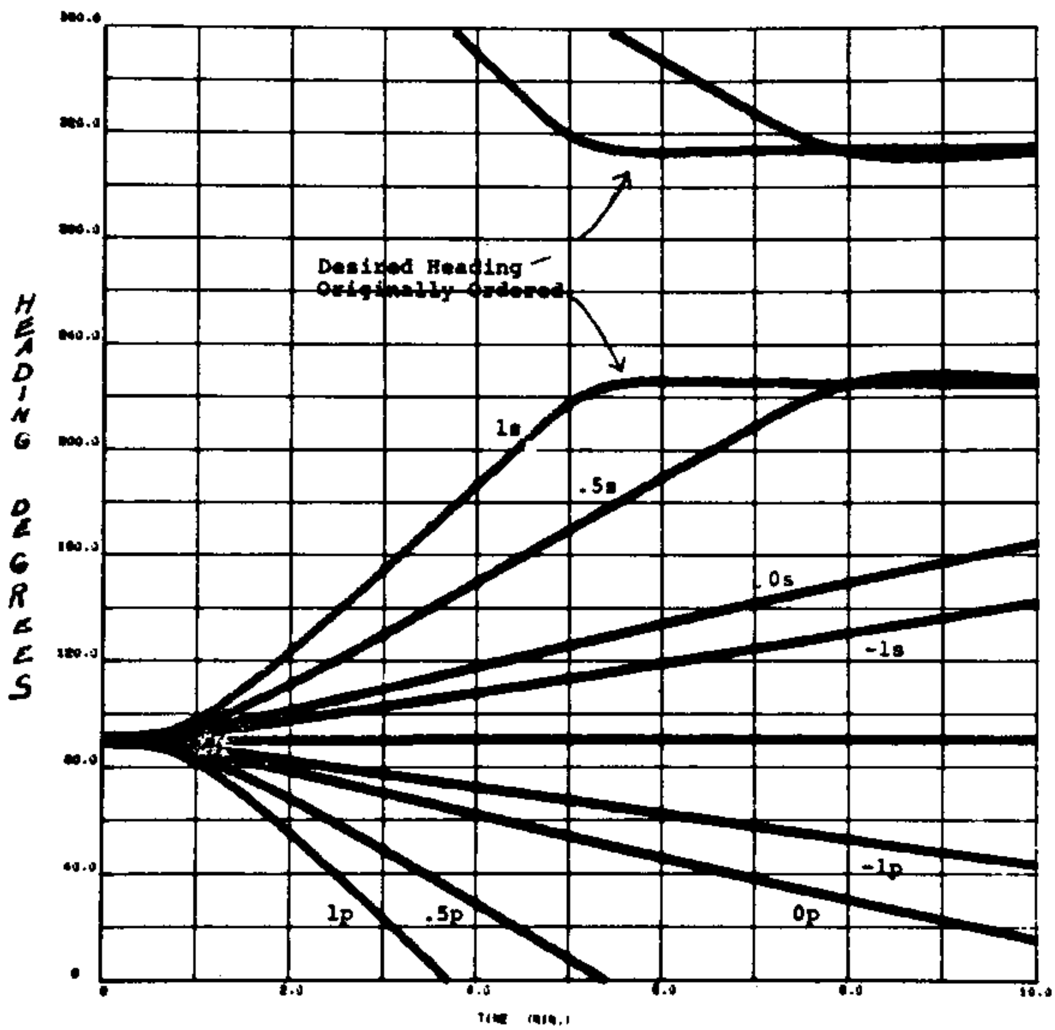
Speed Reduction as a Function of Maneuvers in Fig. 2.3.2



Source: Patell et al, ibid

FIGURE 2.3.4

Heading as a Function of Maneuvers in Fig. 2.3.2



Source: Patell et al, ibid

of changes in throttle. Note that full-ahead throttle resulted in the sharpest turn and the sharpest drop in speed.

The fact that slowing down the engines is a completely ineffective maneuver once a ship is in trouble is hardly an original observation. Tani(1968) gives a rather detailed comparison of head reach under hard-over and hard-astern maneuvers and cites references going back to 1875 on the undesirable effects of going astern. Webster (1974) derived basically the same results as M.I.T. using an independently developed computer model. Crane(1974) displayed a series of full-scale trials on 191,000 ton tankers in which head reach under crash astern was four times that under hard over at service power. Interestingly enough, the side reach for these single-screw ships under the full astern order was approximately the same as that under hard-over.

These basic hydrodynamic facts seem to have had no effect on the Rules of the Road or actual operator responses in collision situations (see next section). Discussions with operators indicate that, while they are quite aware of the "loss in rudder control" associated with sharp throttle decrease, no one wants to go into court in a collision which occurred after he had called for full ahead. The operators claim that court policies effectively rule out this option. The recent revision of the Rules of the Road is no improvement in this regard. The new Rule 8(e) states specifically, "If necessary to avoid collision, a vessel shall slacken her speed or take all way off by stopping or reversing the means of propulsion." No mention is made of advancing the throttle as a collision avoidance mechanism. Clearly, we might do well to rethink our legal attitude toward throttle changes in encounter situations.

However, for present purposes, the basic point remains. In the great bulk of all the collisions in Wheatley's samples, both ships were aware of each other's presence in plenty of time to avoid the collision by taking appropiate action. The vessel collision problem, unlike the air traffic problem, is not one of insufficient response time.

2.4 Actual Maneuvers in Collision Situations

So far we have learned that the vessel collision problem is intimately tied to visibility but, thanks to radar, it is not a detection problem. In attempting to unravel this apparent paradox, it is worthwhile examining what is known about the control changes actually made by ships in collision situations. One hundred and twenty-four ships in Wheatley's sample of collisions reported throttle movement. Twenty-six of these reported no reduction in speed; 21 reported speed reductions up to 50% of initial speed; 23, speed reductions of over 50%; and 47, speed reductions by an unknown amount. In one case, the ship was moving astern, and six reports indicated speed increases by unknown amounts. Most of the throttle adjustments took place in the final moments before collision. Seventy-nine of the reports indicated no change in throttle until the ships were in extremis. The typical pattern, then, seems to be one of no change in throttle until the last moment and then a very sharp reduction.

Clearly, the vessel operators are either not aware of the counterproductive effect of reducing throttle, or feel obligated by legal principles to reduce throttle, even if it means the ships are less controllable and are going to slow down much more slowly. Commentators are sometimes just as bad. Kemp(1972), commenting on the Oregon Standard- Arizona Standard collision, noting that the Oregon Standard in extremis had called for hard left rudder and engines stopped, states, "The last-minute maneuvers were probably correct."

Helm maneuvers are even more interesting. In 47 of Wheatley's collisions, helm maneuvers could be determined. In 20 of these collisions, one ship turned to port, the other to starboard--the classic case of one ship's "reversing" the Rules of the Road, the other not. In five cases, one ship turned to port and the other made no helm maneuver. One can reasonably guess that the bulk of these cases involve one ship's "reversing" the Rules of the Road, to the other's surprise. In only 1 out of 47 collisions did both ships turn to port; in 3 cases, neither ship turned; and in 5 cases, both ships turned to starboard. In short, one can reasonably attribute at least 50% of the collisions to lack of coordination of the maneuvers. In contrast, in only about 13% of the collisions could the maneuver be termed coordinated.

In only 1 case out of the 174 studied by Wheatley was the collision blamed on the two ships maneuvering to avoid a third vessel, despite the congestion in the Channel, the cross traffic, and the high degree of motivation on the part of the colliding parties to place the blame elsewhere.

Finally, Wheatley, in referring to all 174 collisions, adds almost as an afterthought, "There is no report of radio communications being used as an aid to navigation." The emphasis is definitely ours. Wheatley, being familiar with vessel operating practice in international waters, would have been very surprised to find otherwise. This need not be the case. Vessels on inland rivers in the U.S. faced with extremely difficult encounter situations involving blind bends and very limited channels, are in constant communication, and decisions on which side to pass are agreed upon on an ad hoc basis given the river conditions and present characteristics of the tows involved. Vessels on the Great Lakes also have a long history of constant communication. The National Transportation Safety Board(1969) comments, "The value of recommended track lines and bridge-to-bridge radiotelephone communications has been proven by the excellent safety record on the Great Lakes." The Bridge-to-Bridge Communication Act, passed in 1973, requires that all vessels entering American ports have a bridge-to-bridge capability and monitor it. But there is little evidence that bridge-to-bridge is being used outside pilotage waters as a means of coordinating maneuvers in encounter situations.

2.5 The Modal Collision

There is, then, a clear pattern to the foregoing data. Well over half of all collisions involve two ships in an end-on or nearly end-on encounter, proceeding at fairly substantial speeds in lousy visibility, aware of each other's presence through radar, and maneuvering into a collision, often by one ship's "reversing" the Rules of the Road and the other not, and at the last moment throwing the throttle astern. This pattern occurs so often we will call it the most likely or modal collision.

A classic case of the modal collision is the Andrea Doria-Stockholm. Both ships were proceeding at about 20 knots in patchy fog about midnight. Both ships were aware of each other at 10 miles separation almost end-on. The

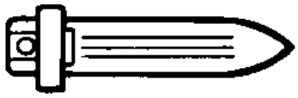
Doria altered to port, the Stockholm to starboard. The relative bearing was always opening throughout the encounter. Both ships proceeded on, the Doria assuming that the other would pass to starboard; the Stockholm assuming the other would pass to port. The relative bearing was still opening when the ships collided.

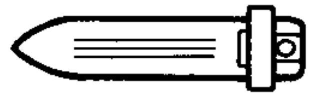
The modal collision occurs over and over again in casualty reports. In an informal review of the literature of the last five years, we have come across 15 collision reports in which it was possible to determine the particulars of the encounter. At least ten of these could be described as a modal collision--poor visibility, end-on or nearly end-on encounter, radar detection in time, and one ship's opting for a port to port passing while the other chose to pass starboard to starboard, "reversing" the Rules of the Road. Table 2.5.1 summarizes these casualties. The Sea Star collision is particulary interesting from an oil pollution standpoint. On the night of December 19, 1971, the Sea Star and the Horta Barbossa were proceeding on nearly complementary courses in the Gulf of Oman. Their courses were sufficiently displaced so that if both had maintained course and speed, they would have passed starboard to starboard with a Closest Point of Approach (CPA) of about one mile. The Sea Star apparently regarded this separation as insufficient and, at a range of about four miles, went starboard to effect a port to port passing. The Horta Barbossa maintained course and rammed the Sea Star amidships. In the ensuing fire, the fully loaded Sea Star sank with 120,300 tons of cargo and bunkers--the largest oil spill on record more than 10,000 tons larger than the Torrey Canyon. Another modal collision.

This pattern of two ships meeting nearly end-on in restricted visibility and maneuvering into a collision is so commonplace that at least one observer calls it the "dance of death." The cause of the modal collision is not difficult to locate. In a very insightful exercise, Kemp (1977) asked a sample of ten randomly selected people what they would do if they were the captains of two vessels meeting perfectly end-on. As might be expected, their replies were random, with roughly half the subjects going left and half going right. When Kemp repeated the question with a sample of ten experienced mariners, all ten turned to starboard to effect the port to port passing called for in the Rules of the Road. Then Kemp repeated the process but this time with the ships displaced as shown below.

TABLE 2.5.1
COLLISION REPORTS EXTRACTED FROM RECENT PUBLISHED LITERATURE

No.	Ships	Modal Collision	Weather	Date (d/m/yr)	Type of Encounter	Radar Detection in Time	Communication	Maneuver
1.	Crystal Jewel/ British Aviator	Yes	Fog	23/9/61	Meeting	Yes	No	One port/ One stbd
2.	Brott/ Nassau	No	Gale, snow	3/2/61	Overtaking	Yes	No	One slowed/ one did not
3.	Andrea Doria/ Stockholm	Yes	Fog	25/7/56	Meeting	Yes	No	One port/ one stbd
4.	Santa Rosa/ Valchem	Yes	Fog	26/3/54	Meeting	Yes	No	One port/ one stbd
5.	Arizona Standard/ Oregon Standard	No	Fog	18/1/71	Meeting	Yes	Yes	No maneuver until too late
6.	Sitala/ Niceto de Larringea	Yes	Fog	23/9/61	Meeting	Yes	No	One stbd/ one straight
7.	Grepa/ Verona	Yes[c]	Fog	/ /65	Meeting	Yes	No	One stbd/ one straight
8.	Bergechief/ Burgan	Yes	Fog	24/5/55	Meeting	Yes	No	One stbd/ one straight
9.	A-anonimous	No	Fog	23/10/62	Overtaking	?	No	One slowed/ one did not
10.	B-anonimous	Yes	Fog	29/3/65	Meeting	Yes	No	One stbd/ one straight
11.	Long Beach/ David Salmon	No	Fog	16/12/74	Meeting	Yes	Yes	No maneuver until too late
12.	Anneliese/ Arietta Livanos	Yes	Fog		Meeting	Yes	No	One stbd/ one port
13.	Hagen/ Boulgaria	Yes	Fog		Meeting	Yes	No	One stbd/ one straight
14.	Cardo/ Toni	Yes			Meeting		No	One stbd/ one port
15.	Sea Star/ Horta Barbosa	Yes	Night	19/12/72	Meeting		No	One stbd/ one straight
16.	Pacific Glory/ Allegro	No		/10/70	Overtaking	Yes	No	No maneuver until too late
17.	A and B in Straits of Florida	Yes	Rain squalls		Meeting	Yes	No	





The ten subjects with no knowledge of the Rules of the Road all maintained course, undoubtedly perplexed as to why they were asked to consider such an obvious problem. The ten master mariners, however, were in a quandary. Should they consider the situation to be a dangerous crossing, invoke Rule 8(e), and turn to starboard to effect a port to port crossing even though it means crossing the other ship's bow and decreasing the closest point of approach (CPA)? Or should they consider the crossing situation does not exist and maintain course or perhaps go to port to increase the CPA further? In Kemp's experiment, when the two tracks were displaced by a mile, half did one, half did the other. The dance of death was being played.

The implication is obvious. The Rules of the Road do not resolve the ambiguity associated with end-on encounters. They only displace it to starboard slightly. In situations with good visibility, the residual uncertainty does not appear to be too dangerous. Several groups, principally in England and Japan, have attempted to apply random encounter theory (molecular analogies) to vessel collisions. When one asks, what is the probability that collisions would occur if ships made no attempt at avoiding each other, and then compares the results with actual collision incidence for regions as disparate as the Straits of Dover and the Inland Sea, one finds that in clear weather, there are very roughly one ten-thousandth as many actual collisions as predicted by random encounter theory. In other words, in good visibility, 9,999 out of 10,000 potential collisions are avoided. However, if one repeats the same analysis for collisions during low visibility, fragmentary evidence indicates that the ratio of actual to potential collisions is about one tenth--only about nine out of ten potential collisions are avoided. A one thousand fold difference in avoidance efficiency is a number well worth contemplating.

This striking difference is almost certainly due to:

a) acceptance of <u>lower</u> CPA's during good visibility, hence less need to maneuver,

b) ability to determine the other ship's intentions almost instantly by visual observations.

Baratt (1976) has studied radar plots of collision avoidance maneuvers in the Straits of Dover, reaching some very interesting and, at first glance, surprising conclusions. Firstly, he found that the incidence of a collision avoidance maneuver was over twice as high during periods when visibility was less than a kilometer than when visibility was greater than a kilometer, despite the fact that traffic density was slightly lower in the low visibility periods. In low visibility, mariners are unwilling to accept CPA's they regard with equanimity in high visibility. Hence, many more maneuvers were initiated. Further, Baratt found that not only were maneuvers twice as frequent during low visibility, they were also initiated at greater range and they were more violent. Mariners, contrary to the impression one would obtain from some defenders of the Rules of the Road, are quite cognizant of the dangers of low visibility and feel the need to do something. Unfortunately, the Rules' prescription of early substantial maneuvers has not prevented the low visibility collision incidence from being a thousand times that of high visibility. The Rules also advocate slow speed in low visibility. The fact is that vessels do not slow down very much in bad visibility, if at all. In May 1972, the NPL did a detailed traffic survey in the Dover Strait. They plotted some 700 ships over 43.5 hours. There was no change in speed with visibility. Mariners are obviously using radar to increase speed in low visibility rather than to decrease collisions. This may be an economically well-founded decision. Proceeding half-speed in all periods of low visibility in the Dover Straits and approaches by all ships would require the fleet to be expanded by at least five percent. Instead, they chose to sacrifice four ships per year. Clearly, the world came out ahead by this choice. The challenge is not to minimize collisions. The challenge is to minimize the sum of the cost of collisions and the cost of preventing collisions--a fact often overlooked by some proponents of massive hardware alternatives. Most importantly, Baratt found that non-standard maneuvers (turning to port) were over four times as frequent during periods of low visibility. Table 2.5.2 summarizes some of Baratt's findings.

Table 2.5.2
Maneuver Incidence

Visibility	Standard	Non-Standard
> 1 km	.21/hr	.08/hr
< 1 km	.28/hr	.33/hr

Mariners clearly feel that during periods of low visibility, a starboard to starboard passing requires a higher CPA than in high visibility. Hence, if they are displaced to starboard, the tendency to alter to port in low visibility when they would stand on in high visibiltiy. When one is displaced well to starboard, the alternative of going starboard and crossing the other ship's bow is obviously not regarded with great favor, and with good reason, as the Sea Star found out. As the statistics reveal, many skippers are making port alterations in bad visibility, in which case the starboard decision can easily lead to disaster.

2.5.A THE TSC SAMPLE OF AMERICAN COLLISIONS

After the above section was written, another sample of collisions became available. This sample was generated by TSC from the Coast Guard Casualty Reports for the period 1972 through 1976. The screening logic used in extracting this sample is described in TSC's report. (TSC 1978). Basically, the sample purports to be all 'offshore' collisions in American waters involving ships greater than 1600 Gross Registered Tons. The sample contains 16 casualties, two of which are rammings of anchored vessels. Six of the 14 collisions were definitely of the modal variety (African Meteor - Golar Tryg, C. G. Ingram - T. St. Philip, Mobil 35 - Captain Sam, Oriental Mariner - Wayway, and Amoco Louisiana - Adabelle Lykes). One casualty, the Vantage Horizon - Daeyang Prosperity probably was a modal collision. In all these cases, one ship attempted a port to port passage, the other a starboard to starboard. At least four of the casualties were absolutely classical examples of the dance of death -- end on meeting in fog, slightly displaced to starboard, detection in plenty of time, one ship went port and the other went starboard. Despite this, nowhere in the Coast Guard commentary is there any allusion to the ambiguity of the Rules of the Road when one encounters an approaching vessel on the starboard bow. Instead there is an almost standard refrain pointing to the "failure of both vessels to make substantial course changes" (even when large course changes had been made) and "the failure to alter to starboard" (even when this meant crossing the other ship's bow and reducing CPA). Coast Guard officers are seamen first and foremost, and seamen are not trained to question the Rules of the Road.

2.6 Some Implications for Collision Reduction Systems

In fact, as we have seen, the vessels are making substantial course modifications in bad visibility. Unfortunately, all this extra maneuvering in low visibility has not had very good results, as we have seen. The problem is really obvious: it's not paucity of maneuvers, it's lack of coordination between the maneuvers. This simple observation has some very important implications for the various alternatives open to us toward reducing collisions. The major suggestions are:

1) changes to the Rules of the Road,
2) automated plotting of other ship's course and speed (usually termed Collison Avoidance Systems),
3) traffic separation,
4) bridge-to-bridge communication
    a) voice
    b) transponder,
5) third party control.

The dangerous ambiguity in the Rules of the Road has been recognized since the inception of the steamship. Listen to a Captain Drew commenting in 1860.

> "Here is a necessity for agreement between both parties as to any danger, utterly unmindful as to differences of opinion: one may think that if he continues his course there is no danger, the other to be on the safe side ports his helm [alters to starboard] and causes the collision, <u>and collision then becomes justification for concluding that there was danger</u>." (Kemp, 1976).

The emphasis is ours and it's quite unnecessary. It's hard to see how the ambiguity inherent in the Rules could be put more succinctly. Present efforts at modifying the Rules appear to be aimed at increasing this ambiguity rather than the opposite. For example, increasing the freedom of the stand-on vessel to alter will extend the same problem to crossing situations, not to mention the fact, also known at least since the 1850's, that in certain crossing situations both ships altering to starboard can lead to a collision.

A real attack on the problem would go in just the opposite direction. One way would be by specifying a starboard to starboard CPA below which both ships must go starboard and above which they must not. There would still be collisions caused by errors in estimating the CPA but at least the captains would have some definite guidelines to operate by. The uncertainty as to the other ship's maneuver would certainly be less than it is now.

Any set of Rules of the Road which has the twin aims of avoiding collisions and avoiding unnecessary maneuvers will generate an area of uncertainty. It need not be as large as it is presently. But non-communicating Rules of the Road cannot decrease ambiguity to zero without requiring clearly extraneous and expensive maneuvers. This fact plus the political difficulties in effecting any change to the Rules of the Road has led many to seek other solutions.

Currently, one of the most popular such panaceas is computerized plotting of other ship's course. This alternative involves a small, special purpose computer attached to the ship's radar. The computer uses sequential contacts to determine a specified target's (or targets') course and speed, much as an officer would do by plotting but much more rapidly and presumably more accurately. (1) In some systems, the target's course and speed are then displayed digitally. Most systems have the capability to extrapolate target's present speed and heading in a straight line and display the projected position on the radar screen. Some systems plot ellipsoids of "danger areas" about the target's projected position, others allow trial maneuvers on the part of own-ship. In a very important respect, the device, usually known as a Collision Avoidance System (CAS), is little more than a mechanization of the navigator's old rule "watch out for ships with constant bearing." And as such, it suffers from the same basic assumption--the other ship does not maneuver. Yet as we have seen, roughly two-thirds of all collisions involve the ships' maneuvering into collision. The assumption that the other ship will not maneuver, when in many cases he is under legal injunction to maneuver, is not only false but also misleading in the worst sort of way. If such devices had been aboard the Stockholm and the Doria,

(1) Care must be taken to integrate out cyclic bearing errors due to ship's roll.

one can easily imagine that the only difference would have been that the bridges would have been even more surprised when the collision occurred. It is fashionable to speak of radar-assisted collisions. It may not be long before we have Collision Avoidance System-assisted collisions.

This is more than a little unfair to the Collision Avoidance System. A sharp watch officer closely watching the CAS would have noted that, while the device was continually predicting no collision up to the last moment, at the same time the CPA was continually dropping despite the fact that own ship was maneuvering "away" from the other and the CPA should have been increasing. More importantly, if he were watching a system which digitally displayed other ship's course and speed, he would have realized that other ship was turning in time to effect a countermeasure. Proper training, careful watchkeeping, and perhaps rejection of misleading projection capabilities could make the CAS a useful device.

Unfortunately, the CAS is sometimes offered as a device which will make up for poor training and intermittent watchkeeping. "The first unattended radar watch," trumpets one ad. In some implementations, the CAS comes complete with audio alarms, with the implication that unless you hear an alarm you have no problem. If the device is actually used in this fashion, it might be a good idea to hook the alarm up to the abandon ship signal. Basically, the CAS, especially the much-heralded projected position displays, begs the fundamental problem, which is not one of being alerted to danger, but of coordinating maneuvers. The CAS's only real contribution to the core communication problem is faster and usually more accurate plotting of other ship's course and speed and hence, at least potentially, faster determination of <u>changes</u> in other ship's course. This latter capability, latent in most current systems, does address the core issue. It could allow ships to communicate by course changes with possibly the same efficiency that they now use course changes to indicate their intentions in good visibility. Note it's the change in course and not the current course which is the key. Our own ideal CAS is one that digitally displays both target's course and speed and target's change in course over a suitable integration interval. We might even include a green and red light which would flash if the target is detected going starboard or port respectively. But we certainly would not include the dangerously misleading projected position displays.

Not only does much of the current CAS design ignore the basic communication problem but so does much of the supposedly objective evaluation of CAS's. A case in point is a rather extensive series of experiments done at the King's Point simulator(CAORF 1977). In these tests, six merchant marine officers were presented with ten different encounter situations. Clear visibility was assumed throughout. (1) In some cases, the officers were given only visual information, in some cases visual plus radar, and in some cases visual plus radar plus a CAS with rather extensive projected position display capabilities. Some of the scenarios were quite complex, involving as many as six vessels converging in the same area. Considerable effort was taken to make the simulation as realistic as possible, including four hour watches, and a digital display of New York Harbor and approaches, extended over several days. The subjects' work habits and decisions were carefully monitored.

The overall conclusion of the CAORF experiment was that CAS and especially projected position plotting, would make a substantial contribution to decreasing collisions. This was based primarily on the fact that the Closest Points of Approach with CAS were consistently higher than without. Throughout these sixty simulations involving several hundred ships, all ships other than own ship were assumed to maintain course and speed. One would be hard put to imagine a more misleading, a more off-the-mark sort of evaluation. The core of the problem has been assumed away. Not only is it totally unreasonable to expect all other ships to maintain course and speed in these tight encounters but, in many of the scenarios, at least some of the other ships would be in clear violation of the Rules of the Road had they done so. In the six-ship encounter, Scenario 10, at least four of the ships are clearly in a burdened position relative to one or more of the other ships.

To make matters still worse, the increased CPA's were obtained by:

a) more maneuvers,

b) more violent maneuvers,

c) a higher percentage of non-standard maneuvers (altering to port),

(1) Given the above statistics this was an unfortunate choice and perhaps a little unfair to the CAS.

than the maneuver which took place without the CAS. As we have already seen in comparing low visibility versus high visibility behavior, more maneuvering and larger (attempted) CPA's do not necessarily lead to fewer collisions. Rather they extend the dance of death to a greater range of situations. One can easily imagine the confusion and consternation aboard the other ships when, in approaching a difficult multi-ship encounter, they find one of the targets performing wild, non-standard turns early in the encounter. The basic problem in vessel collisions is uncertainty about the other vessel's intentions. One sure way to increase collision incidence is to increase this uncertainty. For those who understand the genesis of vessel collisions, the CAORF experiments can hardly be regarded as reassuring.

A final problem associated with the CAS is simply its cost. Operations Research Inc. (1975) reviewed 198 collisions in U.S. waters as to their preventability by CAS. This sample constitutes all collisions reported to the Coast Guard for the period 1970-1974 in which at least one ship was 10,000 G.R.T. or larger. CAS was assumed to be installed only on the ships over 10,000 G.R.T. O.R. Inc. found that in only 32% of the cases was lack of proper detection and evaluation of the collision threat by the larger ship a contributing factor to the collisions. This is consistent with our earlier findings that vessel collision is not basically a detection problem. Further, they found that in half the cases where proper detection was not made, radar capability was hampered (an obstructing land mass, bridge, rain return, sea return etc.) In another third of these cases, maneuvers precluded course projection and CPA prediction. O.R. Inc. concluded that only about ten percent of all U.S. collisions were preventable by CAS. It should be noted that O.R. Inc. did not give the CAS credit for earlier detection of other ship's maneuvers nor did it debit it for the collisions that didn't occur but might have occurred under too great a reliance on straight-line projections of other ship's course and speed. Nonetheless, the number is interesting. It is especially interesting in dollar terms. O.R. Inc. points out that the expected saving associated with preventing 10% of all U.S.A. collisions is about $800,000 per year. The cost of equipping all American ships over 10,000 GRT with CAS would be in excess of $50,000,000. This is pretty clearly a losing proposition.

Of course, there is a simple, cheaper way. If the vessel collision problem is basically a communication problem, the obvious question is why not communicate? Why not have the Stockholm, for example, get on the phone and say, "To ship which is headed west at 22 knots at about xx degrees zz minutes North and yy degrees vv minutes West. This is the Stockholm. I am 10 miles due west of you, headed east at 18 knots on approximately collision course. I am altering (intend to alter) course to starboard. Please acknowledge."

The equipment required to perform this function would cost a maximum of $2,500 per ship as opposed to about $100,000 for the CAS. The cost of equipping the entire world merchant fleet over 500 GRT with VHF Ship-to-Ship equipment would be about $60 million. Giving no credit to this equipment for other functions and assuming a real discount rate of 10%, one would require a decrease in present collision losses of about 5% to justify this investment. If our interpretation of the data is correct, that as much as 50% of present collisions could be avoided with proper communication, then there appears to be a high probability that we could obtain the necessary savings.

The usual arguments offered against voice communication are:

1) Lack of standard equipment

2) Language barriers

3) Identification of transmitter in multi-ship situations

4) Communications channel saturation in really crowded situations.

Arguments 1 and 2 lose a great deal of whatever force they had, given the relative cheapness of the equipment and the limited vocabulary required, with the Coast Guard Bridge-to-Bridge regulations. The problem now is one of making sure that the vessels employ the communications capability they are legally required to carry in American waters offshore.

Arguments 3 and 4 are not so easily dismissed. They deserve careful consideration and they may, in some cases, point to some form of transponder capability.

CHAPTER 3. THE NATURE OF GROUNDINGS

3.1 Introduction

Groundings have not received nearly as much attention in the literature as collisions. Much of the interest and public information in collisions is generated by the attempt to determine which party is at fault. Usually, this is not much of a problem in groundings. Secondly, groundings are much less likely to involve a loss of life than are collisions. From the vessel's point of view, they tend to be less major casualties. For all these reasons, we have been unable to find anything approaching a causal study of groundings in the literature. This is unfortunate. As we saw in Chapter 1, tanker groundings involving spillage are considerably more frequent than collisions involving spillage. Groundings have spilled more oil than collisions to date; and, perhaps most importantly, groundings are much more likely to spill oil close to shore. Not only is the economic and aesthetic damage of a spill which comes ashore much higher than one that does not but there are good biological reasons for believing that spills in shallow water do considerably more damage to the environment than spills in deep water. For all these reasons, groundings are at least as important as collisions as far as tanker pollution is concerned. Therefore, an attempt was made to scrutinize past grounding data which we considered relevent to the offshore tanker pollution issue.

We worked from two samples of groundings. The first was a sample of about thirty major worldwide tanker groundings aimed specifically at those groundings which resulted in large spills. This sample we have called the 'famous' groundings. The second sample contains 48 groundings extracted from the U.S. Coast Guard Vessel Casualty File for FY 72-77 by Prerau and Frankel as part of TSC's overall effort in offshore vessel control. This sample we have dubbed the "TSC groundings."

3.2. The 'Famous' Groundings

One possible source of grounding data are the published reports which invariably emanate from groundings which for one reason or another catch the public eye. The usual such reason, of course, is the magnitude or location of the resulting spill. Such a sample is necessarily extremely biased. What is true of the 'worst' groundings need not and almost certainly will not be true of the population of all groundings. Nonetheless it can be argued that it is just these worst case groundings which we are most interested in decreasing and hence the bias is a useful one. Be that as it may, in examining worldwide casualties we have little choice since, for the most part, only the 'disasters' receive sufficient attention so that the particulars become known in a reasonably public form.

Table 3.2.1. displays a sample of 34 groundings. This sample was developed in an extremely unsystematic manner, mainly on the basis of the size of the spill, occasionally on the basis that it involved the complete loss of a vessel, and occasionally on the basis that causal information on the casualty was obtainable from the sources to which we had access. Of the 34 groundings in Table 3.2.1, four (Ennerdale, Wafra, R.C.Stoner, and Marlena) are included simply to remind us that we have been able to obtain absolutely no descrpitive data on these four very large spills. The effective sample size, therefore, is 30.

In general, we don't think one can make very much of the fact that a surprisingly large percentage of our 30 groundings in which the cause is given are anchor draggings (3) or mechanical breakdowns (5). The main source of data for what little causal information we have was Lloyd's Weekly Casualty Returns . Lloyd's carefully refrains from pointing fingers in its description of the casualty. It never says anything that might prejudice subsequent litigation. So, even if the cause were clearly a navigational error, the Casualty Returns would be very unlikely to say so. We do think something can be made of the fact that in 16 cases the vessel was either entering or leaving harbor or anchored outside the harbor mouth. In only nine cases was the vessel clearly in mid-route. And in two of these 9 cases, the vessel was en route but in very constricted waters (Bosporus, Straight of Magellan). In only seven cases, was it ascertained that the vessels were in mid-route in reasonably open water. However, these seven groundings contain five of the seven largest grounding

TABLE 3.2.1 THE "FAMOUS" GROUNDINGS

VESSEL	DATE	LOCALE	DWT	FLAG	AGE	SPILL	WEATHER	TIME OF DAY	MECH. FAILURE	ANCHOR DRAG	NAV. ERROR	CONN. ERROR	HARBOR ENTRANCE	DISTANCE OFF SHORE	COMMENTS
ACHILLES	9/1/78	NARRAGANSETT BAY	43506	USA	60		GALE	0900	NO	NO	NO	YES	YES	<1	"Swept out of shipping lane by gale force winds."
AGIP ANCONA	1/7/70	BOSPORUS	52588	IT	63		GOOD	DAY	YES	NO	NO	NO	BOSPORUS	0	Lost steering. Killed 6 people on shore.
AMPUNIA	8/70	W. COAST INDIA	16400	PAN	50	16,000(?)			YES	NO			NO		Burn out of main generator. Commentary unclear but may have spilled altine cargo.
ANTILLA BAY		ZUETINA					ROUGH		NO	NO	NO	YES	YES		
ARABIYAH	6/71	SINGAPORE	208907	KUW.	69								NO	13	*Stopped loading due to bad weather, prop fouled by an attempt to leave bay, wind pushed vessel ashore, propane carrier, let loading still in builder's hands.
ARROW	2/70	CANSO BAY	18251	LIB.	48	5,000							YES	3	Poor visibility, inoperable radar and unsuitable charts.
ARGO MERCHANT	15/12/76	GEORGES BANK	128,238	LIB.	53	25,000	O.K.	0700	NO	NO	YES	NO	NO	27	Report came in at 0700 - Vessel aground beforehand
BRITISH MALLARD	15/11/73	LAKSEF-JORDEN, NORWAY	15866	UK	60	2,000	GOOD	NIGHT					YES	4	Strong current in fjord.
CUNOCO BRITTANIA	24/5/73	HUMBER	115,651	LIB.	72	500		1252	YES	NO	NO	?	YES	0	Engine failed approaching humber SBM, anchors dropped, went aground anyway, vessel holed by own anchor.
DONA MONIKA	5/8/73	MILFORD HAVEN	11,000	LIB.	54	3,000	GALE	2104	NO	YES	NO	NO	YES	0	Dragged anchor off mouth of Milford Haven, gale force winds, large seas, gasoline spill.
ENNERDALE	6/70	SEYCHELLES	49,209	UK	63	49,209									
ESSO CAMBRIA		PERSIAN GULF	249,952	UK	69			0400	NO						"Large quantity of oil in water"
ESSO ESSEN	29/4/68	CAPE PT. S. AFRICA	50897	GER	60	4,400									
GOLDEN ROBIN	30/9/74	DALHOUSIE	28,175	BER		300	RAIN	0413	NO	NO			YES	<.5	
GENERAL COLOCOTRONIS	7/3/68	BAHAMAS	18,178	GRE	55	4,400									
JACOB MAERSK	29/1/75	OPORTO	88,000	DEN	1966	84,000	?	1700					YES	<2	*Struck bar entering port. Volatile crude rescue attempts started fire, 5 dead, cargo and ship complete loss.
METULA	9/8/74	ST OF MAGELLAN	206,719	D.W.I.	69	53,600		2218	NO	NO			S.OF.M	2.5	
NAPIER	9/5/	W. COAST OF CHILE	38,561	LIB	57	35,300	ROUGH						NO		
OLYMPIC GAMES	27/12/76	DEL. RIVER		LIB		5,000			YES	NO	NO	?	YES		Maneuvering at terminal, engine failure, 39' draft where controlling depth was 36', needed high water

TABLE 3.2.1 THE "FAMOUS" GROUNDINGS (CONTINUED)

VESSEL	DATE	LOCALE	DWT	FLAG	AGE	SPILL	WEATHER	TIME OF DAY	MECH. FAILURE	ANCHOR DRAG	NAV. ERROR	CONN ERROR	HARBOR ENTRANCE	DISTANCE OFF SHORE	C O M M E N T S
OCEANIC GRANDEUR	3/3/70	TORRES STRAIGHT	58062	LIB	65				NO	NO			NO	20	Struck submerged reef 20 miles NNE Thursday Island.
POLYCOMMANDER	5/5/70	VIGO	50380	NOR	65	10,000		0400		NO			YES	0	Detour to put crewman ashore. Hit reef just after dropping pilot.
POSEIDON		MALTA							NO	NO	NO	YES	YES	0	Hit breakwater, leaving repair dock.
R.C. STOVER	6/9/67	WAKE ISL.				20427									Gasoline spill, no information.
SEA SPRAY	2/74	OFF BORNEO	121,185	SWE	66		GOOD	NIGHT	NO	NO	YES	NO	NO		Navigational error due to change of position of air radio beacon. Charts out of date.
SHOWAMARU	6/1/75	SINGAPORE	237,698	JAP	73	3100		0540	NO	NO	YES	NO	NO	<2	
TARAVO	7/72	HUSSEY SOUND	88,072	NOR	68		CLEAR	0120					YES		Scraped bouy and edge of channel after picking up pilot. Bouy poss. out of pos.
TARIK IBUZIYAD	3/26/75	RIO	119,000	IRAQ		110,000		2045	NO	NO	NO	PROB.	YES	<2	Grounded in inner harbor just inside Niteroi Bridge.
TEXACO EDINBURGH	21/8/	INLAND SEA	18,255	UK	56		TYPHOON		NO	YES	NO	NO	YES	0	Left repair yard to avoid typhoon Anita, anchor dragged in 100MPH winds, owner was considering scrapping vessel anyway.
TEXACO WESTMINSTER	10/73	PALERMO	100,982	UK	68						NO	NO	IN DAY-DOCK		In daydock which broke away during storm.
TORREY CANYON	3/18/67	SEVEN STONES	120,000	LIB		103,200		0850	NO	NO	YES	NO	NO	5	
TRANSHURON	9/26/74	KILTAN ISL. INDIA	19,650	USA	45	5,000		1630	YES	NO	NO	NO	NO		Went aground after engine failure, navy cargo.
TRUNTANIC G	3/14/71	MILFORD HAVEN	5,013	UK	70	150		NIGHT					YES	0	Inside Milford Haven.
TULSA GETTY		CAPE MAY					HEAVY WINDS	0200	NO	YES	NO	NO	YES	13	Anchor dragged in heavy winds.
WAFRA	2/71	CAPE AGULAS	49,762	LIB	56	40,000							NO		

spills on record (Torrey Canyon, Ennerdale (probably enroute), Wafra (probably enroute), Napier, and Argo Merchant).

In 19 cases, it was possible to estimate the distance offshore. In only 3 of these cases was that distance more than 10 miles. In all the others, it was five miles or less. In 13 cases, it was less than two miles.

In 17 cases, it was possible to determine the time of day. 12 of these cases were clearly in periods of darkness. Only three cases occurred in mid-day and two of these were mechanical failure. This jibes with a Japaneses study of groundings in the Inland Sea which found that the incidence of groundings during the night was 4 to 5 times that during the day [Fujii, 1977].

In discussing operating problems, we believe it is extremely important to distinguish where possible between navigation error and conning error. A navigational error occurs when the operator (captain or pilot) is in one place when he thinks he is in another. A conning error occurs when the operator has a good idea of where he is but runs aground anyway due to failure to negotiate a turn or misjudgement of the current set, etc. In the aircraft game, they make the same distinction; the latter type of error is known as a guidance error. The importance of this distinction to system design is obvious. In 4 of the 30 cases, we were able to determine that the cause was definitely a navigation error. In 13 cases, definitely it was not. Three of the cases were definitely conning errors and at least one other case (the Tamano) probably was. In two cases, mechanical failures were probably compounded by conning errors.

In this small sample, there appears to be no striking pattern with respect to age, size, or flag of vessel.

Because of the paucity of causal information in this sample, it is a little difficult to reach any conclusions from Table 3.2.1. alone. However, as we shall see in the next section, combining this information with a more detailed examination of American groundings leads to some rather strong implications.

3.3 The TSC 'Offshore' Groundings

Table 3.3.1 summarizes the 47 'offshore' groundings extracted by TSC from the USCG Casualty reports. The screening logic used in deriving this sample is described elsewhere. For now we merely note that one result of this screening logic is that some of the groundings are 'offshore' in only a rather artificial sense. For example, five of these groundings took place in Long Island Sound: one in the Upper East River a few hundred yards from land, one in the entrance to the Thames River a few hundred yards from land, and one hit a breakwater entering the Connecticut River. Eleven of these groundings occurred within or at the entrance to Guayanilla Bay, a rather small body of water on the south coast of Puerto Rico. In fact, in 38 of the 48 groundings in this 'offshore' sample, the vessel was either entering or leaving protected waters at the end or beginning of a voyage. In five cases, the vessels were transiting protected or inshore waters. In one of the remaining cases, vessel knowingly entered dangerous waters to aid a burning boat. In only four cases was the vessel in mid-route in reasonably open water. (And in one of these cases, the vessel was attempting to enter Delaware Bay but was so far off when he grounded [Ocean City, Maryland], that we felt we had to claim he was in mid-route.)

Moreover, the groundings in the sample are highly localized as the following table indicates.

TABLE 3.3.2
LOCATION OF TANKER GROUNDINGS IN TSC OFFSHORE SAMPLE

LOCATION	NUMBER	EST ANNUAL OIL MOVEMENT THRU ENTRANCE
Guayanilla	11	10 - 12 x m. tons
Delaware Bay	10	60 x m. tons
Long Island Sound	5	
Chesapeake Bay	3	20 x m. tons
Limetree Bay	2	50 x m. tons
Sabine Channel	2	
Cape Lookout Shoals	2	
All Others	7	

Almost half the groundings in this nationwide sample occurred within or at the entrance to either Guayanilla Bay or Delaware Bay. All the Guayanilla groundings occurred

TABLE 3.3.1. THE TSC AMERICAN GROUNDINGS

VESSEL	DATE	LOCATION	DWT	FLAG	AGE	SPILL	TIME	WEATHER	MECH FAIL.	ANCHOR DRAG	NAV. ERROR	COMM. ERROR.	HARB ENTR.	DIST OFF-SHORE	CARGO	SHIP DRAFT	TRANS ITION	COMMENTS
ATLATNIC COMMUNICATOR	1.7.72	ENTRANCE TO CHES. BAY		USA	54	NO	NGT	HAZY	NO	NO	NO	YES	YES		30,000	34'	NO	Moved to allow space for another vessel.
BARBARA MORGAN	5.3.75	OFF E. C. OF P. R.		USA	68	NO	NGT	GOOD	NO	NO	NO	YES	NO	2	4,700	14'6" 15'6"		Barge took stear
CALIFORNIAN	23.8.73	GUAYANILLA		USA	43		0248	GOOD	NO	NO	NO	YES SEE→	YES	1		17' 22'10"	YES	Missed by a few hundred feet.
CHRYSANTHY	12.5.74	ENT. TO DEL. BAY		PAN		NO	DAY	FOG	NO	NO	YES	NO	YES		48,350	41	NO	
CLAUDE CONWAY	10.12.74	L. I. SOUND		PAN	57	NO	1135	GOOD					NO		43,278	36'9" 38'05"	NO	Much draft for L. I. Sound.
COLORADO	6.3.74	1 MILE OFF MIAMI		USA	44/ 72	NO	0128						NO	1	BALLAST	13' 23'		Aiding burning vessel
CIUDAD DE PASTO	7.12.72	SABINE RIV.	FOREIGN	COL	57	NO	0435	GOOD	NO	NO	YES	NO	YES				NO	Misread buoys.
DAPHNE	12.11.74	PARCUERA		LIB	63	NO	0415	POOR VIS.	NO	NO	YES	NO	NO			37'8" 39"		In mid-route
DAPHNE	28.12.76	GUAYANILLA		LIB	63	NO	0910	GOOD	NO	NO	NO	YES	YES	2	47,160	36'11" 38'4"	YES	Waiting for pilot.
EQUATOR	30.5.77	PACIFIC REEF		USA	69	NO	2150	GOOD	NO	NO	YES	NO	NO	8	6,000	16' 14'	NO	
EUGENIE LIVANOS	17.5.73	LIMETREE BAY		LIB	72		1800	GOOD	NO	NO	NO	YES	YES	1	182,000 IRAN	54'6" 54'6"	YES	Boarding pilot.
F. L. HAYS	21.3.72	L. I. SOUND		USA	46 TUG.	80,000 GAL.	0310	GOOD	NO	NO	YES	NO	NO	1	2,000	13'3" 14'61"	NO	Licenses not in order
FALCON LADY	5.3.72	CHESAPEAKE BAY		USA	71	NO	1312	VIS. I-5 MLS. RAIN 4-5	NO	NO	?		YES			36'2" 36'4"	YES	1/2 mile out of channel
FREEDOM	21.5.72	GUAYANILLA		LIB	61		2246	GOOD	NO	NO	NO	YES	YES	~1	33,100	30'10" 30'9"	YES	Off by 50 yards
FEDERICO C.	8.12.73	PORT EVERGLADES	PASS.	ITL	58	NO	0700	ZERO VIS.	NO	NO			YES	~2	PASS.	28' 29'	NO	Went aground while awaiting better vis.
HONDA	13.8.72	LOOK-OUT SHOALS		NOR	55	1635	DAY		NO	NO	YES	NO	NO	~8		14'8" 17'10"		Same as Pres. Adams
J. H. DENLEIL	17.11.73	1 1/2 MONHEGAN ISLAND		USA		NO	NGT						YES	1.5		7' 10"		Hit rock
KATINA	28.5.73	LIMETREE BAY				NO	2235		NO	NO	YES	NO	YES		BALLAST	13' 23'		Gyro error
LIBERTY MANUFACTURER	7.10.72	L.A. HARBOR	FOREIGN	PAN	52	NO	2155	GOOD	NO	NO	YES	NO	YES			2702 2702		Passed buoy on wrong side
MANHATTEN	1.11.71	ENTRANCE TO DEL. BAY		USA	62	NO	1512		NO	NO	Don't know 2-3 miles off course		YFS		BALLAST	18'6" 26' 32' 34'	YES	Moved for out-bound vessel
MARINE HOPE	26.4.74	GUAYANILLA		PAN	45		0590						YES				YES	
MARINE HOPE	17.4.74	GUAYANILLA		PAN	45		2307	GOOD					YES					
MINERVA	8.2.73	SAN JUAN HARBOR	FOREIGN	GRE	49	NO	2026	GOOD	NO	NO	NO	YES	YES			29'6" 28'0"	YES	Misjudged drift while boarding pilot

TABLE 3.3.1. THE TSC AMERICAN GROUNDINGS (CONTINUED)

VESSEL	DATE	LOCATION	DWT	FLAG	AGE	SPILL	TIME	WEATHER	MECH. FAIL	ANCHOR DRAG	NAV. ERROR	COMM. ERROR	HARB ENTR.	DIST. OFFSHORE	CARGO	SHIP DRAFT	TRANS-ITION	COMMENTS
MONTICELLO VICTORY	8.27.76	DELAWARE BAY		USA	62		0400	O.K.	NO	NO	YES	NO	YES		46,016	39 38'6"	NO	Nav.
MERRIMAC	16.2.74	OCEAN CTY. MARYLAND		USA	43	NO	1014	"FOUL"	NO	NO	YES	NO	NOT EXACTLY		BALLAST		NO	Thought at Cape Henolopen
NANCY MORAN	26.12.72	L.I. SOUND	TUG/B	USA	58	400 BBLS	0315	GOOD	NO	NO	NO	YES	YES	0		10'8" 11'6"		Took shift to right.
OCEAN STAR	14.3.76	L.I. SOUND	TUG/B	USA	69	NO	0200	LOTS OF WIND	NO	NO	NO	YES	NO			12' 15'		Upper east river
OVERSEAS ALASKA	16.4.72	SABINE CHANNEL		USA	70		0422	GOOD	NO	NO	NO	YES	YES		20,000	14'0" 30'8"		Took too wide a turn.
OVERSEAS ALEUTIAN	1.8.76	GUAYANILLA		USA	71	NO	2342	GOOD	NO	NO	NO	YES	YES		BALLAST	8' 22'		Anchored
OLYMPIC CHALLENGER	18.7.76	DELAWARE BAY		LIB	60	SLIGHT	2200	GOOD	NO	NO	YES	NO	YES			44'		Discrepancy on draft
PHILLIPS OREGON	7.6.75	ARANSAS PASS		LIB	64		0244	GOOD WIND 4/5	NO	NO	NO	YES	YES			45'	NO	Misjudged current.
POLING BROS	11.5.75	L. I. SOUND	TUG/B	USA	29	NO	1025	VIS V. BAD	NO	NO	YES	NO	YES	0	2,000	12'9" 12'10"	NO	Foggy. Radar went out.
PRESIDENT ADAMS	28.6.72	LOOK OUT SHOALS	5308GRT FREIGHTER	USA		NO	2025	GOOD	NO	NO	YES	NO	NO			16' 24'	NO	Charts not reflect buoy changes
PUERTO RICAN	23.12.76	GUAYANILLA	CHEM. TANKER	USA	71	NO	0104	GOOD	NO	NO	NO	YES	YES	~1	16,400	17'5" 34'7"	NO	Buoy lense obscured
RUBIROSE	16.2.77	GUAYANILLA	CHEM. TANKER	NOR	72			GOOD	NO	NO	NO	YES	YES	~1	BALLAST	5' 16'	NO	Conning err. appr. anchorage
SABINE	8.26.72	GUAYNILLA									NO	YES	YES	~1			YES	Picking up pilot
SEALIFT PACIFIC	5.10.76	COOK INLET	PARCEL TANKER	USA		9421 BBLS		GOOD	NO	NO	YES	NO	NO ONSHORE PASSAGE		22,400 JP-4	27'2" 32'9"	NO	
SERRA TRADER	30.4.76	GUAYANILLA		LIB	65	NO			NO	NO	NO	YES	YES		3,000	13'9" 26'11"		
SOHIO RESOLUTE	8.3.72	ENTRANCE DEL. BAY	20,596	USA	71	NO	1042		NO	NO	?		YES		75,000	41'10" 42'0"		Fully loaded to 75,000 dwt
TAMANO	22.7.72	HUSSEY SOUND		NOR	68		0120	GOOD PREV. FOG	NO	NO	NO	PROB.	YES		82,079	43" 44'	PILOT ON	
TEXACO CALIFORNIA	23.10.74	DELAWARE BAY		USA				GOOD					YES		39,638	36'6" 26'9"	NO	
TEXACO WISCONSIN	7.13.75	DELAWARE BAY				NO		STRONG WINDS	NO	NO	NO	YES	YES		BALLAST	10' 26'	NO	Water low High offshore winds
THORUNN	10.2.77		BULK	NOR	73	NO	0342	GOOD	NO	NO	YES SEE EXP.	NO	YES			36'6"	NO AWAITING PILOT	Read depths in fathoms
TRINITY	6.4.73	GUAYANILLA		USA	44/67		0334	GOOD	NO	NO			YES	-1	BALLAST	10'0" 23'0"		

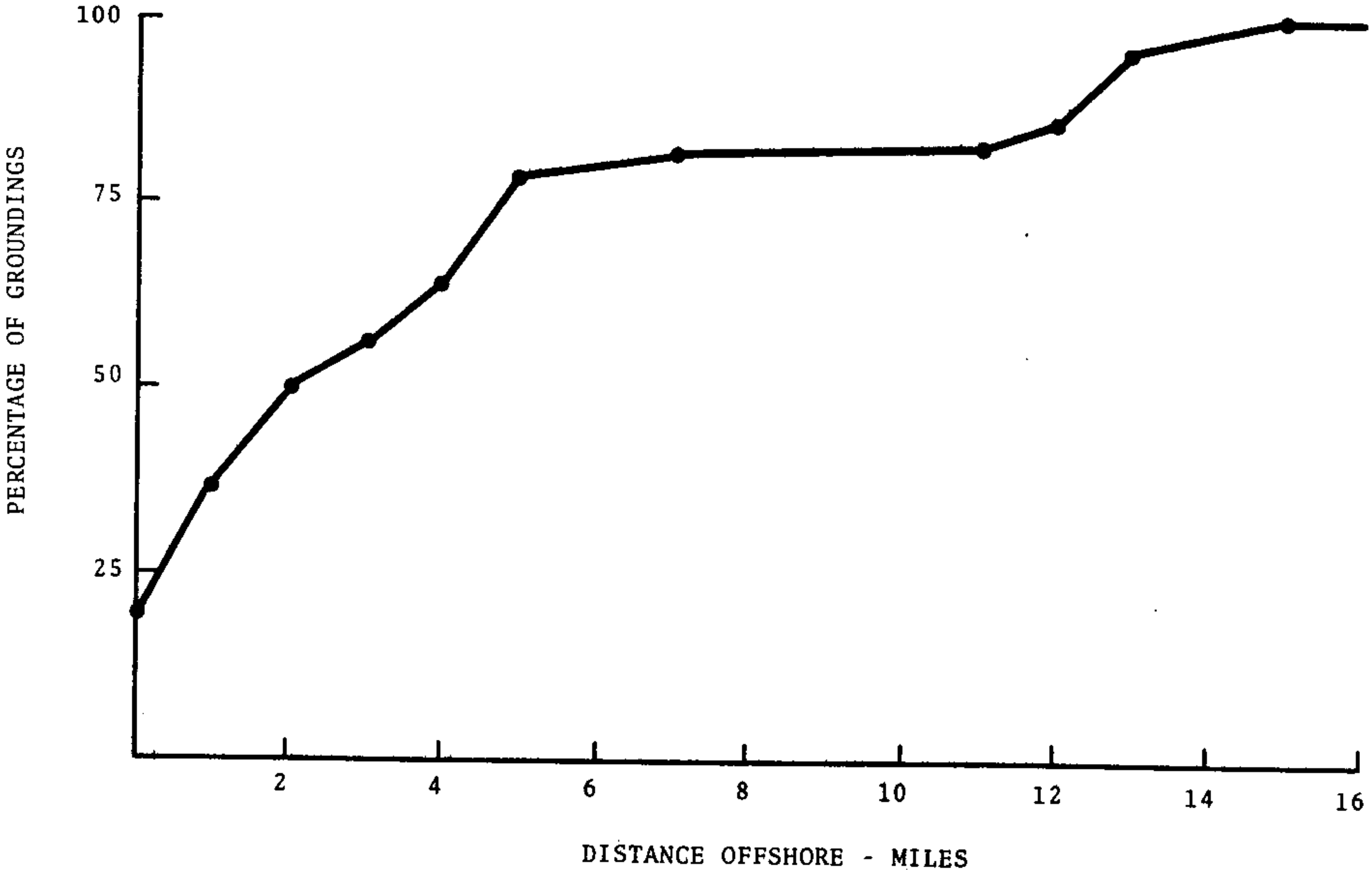
TABLE 3.3.1. THE TSC AMERICAN GROUNDINGS (CONTINUED)

VESSEL	DATE	LOCATION	DWT	FLAG	AGE	SPILL	TIME	WEATHER	MECH. FAIL.	ANCHOR DRAG	NAV. ERROR	COMM. ERROR	HARB. ENTR.	DIST. OFFSHORE	CARGO	SHIP DRAFT	TRANS-ITION	COMMENTS
THOMAS M.	13.4.76	CHESAPEAKE BAY		USA			2338	GOOD	NO	NO	YES	NO	YES		CORN	33' 34'		Mistook buoy.
WESTERN ETHICS		DELAWARE BAY					0435				YES	NO	YES				YES	
UNIVERSE APOLLO	29.12.75	DELAWARE BAY		LIB	59		1537	GOOD					YES			53'8" 53'8"		Inaccurate charts.
TEXACO CALIFORNIAN	10.10.75	DELAWARE BAY											YES					Made approach on wrong buoy.

within five miles of each other. It is clear that there is no correlation between amount of oil moved and number of groundings in this sample. Neither Boston (~20 million tons) nor the seaward entrance to New York Harbor (~50 million tons) are represented in the sample. The entire Gulf Coast (~150 million tons) has only two tanker representatives. There is no Lower 48, West Coast tanker entry in the sample. It is possible -- one suspects it is likely -- that some of the 'holes' in the data are an artifact of the screening logic and the Coast Guard coding. But even if this is the case, it's clear that we have some remarkably strong hot spots.

Given the above, it should come as no surprise that most of these 'offshore' groundings took place quite close to shore. Figure 3.3.1 shows a cumulative distribution of distance offshore. The median distance is 2 miles; the maximum is 15. 80% of the groundings in the sample took place within five miles of land. The tail of the distribution is primarily a product of the width of Delaware Bay at its mouth. If one were to draw a line between Cape Henelopen and Cape May and define that line to be the base for measuring 'distance offshore', then all but three of the spills would be less than five miles offshore and the maximum would be eight. Even allowing for the fact that the Coast Guard's authority only extended to the edge of the territorial sea, it's clear from both this and the preceeding sample that most groundings occur within a few miles of land.

Neither propulsion system breakdowns nor anchor draggings figure in any of the casualties in the TSC sample. This is a product of the screening logic. Hence, using the terminology of the last section, all the groundings are either navigation or conning errors. In 31 cases, it seemed to us that we could fairly safely call the problem a navigation error. Either the vessel was using out of date charts (3), misreading the chart (1) or it was not where it thought it was, although in many of these latter cases the navigation error was less than a mile. In 16 cases, we called the casualty a conning error. The vessel knew where it was, at least within a few hundred yards, but still got into trouble due to misjudgement of turning radius, current or wind drift, or current shear. In a surprising number of these latter cases, the grounding occurred during the transition to or from pilotage. In at least eight cases the vessel grounded either while it was slowing to pick up (drop off) the pilot or immediately upon resumption of course after picking up (dropping off) the pilot. During the period


100
75
50
25
PERCENTAGE OF GROUNDINGS
2
4
6
8
10
12
14
16
DISTANCE OFFSHORE - MILES

while power is off the ship, the vessel is more at the mercy of wind and current, and the bridge is distracted by the boarding/unboarding operation.

In 32 cases, the casualty occured at night maintaining the pattern observed in the earlier sample and by the Japanese. Both navigation and conning errors appear to be roughly four times as likely at night as during the day. There does not appear to be any strong correlation with the weather -- certainly nothing nearly as strong as in collisions. In 36 of these 48 cases, visibility was several miles or better. Nor is there anything particularly striking about the vesssel age, size or flag pattern.

At least 34 of the 48 TSC groundings occurred when the vessel was in the loaded condition, in many cases to within a foot or two of the controlling depth of the harbor being entered or left. In the case of the 29 tanker groundings all but 1 casualty occurred upon entering rather than leaving the harbor. It is the nature of large ship groundings that they rarely occur in waters much shallower than the operating draft of the vessel. Despite this fact, one has the distinct suspicion reading the reports that a foot or two less draft might have made considerable difference, especially in the Delaware Bay cases. In any event, the great preponderance of tanker groundings were incoming loaded ships. Whether this is the result of the marginal amount of water beneath the keel, greater navigational uncertainties upon land fall than upon departure, or decreased crew efficiency at the end of a voyage as opposed to the beginning, is impossible to say. Our guess is that at least in the Delaware Bay the differences in incoming versus outgoing drafts is important.

Finally, it should be noted that in all 48 groundings in the sample, the casualty took place while the vessel was on soundings, i.e. while it was navigating from buoy to buoy. In every case, without exception, the vessel reported it was making use or attempting to make use of one or more aids to navigation. In all but one case, the vessel was equipped with radar. In 3 cases, the radar's being inoperable was cited as a contributary cause. In 2 cases, gyrocompass errors were cited. In 3 cases, the vessel claimed buoys were out of position or not properly functioning. There is surprisingly little mention of the use of Loran.

As we see it, there are no real conflicts between the TSC sample and the worldwide sample discussed in the last section. Both indicate that most groundings occur quite close to shore at either the origin or destination of the trip and that a number of these casualties can be categorized as conning errors rather than navigational. Of course, the TSC sample is much more detailed with respect to cause but there is nothing in the worldwide data which appears even slightly at variance with the basic pattern observed in the American sample.

3.4 Implications for System Design

We believe that, despite the obvious shortcomings in our two samples -- their biases, their small size, and in the case of the worldwide sample, their sketchy causal data -- the pattern that these samples exhibit has some extremely important implications for possible vessel management systems.

Firstly, the grounding problem is highly localized. It is a problem which is almost completely confined to the approaches into and out of protected waters. A system aimed at decreasing groundings which is designed to cover the entire continental shelf in a more or less even fashion would represent an inordinately wasteful allocation of resources. Secondly, with rare exceptions most groundings occur quite close to shore. In going after groundings, there is little point in expending resources to cover an area more than 10 or 12 miles offshore. And a system which does a 'good job' in the band 5 or more miles offshore and a 'poor job' inside that band flies in the face of everything we know about groundings. Thirdly, at least one third and perhaps as many as one half of all groundings appear to be outside the control of any shore based system. Approximately, this proportion of groundings are due either to conning errors or, if they are navigational errors, they are navigational errors of the order of a few hundred yards or less. It's difficult for us to imagine a shore based system which can recognize and properly respond to navigational errors which are of the same magnitude as the vehicle itself. On the other hand, it seems to us the fact that a few hundred yards can be important is an argument for believing that Loran C may put a dent in future groundings statistics provided its proper use is enforced.

Finally, with respect to reduction of American tanker groundings, it is obvious that the single most useful step would be to determine why some approaches, notably Delaware

Bay and Guayanilla, appear to have such horrendous records relative to what appears to be, at least on the surface, roughly equivalent approaches such as New York Bight or Limetree Bay. Is it an artifact of our sampling process or the Coast Guard coding of groundings or a combination? M.I.T.'s past experience with Coast Guard spill statistics would indicate that this possibility had better be checked out thoroughly. If not, is it operating practices such as pilot boarding points or some peculiarity in the current patterns or bottom topography? Is it the placement of the buoys or their visual or radar target strength? Or is it just plain sloppiness? We had better find out. Guayanilla in particular looks like a disaster waiting to happen.

Basically, what we've discovered is that the Argo Merchant scenario -- a grounding in mid-route, well offshore due to a navigational error of several miles or more -- is an extremely unusual casualty. Offshore groundings in general are rare. And even among offshore groundings, this scenario is very much the exception rather than the rule. We've only been able to locate five such accidents in American waters in the last six years, two of them non-tankers. A country should think thrice about building a system around such a rare scenario. And in the specific case of the Argo Merchant, there were so many glaring deficiencies in the Argo Merchant's operating practices that a system aimed directly at correcting such deficiencies, such as an inspection program with teeth coupled perhaps with an ECAREG-like clearance system, deserve first priority. (1)

(1) ECAREG, Eastern CAnada traffic system REGulation, requires all tankers and all vessels greater than 500 tons to obtain clearance before crossing into Canadian territorial waters. Clearance may be denied or compensatory measures may be ordered by the Canadian Coast Guard, if the vessel has a poor operating record or has current deficiencies. The operators and more importantly the charterers (the oil companies) know this, and it affects their choice of tankers. The system is also used to alert traffic in the area to the presence of large tankers. The system was instituted after the Arrow spill. The Arrow was a tanker whose operating condition was roughly equivalent to that of the Argo Merchant.

CHAPTER 4

THE CURRENT TANKER TRAFFIC PATTERN IN U.S. OFFSHORE WATERS

4.1 Introduction and Methodology

As part of this baseline study, M.I.T. has made an estimate of the current inter-regional oil flows and tanker traffic in U. S. waters. The purpose of this estimate is two-fold:

1) To determine if there appears to be any relationship between tanker traffic in offshore waters and the location of tanker casualties.

2) To serve as a baseline for projections of future traffic patterns.

Any present attempt to establish tanker traffic patterns in U.S. waters faces severe data difficulties. Currently there is no readily available data base which contains both origin and destination for voyages in which both the origin and destination are domestic. The Corps of Engineers (COE) publishes tables of entries and exits by ports for those ports where the Corps maintains channel improvements. However, the purpose of this database is to determine channel and harbor improvement usage and hence no attempt is made to determine the origin for entries nor destination for exists. The individual ports maintain more complete information but usually in a much less accessible form. The Corps maintains a computerized database which contains considerably more information than that published, including vessel name and date of port call. Conceivably, one could, through sufficient cross-referencing on vessel name and date, reconstruct the bulk of all cabotage voyages. However, this would be a major project in itself and was not attempted.

The situation with respect to foreign trade is somewhat better. Through use of Custom's data, the Bureau of Census maintains files which do contain both the origin and destination for voyages in a single record. These files are known as the AE350 and AE750 tapes. However, simply extracting the data would be a major project (Census Bureau wants $1000 per tape for copying alone) and the results would be quite incomplete for our purposes. Thus, this was not attempted either.

The situation is changing. Lloyds has now computerized its agents' reports of vessel movements. Worldwide they catch perhaps 80% of all tanker voyages. This information is available by subscription. However, cursory examination of a sample of such reports reveals that they are particularly weak in American cabotage voyages, especially smaller vessels. This effort is still in its formative stages, especially with respect to American flag voyages. The Maritime Administration has a large project underway to determine the use of U.S. waters by both foreign and American flag tankers. However, it is not known exactly what form the results of this project take. In any event, this project was not completed in time to fulfill the purposes of this study.

Therefore, we undertook a manual study aimed at delineating at least in rough terms the overall flow pattern in U.S. offshore waters. We chose six promontories or "choke" points. They are:

1) Georges Bank
2) Cape Hatteras
3) Straits of Florida
4) Point Conception
5) Point Piedras Blancas
6) West Coast, 40N Latitude.

Our thought was that if we could estimate the petroleum flows and tanker traffic crossing a perpendicular extending seaward from these points, we'd have a pretty good idea of the overall traffic pattern.

Our baseline estimates are for the calendar year 1974. The Corps' data is always several years in publication, and for 1974 we had another source which proved useful: the U.S. Geological Survey's Study, <u>The National Energy Transportation System</u>. Terminal draft restrictions and refinery capacity by location have changed little if at all since 1974. Therefore, we feel that 1974 is about as good as 1975 or 1976 (the most recent year for which the Corps' data is available) at describing the pre-Alaska, pre-North Sea, pre-Mexico situation. Finally, since the tanker casualties we are examining took place over the last five or six years 1974 is not a bad year for comparing tanker traffic with the location of these casualties.

The Corps' data contain two kinds of information for each port for which the Corps maintains records. They are:

1) Total annual tonnage by commodity handled by port area, classified as either in or out, and foreign, domestic (coastwise), or internal.

2) Annual number of port calls, by operating draft, classified as in or out, and self-propelled dry cargo and passenger, tanker or towboat, or non-self-propelled, dry cargo or tanker.

Unfortunately, the Corps of Engineers data has some shortcomings in terms of our needs. The most important is that no information is given regarding port of embarcation for ships entering a given harbor, nor the destination for ships leaving a harbor. Even a breakdown such as foreign or domestic would have been of great help.

This implies that there is in general a myriad of possible traffic patterns which are not inconsistent with the Corps' port data. In order to choose a "best guess" pattern from all such possibilities, it is necessary to make a series of essentially arbitrary assumptions. The basic assumption we used throughout is that, whenever faced with two possible patterns, we chose that pattern which minimized loaded ton-miles. All shipments are as short as possible given the Corps' data. This assumption is unequalled in its simplicity and has an obvious relationship to efficiency and the workings of a free market. But given the possibility of further inefficiencies in the flow pattern over and above those clearly delineated in the COE data, it does imply that our traffic flow and density estimates are lower bounds. How tight this lower bound is, we simply had no way of checking in the time available.

The pattern was estimated in a two step process:

1) We attempted to estimate the petroleum flow pattern in tons of oil.

2) We attempted to assign ships to this pattern in a manner consistent with the Corps' port call data.

The petroleum flow pattern estimates are inherently more reliable than the resulting ship traffic pattern both due to the availability of cross-checks from independent data sources and the fact that the petroleum flow obeys strict conservation of mass giving us a series of self-correcting checks along the way. Because of the existence of part loading, multiple port calls, and the difference between loaded and ballast drafts, a similar series of checks does not exist for the ships themselves. Our best guess is that the petroleum flow estimates given below are accurate to within 20%. The inter-regional tanker traffic estimates could be off by as much as 50% in some instances. However, once we have presented our estimated petroleum flow and traffic pattern, we believe that it will be pretty clear that even errors of a factor of two or more will not change the overall implications for offshore vessel management policy.

In developing the tanker traffic estimates shown below, we included only those vessels whose loaded draft is 25' or more -- i.e. tankers and barges of 10,000 tons deadweight or more. This implies we are dealing with inter-regional flows rather than secondary distribution. This secondary distribution within a region is accomplished primarily by small tankers or barges weighing less than 5,000 tons. Since we are going to ignore this intraregional traffic, it behooves us to get some idea of whether or not we are throwing the baby out with the bath. Therefore, before turning to our own nationwide estimates, it is worthwhile reviewing an earlier M.I.T. study which attempted to delineate all the petroleum traffic in New England. (1) This was done in 1973 using 1971 data. The results are summarized in Figures 4.1.1 through 4.1.4.

For our present purposes, the important thing to note is that the oil handled by the 15 minor ports of New England is 2,800,000 tons. New England is undoubtedly the most reliant of all the regions on its offshore waters for the secondary redistribution of petroleum. Most of the region's population is located along the coast and there is essentially no intraregional pipeline network. The only oil pipelines in New England run perpendicular to the coast complementing rather than competing with the coastwise transfer. Yet this secondary transfer is less than 5% of the region's movements by volume. In terms of number of trips, the comparison looks quite different. According to M.I.T.'s estimates the number of inter-regional and intraregional movements is roughly the same.

(1) Offshore Oil Task Group, "The Georges Bank Petroleum Study", Volume I, M.I.T. Sea Grant Report MITSG 73-5, February, 1973, pages 86 to 95.

FIGURE 4.1.1 NEW ENGLAND BARGE TRAFFIC -- 1971. Source: Offshore Oil Task Group, 1973.

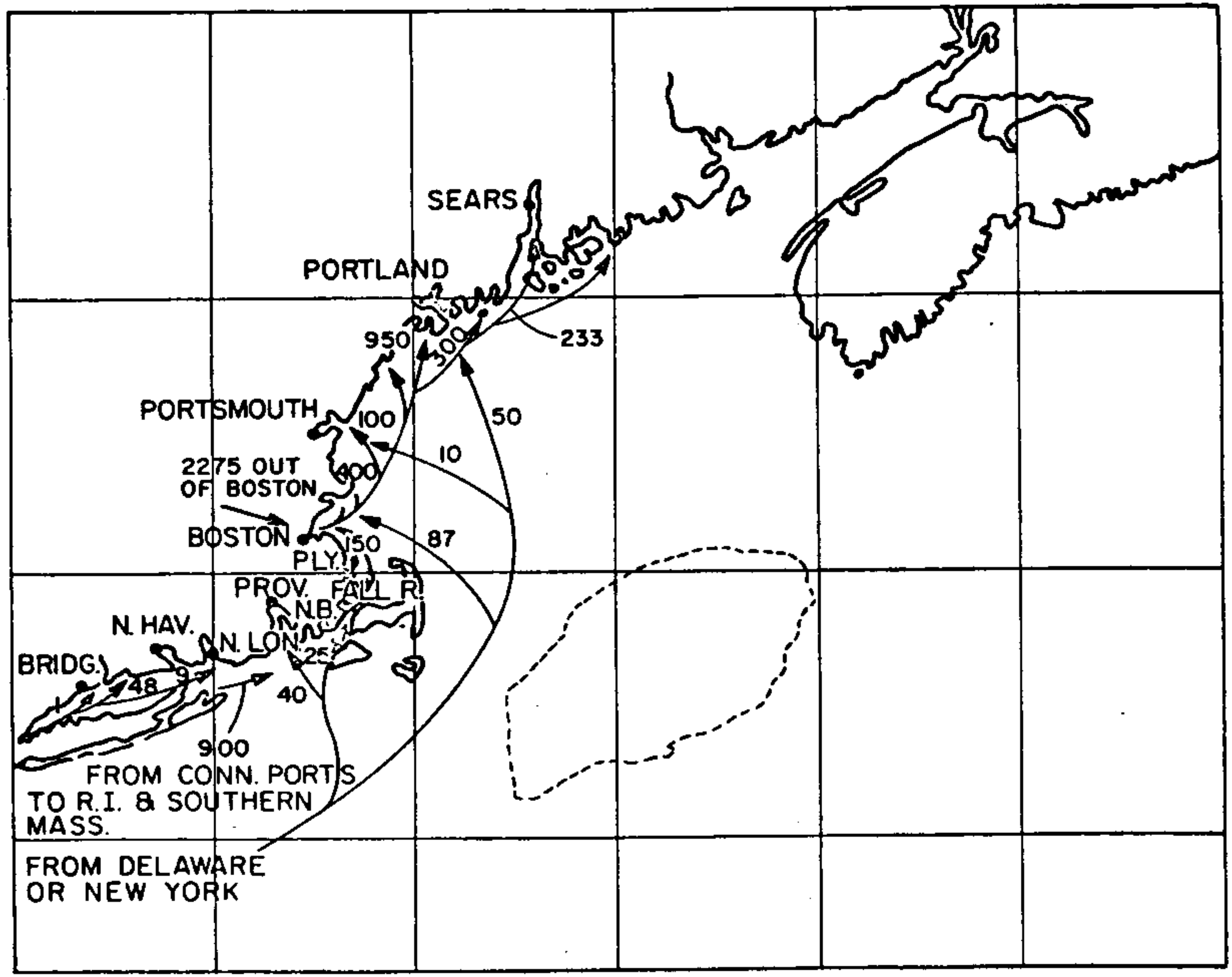


FIGURE 4.1.2 NEW ENGLAND TANKER TRAFFIC -- 1971. Source: Offshore Oil Task Group, 1971.

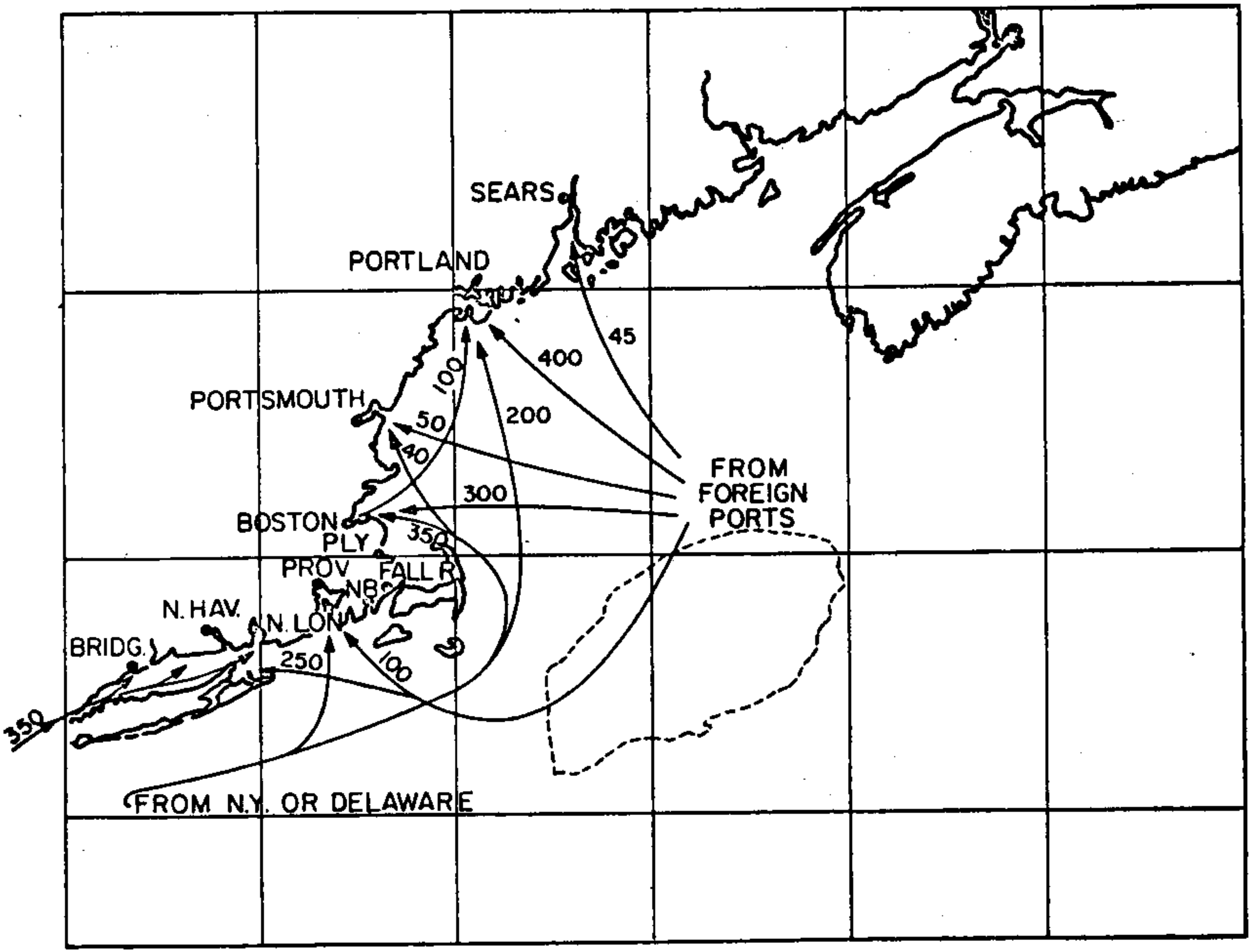


FIGURE 4.1.3 DOMESTIC, NEW ENGLAND OIL MOVEMENTS - 1971 - THOUSANDS OF TONS

Source: offshore Oil Task Group, 1973.

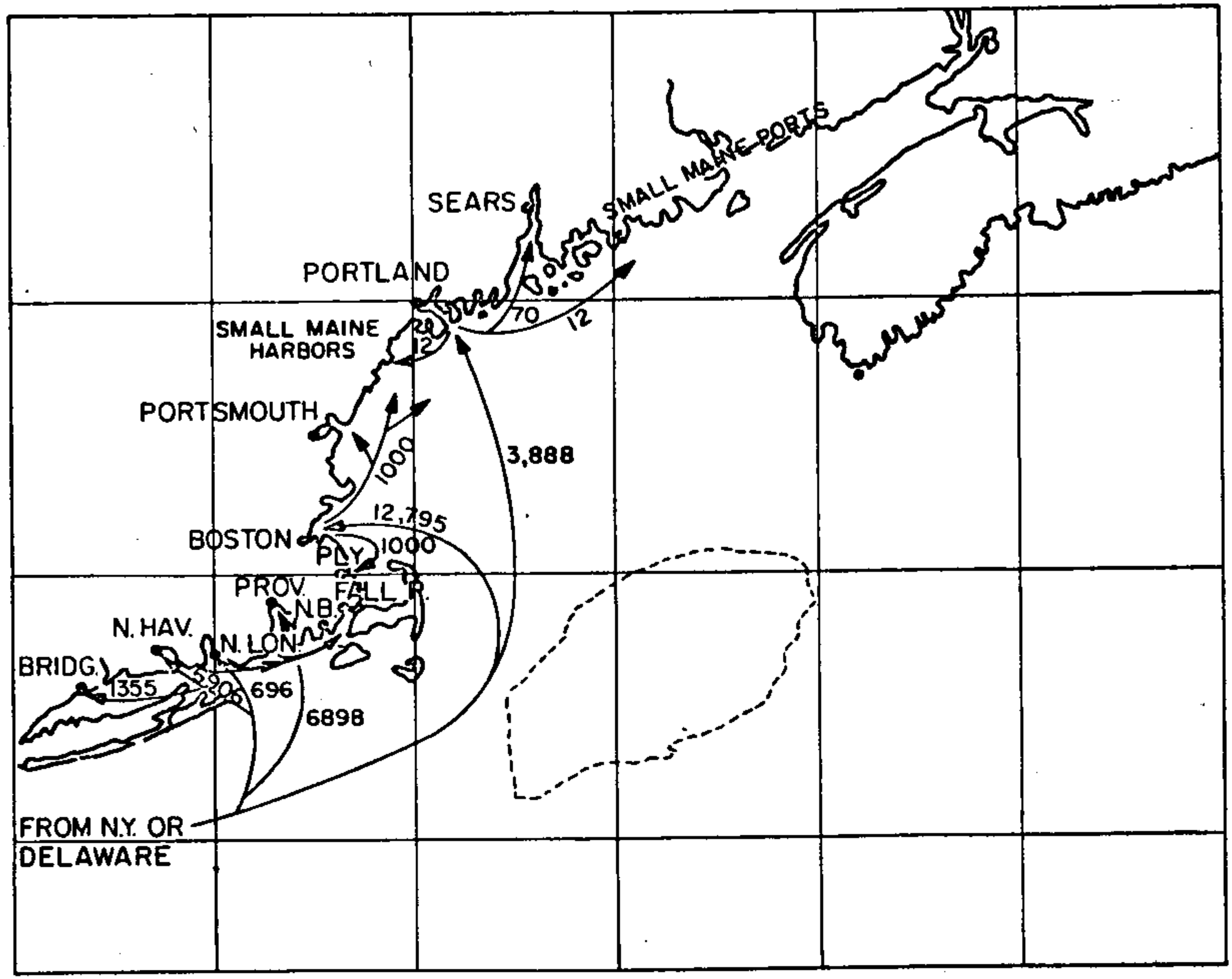
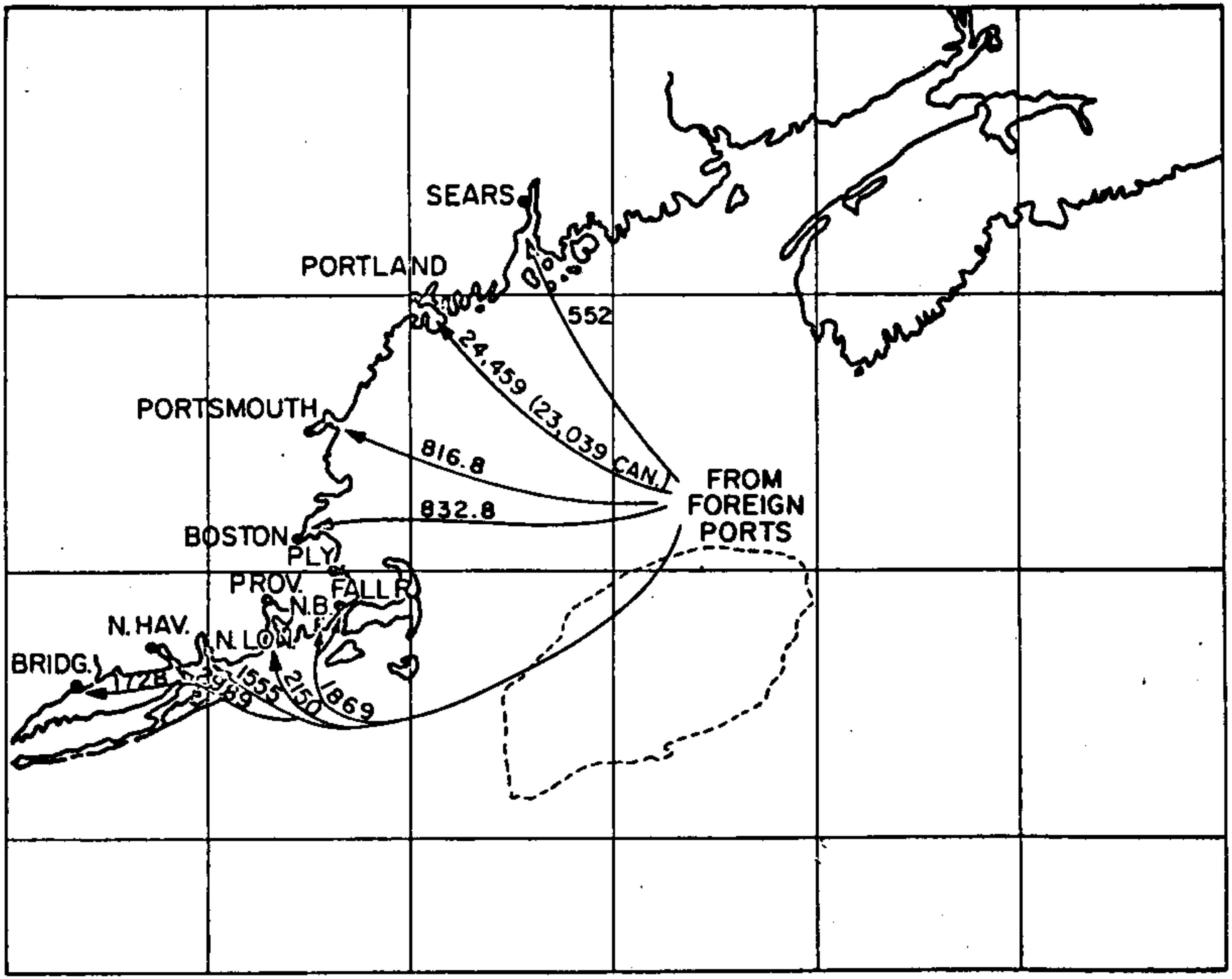


FIGURE 4.1.4 FOREIGN, NEW ENGLAND OIL MOVEMENTS - 1971 - THOUSANDS OF TONS

Source: Offshore Oil Task Group, 1973.



Therefore, it appears we will introduce little or no error into our oil volume pattern estimates by ignoring intraregional offshore movement. However, at least in the case of New England, the tanker traffic densities in some coastal areas are dominated by these secondary movements. This should be kept in mind when interpreting our results.

4.2 Summary of Results of Baseline Traffic Pattern Study

Figure 4.2.1 summarizes the offshore interregional oil flows which resulted from this exercise. In addition, to our estimates for the six coastal "choke points", we have also included the petroleum volumes moving in and out of the major U.S.A. oil ports on this figure. This latter data was taken directly from the COE records. Examining the overall pattern, there are no real surprises. It is noteworthy that the coastwise traffic on the West Coast is an order of magnitude or more smaller than the coastwise traffic on the East and Gulf Coasts. Perhaps the most striking feature of this pattern is the almost complete lack of any correspondence between the location of these flows and the location of the tanker casualties examined in Chapters 2 and 3. The lack of relationship is so obvious that it would be practically nonsensical to attempt any statistical analysis of possible functional forms this relationship might take. It appears rather clear that large oil movements do not necessarily imply a large number of casualties. Conversely, as Guayanilla makes clear, small oil movements (10 million tons per year or less) do not necessarily imply a small number of casualties. It's obvious that one must be moving oil to have a tanker casualty, but in quantifying this risk we must look for explanatory variables other than gross volume moved.

Figure 4.2.2 displays the oil-carrying vessel traffic pattern which resulted from our study. As might be expected, the overall traffic pattern rather closely follows the oil flow pattern of Figure 4.2.1. However, there are some differences. According to our estimates, the average cargo size is higher on the West Coast than the Gulf Coast which in turn is considerably larger than that on the East Coast. Therefore, the East Coast generates the highest interregional tanker traffic densities despite the nearly equal volumes of oil moving in the Gulf. However, the differences are not really significant given the possible errors inherent in our methodology.

FIGURE 4.2.1 ESTIMATED 1974 OFFSHORE, INTER-REGIONAL OIL MOVEMENTS FOR SIX "CHOKE POINTS" AND SELECTED PORTS

All figures are in millions of long tons per year.

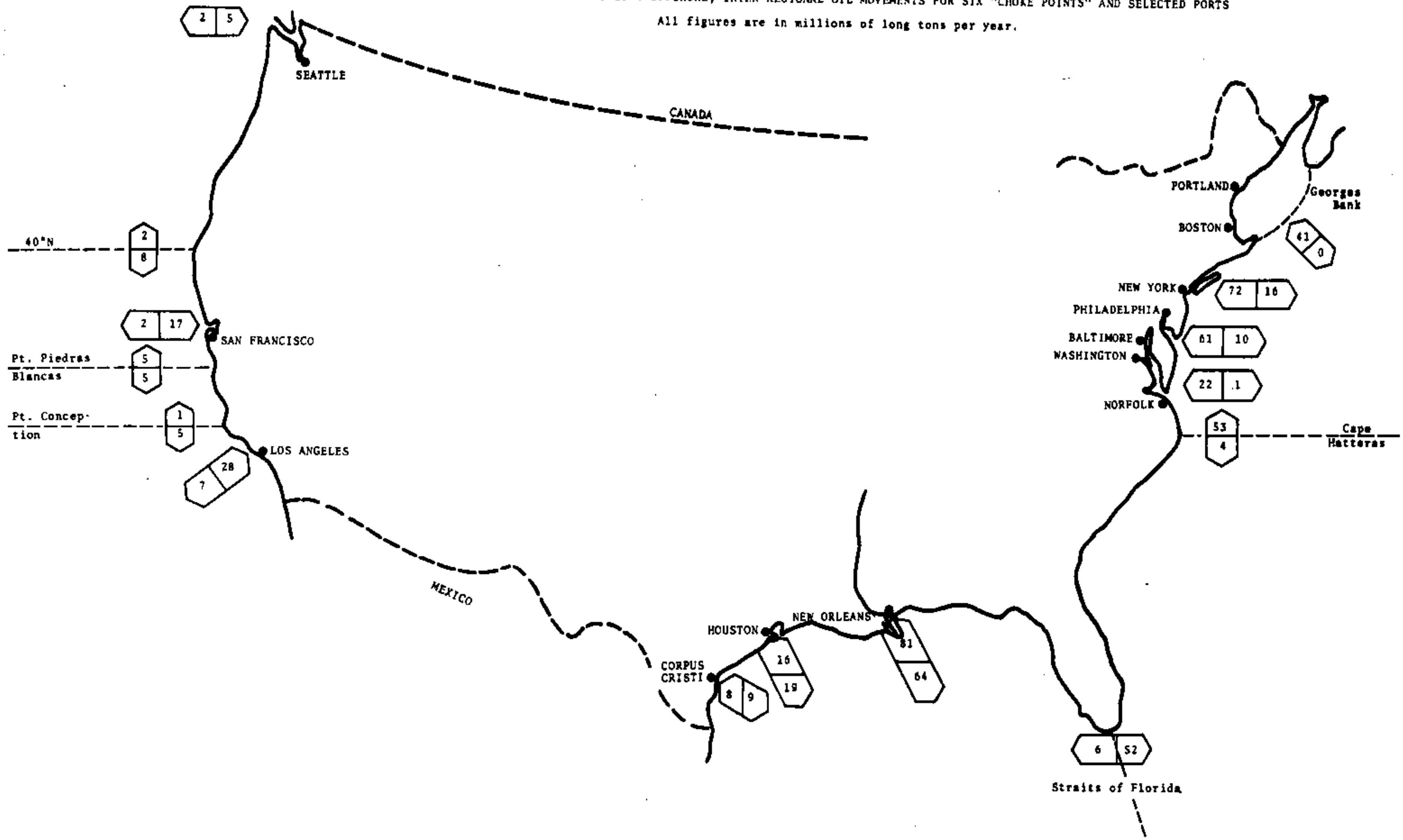
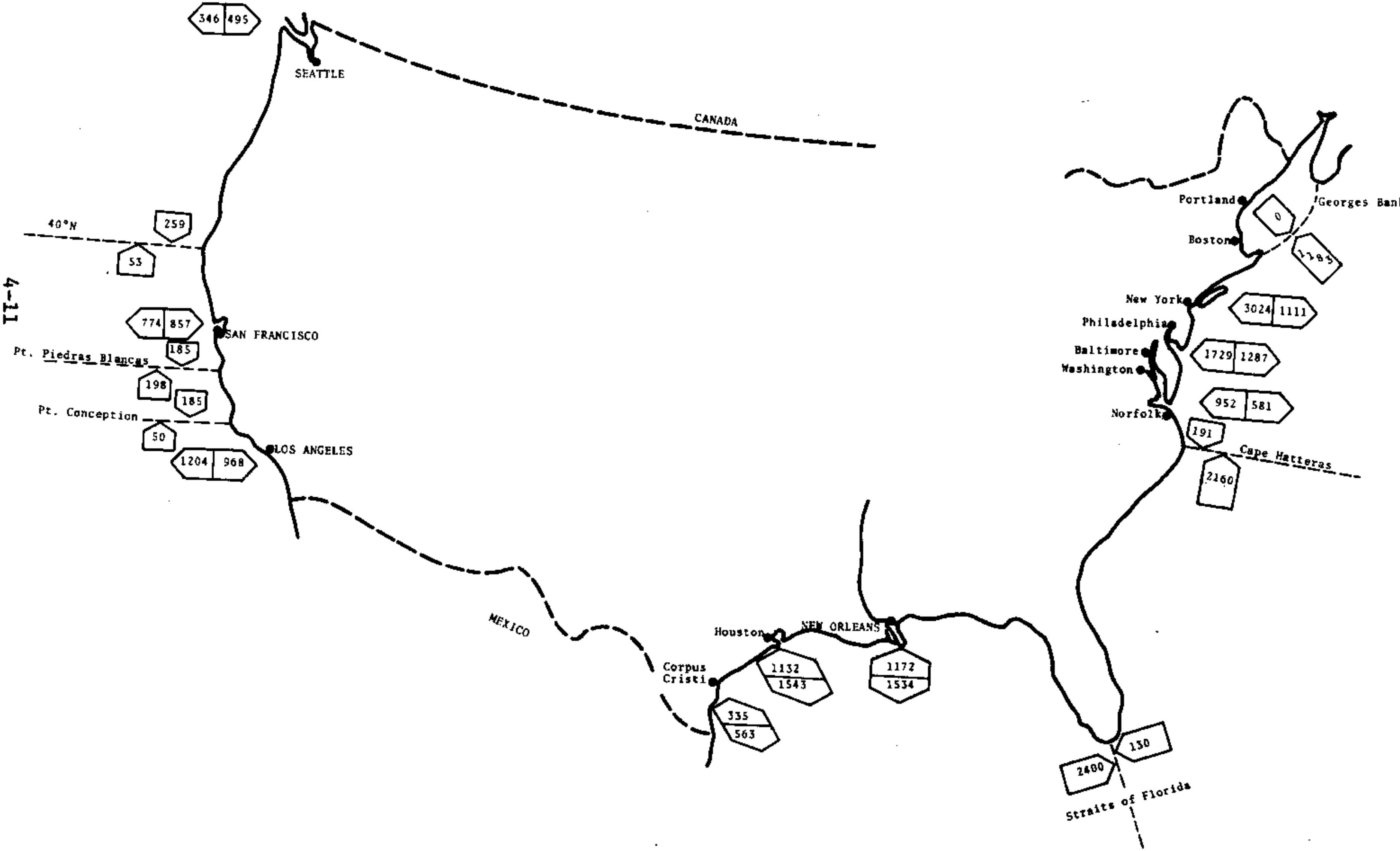


FIGURE 4.2.2 ESTIMATED LOADED 1974 TANKER MOVEMENTS ACROSS SIX "CHOKE POINTS" AND MAJOR PORTS



According to our numbers, the peak coastal "choke point" is the Straits of Florida with about seven loaded tankers per day. The Straits of Florida contributed only one collision and only one tanker grounding (and that was a vessel knowingly entering dangerous waters to assist a burning small boat) to all the tanker casualties examined in Chapters 2 and 3. The Straits of Florida has generally good weather, excellent aids to navigation in the form of a chain of very large, offshore lighthouses, and a traffic separation scheme strongly enforced by Nature. Westbound vessels hug the northern edge of the Gulf Stream to minimize the current; eastbound vessels stay right in the axis of the Stream to maximize the current. Therefore, the fact that we have had few tanker casualties in this area is not totally unexpected. Despite the high tanker traffic density, it may be an unfruitful area upon which to focus offshore vessel control. On the other hand, this area does have a severe, persistent beach pollution problem from tank washings. It is the only area on the East Coast where the prevailing winds are onshore. If we do have a large spill in the Straits of Florida, it is much more likely to reach land than a spill the same distance offshore further north.

The peak harbor for 25' or better port calls is New York with about 11 loaded tankers per day, one-third more than the Delaware Bay. This difference is well within the range of possible errors in these estimates. Nonetheless these numbers are in striking contrast to the complete absence of groundings in the seaward approaches to New York in 1972 through 1976, while Delaware Bay contributed a total of 11 groundings to an overall sample of 48 during the same period. (1)

Overall there is simply no match between the traffic pattern shown in Figure 4.2.2 and the location of the casualties examined earlier. The possible errors in our estimates of this traffic pattern are extremely unlikely to change this conclusion. Any allocation of offshore vessel management resources which is based solely on tanker traffic density and which does not take into account the peculiarities of each specific area will almost certainly be inefficient and uneconomic.

The remainder of this chapter documents the analysis underlying Figures 4.2.1 and 4.2.2. Readers who are interested only in the overall results and are willing to accept our judgement that these numbers are approximately

(1) See Chapter 3.

correct may move directly to Chapter 5.

4.3 1974 U.S. Offshore Petroleum Volume Movements

This section documents our analysis of 1974 oil volume movements for each of the following six "choke" points:

1) Georges Bank
2) Cape Hatteras
3) Straits of Florida
4) Point Conception
5) Point Piedras Blancas
6) 40 degrees North, West Coast

Section 4.4 converts these volume movements to tanker traffic densities.

4.3.1 Georges Bank

For the purposes of this study, all tanker traffic passing westbound between Cape Cod and Cape Sable (Nova Scotia) was deemed to have 'crossed' Georges Bank. Since there are no petroleum shipments outbound from New England, this definition makes the estimation of the Georges Bank oil flow from the Corps data quite simple. Table 4.3.1.1 summarizes the 1974 Corps' data for Northern New England. It is the result of simply aggregating all the in and out oil flows in vessels whose operating drafts were greater than 25 feet for all ports north of Cape Cod. (1)

(1) Department of the Army, Corps of Engineers, "Waterborne Commerce of the United States, Calendar Year, 1974", USGPO, Washington, 1976.

TABLE 4.3.1.1

1974 COE NORTHERN NEW ENGLAND OIL MOVEMENTS
(In Millions of Tons--25' drafts or greater only)

FOREIGN				DOMESTIC			
CRUDE		PRODUCTS		CRUDE		PRODUCTS	
IN	OUT	IN	OUT	IN	OUT	IN	OUT
19.4	--	11.0	--	0	--	16.0	3.7

There is one other source (and outlet) for Northern New England waterborne movements of oil and that is the Cape Cod Canal. Table 4.3.1.2. displays the Corps figures for 1974 movements through the Cape Cod Canal in vessels whose operating draft was 25' or greater.

TABLE 4.3.1.2.

1974 COE MOVEMENTS THROUGH CAPE COD CANAL AT 25+ DRAFT
(Millions of tons--All products)

FOREIGN		DOMESTIC	
EASTBOUND	WESTBOUND	EASTBOUND	WESTBOUND
.9	.8	3.5	1.3

Table 4.3.1.3 compares the results of applying our shortest possible distance assumption to these figures with those from the U.S.G.S study. (1)

(1) U. S. Geological Survey, "National Energy Transportation Systems, Total Petroleum Movements: 1974" (maps), Reston, Virginia, 1977.

TABLE 4.3.1.3

OUR ESTIMATES OF 1974 MOVEMENTS ACROSS GEORGES BANK COMPARED WITH USGS ESTIMATES--Millions of tons

	FOREIGN		DOMESTIC	
	CRUDE	PRODUCTS	CRUDE	PRODUCTS
COE	19.4	10.9	0	10.1
USGS	--	13.8	0	7.1

The calculation underlying the COE figures in this table is quite simple. Take domestic products for example. Under our minimum distance assumption, the westbound Cape Cod Canal flow of 1.3 million tons had to come from the outbound Northern New England flow of 3.7 million tons, leaving 2.4 million tons of intraregional movements in vessels whose operating draft was greater than 25 feet. Total entering domestic product was 16 million tons of which 2.4 was intraregional in origin and 3.5 came in through the Canal. Therefore, 16.0 - 2.4 -3.5 = 10.1 million tons of domestic product had to come across the Georges Bank. The other figures are derived in a similar manner. The dependence of these numbers on our shortest distance assumption is obvious. In this case, since we know independently that there are nil shipments through the Cape Cod Canal to Eastern Canada, the petroleum flow figure for the Bank is probably quite accurate. However, if there were such shipments, it would be incorrect to assume that all the eastbound Canal movements could be subtracted from the required flow across the Bank.

A comparison between the Corps data and the USGS data in Table 4.3.1.3 is interesting. Northern New England has no refineries. All crude entering the region is bound for Canada through the Portland pipeline. Hence, this movement was not included in the USGS study which was focussed on domestic demand. Another major difference between the COE data and the USGS is that the Corps defines movements from the Virgin Islands as domestic which the USGS considered them to be foreign. Given the priveleged position of the Virgin Islands both definitions are defensible. For our purposes, this definitional difference is quite fortunate for it allows us to identify about 3 million tons of the USGS "foreign" products as coming from the very large Amerada-Hess refinery at Limetree Bay, St. Croix. This was about 10% of the Limetree Bay refinery's capacity at this time and hence quite reasonable. With these adjustments, the Corps' data for Northern New England and the USGS study are in excellent agreeement.

In summary, we estimate that in 1974 the oil traffic crossing the Georges Bank comprised:

20 million tons of Canadian Crude

11 million tons of domestic products (3 million tons of this originated in the Virgin Islands)

10 million tons of foreign products

41 million tons total, ALL INBOUND. Almost all the foreign products are undoubtedly coming from either the Caribbean or the Bahamas but we were unable to estimate the split.

4.3.2 Cape Hatteras

Our major aim in this effort was to estimate the offshore but coastwise movement of petroleum. The movements directly into each harbor area can be taken directly from the Corps data. This distinction becomes important when we move to our second "choke point", Cape Hatteras. All the movement into mid-Atlantic ports from sources other than the Gulf of Mexico and the Bahamas approaches the Atlantic coast obliquely. However, a glance at a globe will reveal that this movement can hardly be termed coastwise. Hence, these flows will be deemed to not transit Cape Hatteras. With respect to the "truly" coastal flows around Hatteras, we have the following aggregated data from our two sources.

TABLE 4.3.2.1

1974 PETROLEUM MOVEMENTS - - U. S. EAST COAST NORTH OF HATTERAS (millions of tons)

	FOREIGN				DOMESTIC			
	CRUDE		PRODUCTS		CRUDE		PRODUCTS	
	IN	OUT	IN	OUT	IN	OUT	IN	OUT
COE	80.7	-	66.5	-	9.7	.3	78.3	34.5
USGS	61.2	-	84.3	-	8.9	-	30.1	-

These figures are simply the aggregated flows for all USA ports North of Hatteras where in the case of the COE data the summation is only over movements in vessels whose operating draft was greater than 25 feet.

The crude picture revealed by Table 4.3.2.1 is relatively straightforward. No foreign crude doubled Cape Hatteras in 1974 for Mexico was not an exporter and Venezuelan production is routed through the Windward Passage and approaches the mid-Atlantic from seaward. The 19.5 million tons difference in foreign crude in Table 4.3.2.1 is Canadian crude to Portland, so there is no disagreement there. In 1974, all the domestic crude in Table 4.3.2.1 had to come from the Gulf of Mexico and hence did double Cape Hatteras. Both sources agree that this flow was about 9 million tons.

The product picture is not nearly as clear. The problem is that the difference in products imports between the two sources is 17.8 million tons while the difference in net regional products receipts is 13.7 million tons. (1) The only reasonable way of resolving this discrepancy in our opinion is to assume 17.8 million tons of product receipts from the Virgin Islands (which would be counted as foreign in the USGS figures) and then assume a product flow of 4.1 million tons southward from the mid-Atlantic to ports below Hatteras. While this involves some cross-hauling, for these southern ports could be served directly from Gulf Coast refineries, this pattern is consistent with both the refinery capacity at Limetree Bay in 1974 and the concentration of almost all East Coast refining north of Hatteras. More compellingly, the only alternative is to assume the difference away as a statistical discrepancy. But this would imply very sloppy work on the part of either the Corps or USGS. In any event, this is how we balanced the domestic products figures.

With respect to the "truly" foreign products the only possible source of traffic doubling Cape Hatteras is the Bahamas. In 1974, the only Bahamian refinery, the NEPCO plant at Freeport, was operating at about 10 million tons per year. Most of this undoubtedly went to U.S. ports north of Hatteras. Hence, 10 million tons of foreign products will be assumed to transit Hatteras even though a signifi-

---

(1) Net regional domestic products receipts according to the COE is 78.3 - 34.5 = 43.8. Net regional domestic products receipts according to the USGS is 30.1 million tons.

cant portion of these products undoubtedly went directly to New England which means that some of this traffic was several hundred miles offshore at Hatteras's latitude.

In summary, we estimate that in 1974 the oil traffic doubling Cape Hatteras comprised:

9 million tons of domestic crude northbound
34 million tons of domestic product northbound
4 million tons of domestic product southbound
10 million tons of foreign product northbound.

4.3.3 Straits of Florida

Given the sources at hand, the transport of domestic petroleum from the Gulf Coast to the East Coast through the Straits of Florida can be estimated two ways. An estimate can be produced by looking at the petroleum balance for the East Coast. The petroleum balance for the Gulf Coast generates another estimate. Table 4.3.3.1 shows the requisite summary figures from our two sources.

TABLE 4.3.3.1

1974 PETROLEUM BALANCES: EAST COAST - GULF COAST

(Millions of tons--COE figures include only 25'+ drafts.)

	FOREIGN				DOMESTIC			
	CRUDE		PRODUCTS		CRUDE		PRODUCTS	
	IN	OUT	IN	OUT	IN	OUT	IN	OUT
East Coast, COE	81.8	-	79.9	-	9.7	1.0	94.0	35.1
East Coast, USGS	61.2	-	95.5	-	9.3	-	41.9	-
Gulf Coast, COE	54.5	.1	7.6	.3	5.9	14.2	13.1	49.6
Gulf Coast, USGS	58.7	-	19.6	-		9.3	-	41.9

After adjustment for the Canadian crude, all the crude flows agree nicely pointing to approximately 9 million tons of domestic crude moving eastward through the Straits of Florida. Accepting this, the Corps data then indicates an intraregional movement of about 5 million tons of crude within the Gulf in 25' draft vessels or larger. The only possible foreign crude flow through the Straits of Florida in 1974 was North African crude to the U.S. Gulf. We have been able to locate no source of data which breaks down U.S. imports by country of origin and by whether the crude was landed on the East Coast or the Gulf Coast. The USGS study shows 29.3 million tons of African crude going to the U.S. Gulf. Western African oil will move into the Gulf through the Yucatan Channel. Only Algerian and Libyan crude will move into the Gulf through the Straits of Florida. In 1974, 20% of all U.S. imports of African crude came from Libya and Algeria. (1) For lack of anything better, we assumed that the proportion of North African to all African imports was the same on both the East and Gulf Coasts despite the relative proximity of the former to North Africa. This results in 6 million tons per year of North African crude moving westward through the Straits.

The products figures in Table 4.3.3.1 are a mess. The only way we were able to get them to all balance was to assume 29 million tons of product produced on St. Croix, 12 of which went to the Gulf and 17 of which went to the East Coast. Then all the product import figures agree leaving about 43 million tons of domestic products flowing from the Gulf to the East Coast with an intraregional Gulf movement of products in 25'+ draft vessels of about 7 million tons. The operating capacity at Limetree Bay in 1974 was 29 million tons so this pattern is possible from that point of view, but very tight. Unfortunately, direct communication with Amerada Hess personnel at St. Croix revealed that little, if any, of their product goes or ever went to the Gulf.

As long as any Virgin Islands to Gulf shipments go south of Cuba, whether or not one accepts the USGS data at face value, the same set of flows through the Florida Straits results. Our own judgement is to assume that the Amerada Hess people know what they are talking about. At this point in time, the discrepancy between the USGS figures and the Hes information remains unresolved. In any event, our baseline pattern involves no Virgin Islands' product moving westward through the Straits of Florida.

In summary, all these assumptions lead to the follow-

(1) Anon., International Petroleum Encyclopedia, Volume 7, The Petroleum Publishing Company, Tulsa, 1975.

ing petroleum flows past the Florida Keys:

43 million tons of domestic products eastbound
9 million tons of domestic crude eastbound
6 million tons of foreign crude westbound.

This traffic pattern combined with our assumptions about Hatteras imply that the South Atlantic received 13 million tons of domestic product by water.

4.3.4 Petroleum Flows on the West Coast

The COE information on West Coast oil flows contains considerably larger gaps than the data on the East and Gulf Coasts. There are several specialized oil handling ports on the West Coast for which the Corps reports only gross throughput by commodity. Presumably, these are privately maintained facilities. In any event, the data is not broken down by whether it's a shipment or a receipt, or whether it is domestic or foreign. Obviously, we will require even more heroic assumptions than those needed further east. Fortunately, in most cases, the assumptions required are fairly obvious.

We'll start with Point Conception. Table 4.3.4.1 shows the COE data for all ports south of Pt. Conception for which shipments are broken down by in and out, and foreign and domestic.

TABLE 4.3.4.1

1974 PETROLEUM MOVEMENTS SOUTH OF PT. CONCEPTION
(Millions of tons, 25'+ draft, COE data includes only those ports for which full COE data is published.)

	FOREIGN				DOMESTIC			
	CRUDE		PRODUCTS		CRUDE		PRODUCTS	
	IN	OUT	IN	OUT	IN	OUT	IN	OUT
COE	11.2	-	3.1	-	5.5	.6	4.1	4.4
USGS	15.2	-	3.3	-	5.5	-	-	-

In addition, abbreviated information is available from the COE for the four ports shown in Table 4.3.4.2.

TABLE 4.3.4.2

PORTS SOUTH OF PT. CONCEPTION FOR WHICH ONLY ABBREVIATED INFORMATION IS AVAILABLE FROM COE

	CRUDE	PRODUCTS	REMARKS
CARPINTERIA	.2	.1	Assume receipts.
EL SEGUNDO	5.6	1.9	Assume crude in, product out
ENCINA		.7	Assume receipts.
VENTURA	1.5	-	Assume shipment.

Several large refineries are located in the El Segundo area. Ventura serves the Santa Barabara Basin fields and has almost no refining capacity. Hence, the above in and out assumptions.

Table 4.3.4.1 shows a 4 million ton difference in crude imports. This can be resolved by assuming 4 million of the 5.6 million tons of crude into El Segundo are foreign, leaving 1.6 million tons of domestic crude into El Segundo which matches the Ventura figure. The 5 million tons of domestic crude shown in Table 4.3.4.1 then is all extra-regional flow from Alaska. This jibes nicely with the Alaskan output in 1974 of about 250,000 barrels per day. Therefore, under these assumptions all the crude flows balance.

The products import figures in Table 4.3.4.1 match, which is consistent with the assumption that all the product flows in Table 4.3.4.2 are domestic in origin. This set of assumptions leads to a net product surplus of about 1 million tons which we assumed to be shipped up the coast to ports north of Pt. Conception. In summary our assumptions lead us to

5 million tons of Alaskan crude southbound
1 million tons of product northbound

doubling Point Conception. We should also point out that under our assumptions the coastal traffic between Ventura and Los Angeles includes another 1.5 million tons of domestic crude southbound.

The next "choke point" we looked at was Point Piedras Blancas. On the coast from Point Conception to Point Piedras Blancas, the petroleum trade is concentrated in two harbors: Estero Bay and San Luis Obispo. Only, abbreviated data is available in the COE tabulations for these two ports, making it necessary to assume both direction and type (domestic or foreign). Table 4.3.4.3 shows the available information from the COE.

TABLE 4.3.4.3.

1974 OIL MOVEMENTS - - ESTERO BAY AND SAN LUIS OBISPO
(Million of tons per year)

HARBOR	CRUDE	PRODUCTS
Estero Bay	3.8	.3
San Luis Obispo	.8	.5

These ports are outlets for San Joaquin Valley production; there is much more production than refining capacity in this area. Therefore, all the crude movements in Table 4.3.4.3 were assumed to be outbound. Since there were no major crude exports from the West Coast in 1974, we assumed these shipments were domestic. Since we have already balanced the crude trade south of this area, we assumed these shipments were northbound to the San Francisco area, even though this involves some cross-hauling.

The products shipments may either be inbound or outbound. We assumed them to be inbound because it balanced the products flow further north better and resulted in less cross-hauling, but given the refining capacity in the Bakersfield area we may well be wrong. In any event, this assumption combined with our earlier estimates of 1 million tons of products moving northward at Point Conception, which we now assume to be receipts for this area leaving .2 million tons continuing northward, leads to the following flows at Point Piedras Blancas:

5.0 million tons of Alaskan crude southbound
4.6 million tons of California crude northbound
.2 million tons of domestic products northbound.

For the San Francisco area, we have the in and out figures shown in Table 4.3.4.4 from our two sources and the more abbreviated COE data shown in Table 4.3.4.5.

TABLE 4.3.4.4

PETROLEUM MOVEMENTS - - SAN FRANCISCO AREA
(Millions of tons per year)

	FOREIGN				DOMESTIC			
	CRUDE		PRODUCTS		CRUDE		PRODUCTS	
	IN	OUT	IN	OUT	IN	OUT	IN	OUT
COE	8.3	-	.6	.1	7.8	-	4.1	5.9
USGS	10.0	-	1.4	-	2.4	-		1.8

TABLE 4.3.4.5

COE FIGURES FOR SAN FRANCISCO AREA--NOT BROKEN DOWN

HARBOR	CRUDE	PRODUCTS	ASSUMPTIONS
Other Harbors, S.F. Bay	1.6	.5	Crude assumed receipt

Since there is no production in the San Francisco Bay area, all the crude in Table 4.3.4.5 can safely be assumed to be incoming. The crude flows balance better if we take the incoming crude in Table 4.3.4.5 to be foreign. The USGS domestic crude in Table 4.3.4.4. is that from Alaska only. When we combine these 2.4 million tons with our earlier estimate of 4.6 million tons of Southern Californian crude moving northward, we get pretty good agreement with the 7.8 million COE figure. Thus, all the crude figures are reasonably well balanced, with a total of 7.4 million tons of Alaskan crude moving south along the northern Californian coast.

If we assume the .5 million tons of products in Table 4.3.4.5 to be domestic receipts (roughly matching the .2 million tons estimated to be coming from the south), we obtain a net shipment outbound of 1.3 millions tons. Some of this product probably goes to Hawaii but we assumed it all to be shipped northward to the Portland, Oregon area which has a net receipt of 3 million tons of products (from COE data). The remaining 1.7 millions tons we took to be shipped from refineries in the Puget Sound area.

Our summary estimates for the Northern California Coast then are:

7.4 million tons of Alaskan crude southbound

1.3 million tons of domestic products northbound.

Finally, for the northern Oregon coast, we have the same Alaskan crude flow southbound and 1.7 million tons of products southbound.

4.4 Conversion of Petroleum Flows to Tanker Traffic

4.4.1 Methodology

In this section, we will use the COE data on arrivals and departures of tankers over 25' draft, together with the previously estimated petroleum flows to develop estimates of tanker traffic at each of our six "choke points". A number of important problems present themselves in this conversion including part-loading, multiple discharge ports on the same voyage, and most importantly the lack of correspondence between incoming and outgoing draft. Since the Corps is interested in the actual use of its harbor improvements, it collects data in terms of the actual operating draft at the time the channel was transited. A fully loaded tanker which entered a harbor at 37 feet may depart that harbor in a number of different ballast conditions. A normal ballast condition for such a ship leaving sheltered water in good weather would be about 25 foot draft. But it could easily be four or five feet more depending on conditions. Worst of all the COE data does not specify whether or not the ship was coming from or bound to a foreign or domestic port. Whether or not the port of embarcation (destination) is foreign or domestic is crucial to our estimates of coastwise traffic. In short, we had to find some way of accounting for the difference in loaded and ballast drafts and some way of breaking the tanker port calls into foreign and domestic voyages.

For our purposes, we may regard the COE port call data to contain the following information for each harbor for which records are kept:

Petroleum Flows: inbound foreign
inbound domestic
outbound foreign
outbound domestic

Port Calls:	inbound, draft 25 ft. or more inbound, draft 37 ft. or more inbound, draft 40 ft. or more (46 ft. on West Coast) outbound, draft 25 ft. or more outbound, draft 37 ft. or more.

The reasoning behind the draft breakdown is:

a) We are only interested in loaded ships with a draft of 25 feet or greater.

b) Tankers whose loaded draft is less than 37' will have a normal light ballast draft of less than 25'. Tankers whose loaded draft is in excess of 37' will generally be ballasted to greater than 25' on commencing the return voyage.

c) All vessels which have a draft in excess of 40' (46' on the West Coast) can safely be assumed to have arrived from a foreign origin. The deepest draft, loading port in the Gulf of Mexico is about 40' while the deepest American loading port in 1974 was Alaska's 46 feet.

With these observations in mind, we estimated the number of loaded tankers leaving each port, with a loaded draft greater than 25', to be the total number of tanker exits over 25' leaving that harbor less the number of entries at 37' or greater. Similarly, the number of loaded, 25+ draft tankers entering a harbor was taken to be the total number of entries at 25 feet or greater, less the number of exits at 37 feet or greater. The dependence of these assumptions upon the tanker operators' ballasting habits is obvious.

The next step was to distribute the loaded arrivals and departures so determined to foreign and domestic trade. All loaded departures were assumed to be bound to a domestic port since the U.S. had nil petroleum exports in 1974. The entries were distributed as follows:

a) All entries over 40' (46' on the West Coast) were taken to be loaded tankers from foreign origins. For each harbor, these entries were subtracted from the total number of loaded entries over 25' as estimated above.

b) The total inbound tanker capacity was estimated by multiplying the number of entries at each draft by the draft-capacity table displayed in Table 4.4.1.1 and summing over all drafts over 25'. A similar capacity figure was estimated for only those entries over 40' (46' on the West Coast).

TABLE 4.4.1.1

OPERATING DRAFT (feet) VERSUS CARGO CAPACITY (long tons)
ASSUMPTIONS USED IN ESTIMATING CARRYING CAPACITY
OF LOADED ENTRIES AND EXITS

DRAFT	CARGO DWT.	DRAFT	CARGO DWT.
55	135,000	39	48,000
54	123,000	38	43,000
53	120,000	37	38,000
52	118,000	36	33,000
51	112,000	35	30,000
50	107,000	34	27,000
49	102,000	33	25,000
48	96,000	32	22,000
47	91,000	31	21,000
46	86,000	30	17,000
45	80,000	29	14,000
44	75,000	28	12,000
43	70,000	27	11,000
42	64,000	26	10,000
41	59,000	25	9,000
40	54,000		

c) The ratio of the inbound domestic oilflow to the inbound capacity after removal of the over 40' (46') tonnage was computed. The ratio of the inbound foreign flow net of the capacity over 40' (46') to the inbound capacity after the removal of the 40' (46') tonnage was also computed. These two ratios were then normalized so that they summed to one.

d) The number of domestic entries was taken to be the first ratio times the total number of loaded entries over 25' after removal of the the over 40' (46') arrivals. The number of foreign entries was taken to be the second ratio times the same number.

Basically, all we are doing is assigning the total loaded entries to foreign and domestic entries in proportion to the ratio of the domestic flow to the foreign flow after adjustment for the foreign flow assumed to be moving on greater than 40' (46') ships. The computed capacity was always higher than the actual flows. The normalization corresponds to assuming that both foreign and domestic movements operate under the same relative 'inefficiency'. To put it another way, we are assuming the same size distribution in the less than 40' (46') ships serving the foreign trade as those serving the domestic trade.

The nice thing about this procedure is that it does not involve an assumption about average tanker cargo size. Hence, the average cargo sizes (both domestic and foreign) obtained from this procedure can be used as a check on the numbers.

4.4.2 Georges Bank Tanker Traffic Estimates

For 1974, the COE shows a total of 1505 tanker and tank barges over 25' inbound to New England ports north of Cape Cod on 25' or better drafts. The total capacity of these vessels using the tonnage assumptions of Table 4.4.1.1 is 48 million tons. The outbound loaded traffic, after adjustment for the greater than 37' arrivals, is 252 vessels, all domestic; and all bound, we assume, for other New England ports. The estimated capacity of these intraregional vessels is 7 million tons. The net inbound capacity is 41 million tons which is just slightly higher than our estimate of 40 million tons of oil crossing the Georges Bank. When we distribute the entries by the above procedure, we find we have 857 loaded arrivals from foreign ports and 648 - 252 arrivals from domestic ports outside Northern New England. The Georges Bank is our one "choke point" in which the distribution of entries to foreign and domestic origins has no effect on the traffic density at the "choke point". We thus have 30 million tons of foreign crude and products moving in 857 vessels for an average cargo size of 35,000 tons and 10 million tons of extra-regional domestic products moving in (648-252) arrivals for an average domestic cargo size of 25,000 tons. Both these numbers seem quite reasonable. Under these assumptions, the estimate of total 1974 <u>loaded</u> tanker traffic on the Georges Bank is 1183 vessels, one way. This translates to 3.2 tankers per day, each way.

4.4.3 Cape Hatteras

The COE data for 1974 shows a total of 7937 arrivals of tankers over 25' draft to ports north of Hatteras. When we apply the above reasoning to these numbers, we find we estimate that the number of foreign arrivals is 4469, the number of loaded domestic arrivals is 3468, and the number of loaded domestic departures is 963. The net incoming capacity, according to our estimates, is 217 million tons, about 10% higher than our earlier estimate of 200 million tons for the net petroleum transport into the area. So we have essential agreement in this respect; the excess can easily be ascribed to part-loading.

Our numbers claim that there is a net of 2523 loaded tankers into the region in domestic trade. We must deduct from this the Virgin Islands shipments for they do not double Hatteras. We did this by assuming the same size distribution for these shipments as for other domestic traffic. We must also add in the Bahamian traffic. This was done by assuming the same size distribution in this trade as in the rest of the foreign trade. All these assumptions lead to an average domestic cargo size of 21,000 tons which may be a little low (perhaps due to multiple discharge ports) and a foreign average cargo size of 33,000 tons which seems quite reasonable. In any event, our overall estimate for Hatteras is 2160 loaded tankers northbound per year and 191 loaded tanker southbound

4.4.4 Straits of Florida

For the Florida Straits we have two independent bases for our traffic density estimate: the East Coast port call data, and the Gulf Coast data. According to the 1974 COE East Coast figures, there were 9768 tanker arrivals on the East Coast on 25'+ drafts. Our estimate of the capacity of these vessels at these drafts is 296 million tons. Our methodology claims that 5339 of these vessels were in foreign trade and 4429 in domestic. Comparing the number of departures over 25' draft with the number of arrivals over 37 feet we estimate that there was 1395 loaded departure from East Coast ports in 1974 at better than 25' draft. The capacity of these outbound loaded tankers we estimate at 52 million tons from their draft distribution. This leaves a net incoming capacity of 244 million tons which is in quite good agreement with the net incoming oil flow of 229 million tons estimated earlier. For the Straits of Florida our big concern is the net domestic traffic inbound to the East Coast which, according to the above numbers, is 4429 - 1395 = 3034 vessels. There are only two places whence these tankers can come: the Gulf and the Virgin Islands. Earlier we estimated the Gulf to East Coast flow at 52 million tons and the Virgin Islands to East Coast trade at 16 million tons. Assuming the same size distribution in each trade results in 2320 loaded tankers moving eastward through the Straits of Florida.

Working the same problem from the Gulf of Mexico side, the COE shows a total of 3667 arrivals over 25' draft to Gulf Coast ports. Our methodology distributes 2404 of these vessels to foreign trade and 1263 to domestic trade. The COE shows a total of 4469 departures over 25'. Our methodology attributed 3386 of these ships to loaded domestic. This leave a net of 2126 loaded vessels out of the region in domestic trade. Aside from a few odd shipments to the West Coast, all these ships are bound for the East Coast through the Straits. This number agrees to within 10% with the number obtained from the East Coast port call data. Therefore, we can be reasonably confident that there were approximately 2300 loaded tankers moving eastward through the Straits of Florida in 1974.

With respect to the westbound, North African to Gulf Coast crude trade, we used the total number of foreign arrivals over 25' to the Gulf and the total foreign flow into the Gulf (61 million tons) to obtain an average cargo size of 40,000 ton which appears reasonable since we are talking about longer routes loading in deepwater terminals, and discharging for the most part to large refineries capable of handling such lot sizes. Applying this average cargo size to our estimate of the westbound crude trade leads to 130 loaded foreign crude carriers moving westward through the Florida Straits in 1974. The total loaded traffic through the Straits then is estimated at 2420 tankers per year.

4.4.5. West Coast Traffic Densities

Given the gaps in the West Coast COE port call data, we really have no choice but to abandon the above methodology, assign an average cargo size to at least part of the trade, and check this assumption with what port call data we do have. For Point Conception, we estimated 1 million tons of products moving northward and 5 million tons of Alaskan (Cook Inlet) crude moving southward. If we assume an average cargo size of 20,000 tons for the Northbound trade, subtract these departures from the COE data for ports south of Point Conception, we are left with 140 arrivals of Alaskan oil. This translates to 36,000 tons per cargo on this trade which seems quite reasonable. In short, for Point Conception, we estimate 140 loaded tankers downbound in 1974 and 50 loaded products tankers northbound.

The situation for Point Piedras Blancas is even worse. The petroleum trade in this area is dominated by Estero Bay and San Luis Obispo. Not only do we have only abbreviated volume data for these ports but the port call data consists only of the total number of ships and the maximum ship size. There is no information on draft distribution. To obtain an estimate of the averge cargo size for these harbors, we used figures for other harbors with the same maximum ship size. For Estero Bay, with a maximum reported ship size of 44' draft, we used an average cargo size of 27,000 tons. For San Luis Obispo with a maximum ship size of 34' draft, we assumed an average cargo size of 20,000 tons. Combining these numbers with the earlier volume estimates, we obtain 141 tankers leaving Estero Bay with crude northbound and 40 tankers leaving San Luis Obispo, also northbound. Combining this traffic with the flows passing by the area, we end up with 185 loaded tankers southbound and a 198 loaded tankers northbound.

For San Francisco Bay entrance, our methodology resulted in 857 loaded tankers inbound with an estimated capacity of 21 million tons and 774 loaded tankers outbound with an estimated capacity of about 14 million tons. The inbound capacity compares reasonably well with the total of 17 million tons flowing inbound to San Francisco Bay but the outbound capacity is over six times our estimated outbound flow of about 2 million tons. This may be evidence of an underestimation of the outbound flow. A much more likely explanation in our opinion is that tankers leaving San Francisco Bay ballast much more heavily than normal when going through the Golden Gate. In any event, we fell back to assigning average cargo size to the Northern California flows estimated earlier. Using the average Alaskan crude and coastwise products cargo size derived for Southern California, we estimate 53 loaded tankers a year moving northbound at 40N and 259 loaded tankers moving southbound at this point for 1974.

4.5 Postscript on Tanker Information Requirements

It should be obvious that all the foregoing estimates are uncomfortably dependent on a whole chain of assumptions. The need for better information about tanker traffic is obvious. Our own feeling is that this could be done relatively cheaply by slightly upgrading the COE database. The COE already requires monthly reports of all commercial vessels using COE harbor improvements. The Corps need only require that in addition to the information presently supplied, oil carrying vessels entering and exiting the harbors give last port of call, next port of call, and the volume of cargo on-board in and out. No new system need be set up. THe COE could still be responsible for maintaining the confidentiality of the data. We would need the COE system to be extended to privately maintained, oil handling ports, most importantly, Limetree Bay and Guayanilla. However, the need for an entirely new data collection system and data base escapes us.

CHAPTER 5. PROJECTIONS OF MAJOR OIL FLOWS AND LARGE TANKER TRAFFIC IN U.S. WATERS

5.1 Methodology

The movement of oil in American waters is in a state of sharp transition due to:

a) decreasing Lower 48 production in the face of continuing domestic oil demand growth,

b) the advent of Alaskan and Mexican oil,

c) the likely introduction of deep draft terminal facilities in the Gulf in the near future.

To study some of the implications of these changes on future oil flows and tanker traffic in U.S. waters, we used the Martingale World Petroleum Network Model, PETNET1. (1) Tanker traffic is a product of the volume and location of oil consumption, the volume and location of crude production, the physical characteristics of the world petroleum network, and the amount and type of tanker capacity afloat. PETNET1 describes the supply of tankers in terms of the deadweight afloat in each of ten tanker size categories. Hence, on each run, PETNET1 takes as input:

a) a set of assumptions about future oil consumption in each of 20 market regions for each year in the run,

b) postulated oil production capacity for each of 30 producing areas for each year in the run,

c) a description of the world oil transportation network (route lengths for some 450 routes, pipeline capacities, transhipment facilities, canal and terminal draft restrictions, canal and pipeline tolls) to be assumed in each year of the run,

---

(1) PETNET1 is the copyrighted property of Martingale, Inc. Its use has been loaned to M.I.T. solely for these analyses.

d) a set of assumptions about the tanker capacity afloat in each of ten tanker size categories for each year in the run, together with sufficient data about each size ship to allow the program to compute the unit short-run cost of assigning each size tanker to each route in the network on which that tanker can safely operate.

For each year in a run, PETNET1 finds that set of oil flows and the corresponding assignment of tankers by size to each route such that supply and demand are in balance throughout the network. In so doing, PETNET1 operates under the assumption that tanker transportation markets operate under textbook competition. In each year of a run, it finds the short-run competitive market equilibrium set of flows and the corresponding set of market clearing spot tanker rates by route for the supply and demand pattern, the network, and the fleet specified by the user. The output then is:

1) the equilibrium set of flows by route and tanker size category,

2) the fob and cif crude locational price differentials for each source area and market region,

3) the tanker spot rates by route and tanker size category.

Thus, for our purposes not only can we obtain an estimate of the major oil flows into the United States by coast but also the size ship which will carry these flows under the postulated supply and demand pattern and the given network and fleet.

For the purposes of these analyses, we made two runs of PETNET1, each covering the period, 1977 to 1987 inclusive. In the first run, we assumed the Louisiana Offshore Oil Port (LOOP) goes into operation in 1980 at 2.4 million barrels per day operating capacity, expanding to 4.0 million barrels per day in 1984. In the second run, we assumed no provision of deep draft terminal capacity in the USA throughout the decade under analysis. Since our primary interest was in the impact of LOOP on tanker traffic, all other variables were held constant in these two runs.

The 1977 baseline supply and demand pattern used in these runs is shown in Table 5.1.1. which also gives an idea of the level of aggregation of PETNET1.

TABLE 5.1.1

1977 BASELINE PRODUCTION AND CONSUMPTION PATTERNS

SOURCE AREA	PRODUCTION (mm tons/qtr)	MARKET REGION	CONSUMPTION (mm tons/qtr)
Saudi Arabia	118	Northern Europe	115
Kuwait	23	Southern Europe	54
Iran	69	USA East	79
U.A.E.	25	USA Central	120
Southern Iraq	15	USA West Coast	33
Northern Iraq	12	Canada	23
Qatar	5	Mexico	9
Oman & Bahrain	5	Central Amer. & Carib.	8
Egypt	6	Venezuela	5
Libya	25	East Coast, S. Amer.	22
Algeria & Tunisia	13	West Coast, S. Amer.	7
Nigeria	26	Japan, Korea & Taiwan	73
Gabon	3	Australia & N. Zealand	8
Other Africa	3	Southeast Asia	14
Indonesia	21	India, Pak. & Burma	7
Australia	5	Middle East	15
China	2	Eastern Mediterranean	7
Other Asia	3	North Africa	4
Venezuela	29	South & East Afrca	6
Mexico	13	West Africa	2
Ecuador	2		
Other South America	14		
USA PAD 1	1		
Usa PAD's 2, 3 & 4	88		
USA PAD 5	22		
Alaska	12		
Canada	18		
North Sea	13		
Western Europe	4		
Eastern Mediterranean	3		
Eastern Bloc Exports	10		

The 1977 figures are based on actual DOE and OECD figures as reported in the Oil and Gas Journal and Petroleum Economist except for consumption in a few third world nations which are projections from 1976 figures. In our two runs, we assumed a 2.5% annual oil demand growth rate for Europe and 3% elsewhere.

5.1.1 Sampler of Recent Oil Consumption Growth Forecasts.

USA: On the high side are the Administration's pronouncements in support of President Carter's National Energy Program and Congresssional critiques of that program. The Administration, based on FEA analyses, predicts 3-4% USA oil demand growth absent of aggressive energy policy. (Executive Office of the President, Energy Policy and Planning, The National Energy Plan, April, 1977). The Congressional Research Service puts American oil consumption at 4.5% per annum until 1980, 2.5% from 1980 to 1985, and about 2% from 1985 on (Congressional Research Service, Project Independence: U.S. and World Energy Outlook through 1990, Pub. No. 95-31, U: Washington, June, 1977). The OTA also suggests we may see a return to pre-embargo growth rates of about 4.5% per year (Office of Technology Assessment, Analysis of the Proposed National Energy Plan, USGPO, August, 1977). With one exception, the lowest projection of U.S. oil demand growth I have seen for the period 1977 to 1990 is 1.5% by Exxon ("Exxon Finetunes U.S. Energy Forecast", Oil and Gas Journal, 19 December 1977). This is down one-half percent from Exxon's early 1977 projections (Exxon, Energy Outlook, 1977-1990). OECD has developed two recent projections, a so-called 'reference' case representing continuation of present trends and policy and an 'accelerated' case representing rapid implementation of aggressive and successful energy policy on the part of the oil consuming nations (Organiztion for Economic Cooperation and Development, World Energy Outlook, Paris, 1977). The postulated policy includes complete deregulation of energy prices and rapid leasing of all unexplored oil prospects. OECD puts USA oil consumption growth rate (1974 to 1985) at 1.5% for the 'accelerated" case and 2.8% for the 'reference' case. The lowest projection of USA oil demand growth is .6% per annum through 1985 by the Administration if the National Energy Plan is impemented. This claim for the energy program has been met with considerable skepticism by both congress and industry. For one thing, it is not consistent with FEA's own analyses of two yeares ago which indicated that even with complete price deeregulationn and stringent conservation measures, the best that could be hoped for was a gradual reduction to a 1% annual oil consumption growth rate (Federal Energy Administration, National Energy Outlook, USGPO, Washington: February, 1976). All the other recent forecasts of future USA oil consumption fall within the range of 2% to 4% per year. Since USA petroleum consumption grew 6.5% in 1976 and 5% in 1977, all these projections assume an immediate and substantial reduction in U.S. oil consumption growth. (Oil Expands U.S. Energy Demand Role", Oil and Gas Journal, 30 January 1978)

EUROPE: OECD's most recent projections puts 1974 to 1985 European oil consumption growth at 3% for the 'reference' case and 1% for the 'accelerated' case. (OECD, ibid.) Preliminary figures indicate that European oil consumption in 1977 will be almost flat due to a sharp reduction in heavy fuel usage balanced by continued growth in gasoline demand. ("OPEC Trade Surplus Shrinks $3 billion", Oil and Gas Journal, 19 December 1977)

JAPAN: OECD puts 74 to 85 Japanese oil consumption growth at 4.0% ('accelerated') and 5.5% ('reference'). (OECD, ibid.) 1977 Japanese consumption growth will be about 5%. (OPEC Trade..., ibid.)

OVERALL: All the overall projections fall in the range of 1.8% to 3.5% for the period through 1985. OECD forecasts 3.1% for the 'reference' case and 1.8% for the 'accelerted'. (OECD, ibid.) Exxon estimates 4.2% from 1975 to 1980 and 2.5% overall from 1980 to 1990. (Exxon Public Affairs Department, World Energy Outlook, Exxon Background Series, 4/77; see also: Kameros, R. "The World's Tanker Fleet Outlook for the Future", Exxon Marine, Volume 22. No. 2. Fall, 1977) Irving Trust predicts 2.5% through 1985.("Irving Trust Sees No Global Oil Pinch", Oil and Gas Journal, 2 January 1978) Most prognosticators show declining oil consumption growth rates through the 80's. For example, the World Energy Conference predicts overall growth rates of 1.9% to 3% through 1985 dropping to .7% to 1.9% for the post-1985 period.
(World Energy Conference, World Energy Resources 1985-2020) The widely disseminated WAES study has world non-Communist oil demand growing at 3.2% (HIGH) to 2.0% (LOW) through 1990 with oil consumption growth dropping to .4% (HIGH) and -.7% (LOW) for the 1990 to 2000 period. (Workshop on Alternative Energy Strategies, Energy: Global Prospects, 1985-2000,McGraw Hill: New York, 1977). The OECD suggests

that OECD oil consumption could begin to decline in the mid-80's but only if "strenuous effort and commitment by governments and their citizens" occurs and under "admittedly favourable assumptions that supply expansion and conservation will be sustained". The OECD's past predictions of increase in non-OPEC energy supply and decrease in oil demand growth rates have been laughably (if that's the word) overly optimistic. In their 1974 study, OECD predicted that at present price levels, the USA would be a net oil exporter in 1980. (OECD, Energy Prospects to 1985, 2 vols., Paris: 1974) Their most recent study represents a sharp change in this position but still leaves their 'accelerated' scenario very much on the low end of all present predictions of oil consumption growth. Preliminary figures for 1977 indicate overall non-Opec, non-Communist oil consumption growth of 4.5% compared with 6% for 1976. (OPEC Trade...", ibid.)

5.1.2 Oil Production Pattern

The future production pattern used assumes:

1) No embargo. No OPEC nation artificially limits production. Future OPEC production capacity by nation is based on the CIA 1981 and 1985 projections. (1) Near-market OPEC with the exception of Iraq (Venezuela, Indonesia, Nigeria, Algeria, and Libya) are all relatively mature, well explored oil provinces from which little if any new production can reasonably be expected. The CIA figures reflect this judgement. Production in these countries was held constant or decreased slightly throughout the thirteen year period of these runs. Iraq is pushing aggressively to double their present 2.4 million barrels per day capacity. There is little doubt that the prolific Iraqi fields are capable of producing at the targeted levels. In these six runs, Iraq was assumed to gradually increase production capacity to 5 million barrels per day by the late 1980's. The United Arab Emirates is the only Persian Gulf country outside of Saudi Arabia which appears to have substantial room for production increases. UAE production was increased from its present level of about 2.1 million barrels per day to 3.5 million barrels per day by the late 80's. PETNET1 'floats' Saudi Arabian production. That is, in each year of each

(1) Central Intelligence Agency, The International Energy Situation: Outlook to 1985, ER 77-10240 U, April, 1977

run, whatever additional production is required to meet the postulated demand for that year in that run after all other available production capacity is lifted is assumed to be produced by Saudi Arabia. This is consistent with Saudi Arabia's role as the 'price-leader' in the OPEC oligopoly and OPEC's use of the most important Saudi Arabian crude as the 'marker crude' to which all other crude prices are tied. In any event under this assumption Saudi Arabian production is an output of the model's computations and not an input. In our two runs, Saudi Arabian production had to go to almost 19 million barrels per day in 1987. There is no doubt that the Saudi Arabian reserves of more than 160 billion barrels can be made to produce at well over 19 million barrels per day. Presently installed production capacity is conservatively rated at ten million barrels per day and Aramco recently announced plans to increase this to 14 million barrels per day by 1983. In short, under the assumption that Saudi Arabia and the other OPEC nations do not produce substantially below their demonstrated capability, there appears to be enough oil around to effect the two scenarios we have postulated.

2) The basic assumption with respect to non-OPEC production used is that no new major, near-market finds come on-line in real quantity before 1988. Alaska is assumed to level off at 1.6 million bpd in the early 80's; Mexico at 2.3 million bpd by 1984 and the North Sea at 3.5 million barrels per day by 1982. USA Lower 48 and Canadian production are assumed to continue the 3% decline per year observed over the last five years. Most of the non-OPEC on-shore areas are quite well-explored. And even if a really large, offshore find were made tomorrow, it would take a minimum of 6 or 7 years to bring it on-line in quantity. (1) The first North Sea oil discovery was made in 1969 but it wasn't until last year that North Sea oil began to flow in quantities exceeding a few hundred thousand barrels per day.

3) Net Eastern Bloc exports to the West have been assumed to remain at present levels in these six runs. It would take a really big change in net East Bloc exports to substantially effect the timing of the next boom and there are no real signs at the present that such a change is likely to occur.

(1) Exxon claims 10 to 12 years. (Exxon, World Energy Outlook, Exxon Background Series, EBS 4/77)

With respect to the network itself, all pipelines presently in place were assumed to be in operation throughout with the exception of the currently closed TAP Line and I.P.C. Lines which were assumed to resume operation in 1980. All presently planned expansion plans were brought on line as scheduled including the Yanbu Line, the SOHIO Line and the reversal of the Transmountain Line. Neither the Northern Tier Line nor the Kitimat Line were included. The Phase I deepening of the Suez Canal to 52' was assumed to be completed on schedule in 1980 but the Phase II plan was not included. Transhipment capacity in the Western Caribbean, Eastern Caribbean and Bahamas was assumed to level off after 1980 as was the lightering capacity at the Pacific end of the Panama Canal. In the first run, the Louisiana Offshore Oil Port (LOOP) was assumed to begin operation on schedule at the capacity projected by Arthur D. Little and to expand in 1984 to 4.0 million barrels per day capacity -- again an A.D.L. projection. (1) In the second run, LOOP was not included. Neither SEADOCK nor an East Coast deepwater terminal were included in either of the runs. Table 5.1.2 shows the pipeline and transhipment capacities assumed to be operating through time in these runs.

---

(1) U.S. Department of Transportation, "Final Environmental Impact/4(f) Statement for the LOOP Deepwater Port License Application, Executive Summary", Deepwater Ports Project, Office of Marine Environment and Systems, Washington, D.C., 1976

TABLE 5.1.2

PIPELINE AND TRANSHIPMENT TERMINAL CAPACITIES ASSUMED IN TSC RUNS

Link Name	1977	1980	1984
I.P.C. Line	0	1200	1200
TAP Line	0	500	500
SUMED Line	1600	2300	2300
T.I.P. Line	1000	1200	1200
Dortyol Line	500	700	1000
Yanbu Line	0	2000	2300
Strategic Line	800	800	2800
Colonial/Plantation	1500	1500	1500
SOHIO & Four Corners	30	650	650
Transmountain Line	0	180	180
Bantry Bay	600	600	600
Western Caribbean	1600	1200	1200
East. Carib. & Bahamas	1000	1200	1200
Panama Canal Terminal	250	250	250
LOOP Run No. 1	0	2400	4000
LOOP Run No. 2	0	0	0

Basically, we assumed no major changes in terminal draft restrictions other than LOOP.

PETNET1 breaks the world tanker fleet into ten different size categories. In effect, it acts as if there were only ten 'standard' tankers in the fleet. The characteristics of these ten ships used in these runs are shown in Table 5.1.5. Presently, the largest of these tankers which can enter East and Gulf Coast ports fully loaded is Tanker Category 3. For these runs, we assumed that scrappings and deliveries would balance out through the next ten years. That is, we assumed that the deadweight afloat in each of the ten tanker size classes would remain unchanged. The deadweight afloat used in these runs was taken from that existing in January, 1978 according to Shipping Statistics and Economics. These numbers are shown in Table 5.1.6. which includes 80% of the combination tonnage on the grounds that before a boom can occur this fraction of the combination tonnage will be pulled into the oil trades.

Table 5.1.3

DEADWEIGHT AFLOAT BY TANKER SIZE CATEGORY USED IN TSC RUNS

SIZE CLASS	MILLION TONS
1	8.1
2	12.2
3	23.8
4	18.0
5	35.0
6	25.0
7	40.0
8	111.0
9	57.0
10	18.2

Table 5.2.1. of the next section shows the results of the 1977 base year runs. Comparison with actual market history for last year will reveal good overall agreement with actual flows throughout and excellent agreement with respect to foreign flag spot rates by tanker size category. Note that Alaskan oil is just barely in surplus on the West Coast with a small amount being transhipped through the Panama Canal which also corresponds to actual history. PETNET1 does have three significant shortcomings for the purposes of this analysis:

a) Firstly, PETNET1 does not comprehend slow-steaming. It allows tanker owners only the option of operating at service speed or laying up. Hence, when the market is overtonnaged as it is now, PETNET1 overpredicts the VLCC and ULCC spot rates by about 5 Worldscale points.

b) Secondly, PETNET1 does not allow partloading. In reality 45' draft tankers can enter American ports if they partload. Therefore, the difference between the Category 3 spot rates and the Category 4 spot rates tends to be a bit large.

c) Thirdly, PETNET1 does not comprehend the Jones Act. Spot rates on Jones Act routes are predicted correctly only when the world tanker market is in boom.

These caveats notwithstanding, a great deal of insight into future petroleum flows in US waters can be gained by studying the response of world petroleum shippers to a range of American deep draft terminal possibilities as if (a), (b) and (c) were of no importance, as we shall see in the next section.

5.2 The Results of the PETNET1 Projection Runs

Tables 5.2.1 through 5.2.5 summarize the key results of our two projection runs for present purposes. Table 5.2.1 shows the major American flows for the 1977 base case. Table 5.2.6 below compares the USA import pattern as predicted by PETNET1 with actual results as reported by Oil and Gas Journal. (1)

TABLE 5.2.6

ACTUAL VS COMPUTED USA 1977 IMPORT PATTERN
(Millions of Barrels per Day)

	PETNET1	OGJ
Total USA Oil Demand	18.55	18.53
Total USA Oil Production incl. NGL	9.82	9.80
Total USA Oil Imports	8.72	8.71
Imports by Origin		
Canada (by pipeline)	.20	.28
South America	1.78	1.78 (2)
North Africa	1.77	1.55 (2)
West Africa	2.31	1.56 (2)
Europe	.22	.13
Persian Gulf via Transhipment	2.45	2.81 (2)
Far East		.58 (2)

In interpreting Table 5.2.6, it is important to note that we have no data as yet on the crude origin of 1977 products imports. Total foreign refined products imports totaled 2.1 million barrels per day in 1977. In Table 5.2.6, 1.2 million barrels of this were assigned to

(1) "1978: Oil's Biggest Volume Year Yet", Oil and Gas Jounrnal, 30 January 1978, p. 136.

(2) See text for treatment of imported products. The agreement in the first three lines of this table is, of course, the product of the input and not the result of PETNET1 computations.

TABLE 5.2.1. MAJOR INTERREGIONAL OIL FLOWS IN U.S. WATERS BASE CASE 1977

	MILLIONS OF TONS	NUMBER OF LOADED SHIPS
FOREIGN TO U.S. EAST COAST		
NORTH AFRICA - USA EAST	117	2344
WEST AFRICA - USA EAST	83	2276
OTHER - USA EAST	11	224
	211	4844
STRAITS OF FLORIDA		
US GULF - USA EAST	40	1000
LANDED IN USA GULF		
ALASKA - USA GULF VIA PAN.	2	44
ECUADOR - USA GULF VIA PAN.	9	292
VENEZUELA - USA GULF	80	1200
TRANSHIPMENT - USA GULF	94	1884
NIGERIA - USA GULF	32	914
	217	4334
LANDED IN USA WEST COAST		
ASIA - WEST COAST	-	500
ALASKA - USA WEST	45	-
PASSING PAST WEST COAST		
ALASKA - USA GULF BY PAN.	2	44

TABLE 5.2.2.
MAJOR
INTERREGIONAL - OIL FLOWS
IN US WATER - 1982
LOOP AT 2.4 MM BPD
SOHIO TRANSMOUNTAIN OPERATING
3% OIL DEMAND GROWTH

FOREIGN TO USA EAST COAST		
NORTH AFRICA - USA EAST	149	2980
WEST AFRICA - USA EAST	79	2568
TRANSHIPMENT - USA EAST	33	660
	261	6208
STRAITS OF FLORIDA		
USA GULF - USA EAST	40	1000
LANDED IN USA GULF		
ECUADOR - USA GULF VIA PAN.	9	292
VENEZUELA - USA GULF	91	1825
MEXICO - USA GULF	11	220
P.G. TO U.S. GULF VIA LOOP	113	323
TRANSHIPMENT TO US GULF	80	1597
	304	4257
LANDED IN USA WEST COAST		
INDONESIA - WEST COAST	36	367
ALASKA - USA WEST	80	736
	116	1103
PASSING PAST WEST COAST		
ALASKA - USA GULF BY PAN.	-	-
ALASKA - EAST VIA HORN	-	-

TABLE 5.2.3.
MAJOR INTERREGIONAL FLOWS
IN U.S. WATERS - 1982

NO LOOP, 3% DEMAND GROWTH
SOHIO: TRANSMOUNTAIN OPERATING

FOREIGN TO US EAST COAST		
NORTH AFRICA - USA EAST	144	3600
NORTH SEA - USA EAST	118	2360
	262	5960
STRAITS OF FLORIDA		
US GULF - USA EAST	40	1000
LANDED IN USA GULF		
VENEZUELA - USA GULF	91	1825
ECUADOR - USA GULF VIA PAN.	9	292
NIGERIA - USA GULF	67	2139
MEXICO - USA GULF	11	220
TRANSHIPMENT - USA GULF	113	2264
PANAMA TEAM - USA GULF	12	393
	303	7133
LANDED IN US WEST COAST		
INDONESIA/BRUNEI - USA WEST	48	480
ALASKA - USA WEST	71	710
	119	1190
PASSING PAST WEST COAST		
ALASKA- USA GULF VIA PAN.	8	80

TABLE 5.2.4.
MAJOR INTERREGIONAL OIL FLOWS
IN U.S.A. WATERS IN 1987

NO LOOP - 3% DEMAND GROWTH
SOHIO: TRANSMOUNTAIN OPERATING
(SMALL TANKERS ARE IN BOOM)

FOREIGN TO USA EAST COAST		
NORTH AFRICA - USA EAST	140	2800
NORTH SEA - USA EAST	118	4200
PG VIA SUMED	63	1500
	321	8500
STRAITS OF FLORIDA		
USA GULF - USA EAST	40	1000
LANDED IN USA GULF		
VENEZUELA - USA GULF	76	2527
ECUADOR - USA GULF VIA PAN.	9	292
NIGERIA - USA GULF	127	3100
PG VIA SUMED	31	620
TRANSHIPMENT TO US GULF	113	3766
PANAMA TEAM TO US GULF	12	393
CALIFORNIA - USA GULF VIA PAN.	63	2100
	431	12,798
LANDED IN US WEST COAST		
P.G. - US WEST	82	900
S.E. ASIA - US WEST	66	700
ALASKA - US WEST	68	800
	216	2400
PASSING PAST WEST COAST		
ALASKA - USA GULF VIA PAN.	12	494

TABLE 5.2.5.
MAJOR INTERREGIONAL OIL FLOWS
IN U.S. WATERS - 1987

LOOP AT 4.0 MMBPD
SOHIO: TRANSMOUNTAIN OPERATING
3% OIL DEMAND GROWTH

FOREIGN TO USA EAST COAST		
NORTH AFRICA - USA EAST	140	2800
WEST AFRICA - USA EAST	63	1254
NORTH SEA - USA EAST	118	3933
	321	7987
STRAITS OF FLORIDA		
USA GULF - USA EAST	40	1000
LANDED IN USA GULF		
ECUADOR - US GULF VIA PAN.	9	292
VENEZUELA - USA GULF	76	2527
NIGERIA - USA GULF (NO LOOP)	7	133
PANAMA TERMINAL - USA GULF	12	393
CALIFORNIA - USA GULF	33	1097
TRANSHIPMENT - USA GULF	113	3766
PERSIAN GULF - USA GULF VIA LOOP	181	602
	431	8810
LANDED IN USA WEST COAST		
PERSIAN GULF - USA WEST	52	550
ASIA - USA WEST	66	700
ALASKA - USA WEST	68	800
	186	1850
PASSING PAST WEST COAST		
ALASKA - USA GULF VIA PAN.	12	393

Venezuelan crude on the basis of 1976 figures. The remaining 900,000 bpd were arbitrarily divided equally among North Africa, West Africa, and the Persian Gulf. The great bulk of this 900,000 bpd was undoubtedly refined in the Virgin Islands and the Bahamas.

With this assignment of products imports, the overall import pattern matches rather well with one glaring exception. PETNET1 in its 1977 computations moved no Asian crude to the West Coast. In reality, about 600,000 bpd of Indonesian and Brunei crude was imported, presumably to the West Coast. PETNET1 ignores crude quality differentials. It may be that the West Coast refineries require the lighter Asian crudes to mix with the generally very heavy Californian crudes to produce their high gasoline product mix. A secondary error is the underprediction of Persian Gulf imports despite the underprediction of Asian imports. It's probable in our input hypotheses that we have underrated Gulf of Mexico and Caribbean transhipment capacity. For example, we know that Exxon has two 70,000 ton tankers shuttling between Baytown and a lightering station 60 miles offshore in the Gulf. This operation alone represents 200,000 bpd of transhipment not included in PETNET1. Other companies also are running lightering operations in the Gulf. The combined effect of these two errors is an overprediction of African imports.

Overall the match is reasonably good but we do need to keep in mind the apparent crosshauling of Asian crude for it implies that there may be more tanker traffic on the West Coast (and more surplus Alaskan crude) than PETNET1 predicts. On the other hand, as West Coast refiners adapt to Alaskan crude, Asian imports to the West Coast may drop to nothing as PETNET1 predicts.

Turning to the 1982 and 1987 projections, Tables 5.2.2 through 5.2.5, there are several interesting points.

1) In both cases, under our 3% demand growth postulate, there is a substantial rise in the number of loaded tanker port calls on the east Coast. (1) From a base of about 6000 port calls at present, the East Coast rises to 7000 in 1982 and 9000 in 1987. LOOP has essentially no effect on

---

(1) These tables do not include Canadian crude flowing through Portland which we can expect to remain unchanged due to pipeline restrictions.

these numbers.

2) The percentage rise of port calls on the West Coast, much of it associated with through shipment of Alaskan oil to the Mid-continent, is still more rapid. But in absolute terms it is considerably lower than the East Coast rise due to the much lower original base and the large unit cargoes. 1982 landings on the West coast are independent of deep draft terminal capacity on the other coasts; but, interestingly enough, 1987 West Coast landings and liftings are not. In the mid to late 80's, the tanker market is very tight in these runs. Smaller tankers are in especially short supply. PETNET1 is desperately trying to economize on these smaller ships. One way it finds to do this is to use medium size ships to bring foreign crude to the 50 foot plus West Coast ports and then use shallow draft vessels to take crude from california to the USA Gulf via the relatively short Panama Canal route. The program is in essence using California as a transhipment terminal. Of course, the program doesn't realize it is substituting a Jones Act route for a foreign flag route and further we can be sure that transhipment capacity in the Gulf would further expand before this would happen. But it does demonstrate how hard the world petroleum system will have to work in the mid to late 80's if the U.S. doesn't expand its Gulf and east Coast deep draft terminal capacity well beyond that presently contemplated by LOOP. The program never chose to take Alaskan crude to the U.S. Gulf or East Coasts via Cape Horn.

3) PETNET1 indicates that the surplus of Alaskan crude on the West Coast will be relatively short-lived if Alaskan production levels off at 1.6 million bpd, and the SOHIO and Transmountain Lines enter operation as scheduled, and the West Coast refineries are able to switch from Asian crudes to Prudoe Bay oil.

4) The Gulf of Mexico future is, as might be expected, completely dominated by LOOP. Without LOOP, the number of loaded port calls in the Gulf nearly doubles by 1982. With LOOP it decreases slightly. In the mid 80's, unless further expansion of deep draft terminal capacity occurs, the

number of port calls begins to rise rapidly even with LOOP. By 1987 without LOOP, the number of port calls will be triple current levels under the assumptions used in these runs. Even with 4 million barrels per day of LOOP deep draft capacity, this number will double.

5.3 Implications for System Design

The obvious impact of LOOP and the potential impact of other offshore terminals should play an important role in our thinking about offshore vessel traffic management. If our findings on groundings mean anything, moving vessels to deeper, less restricted waters and moving the transition to pilotage further offshore can't help but be beneficial in terms of number of casualties. On the other hand, the size of the indiviual units, and the fact that total spill volumes are dominated by a handful of extremely large spills, suggests that the VLCC and ULCC traffic to these terminals receive special treatment. We certainly don't want LOOP to be a 'hot spot' in future tanker casualty studies.

There are indications in our casualty data that aids to navigation may need improvement, with special emphasis on radar target strength and identificiation. There appears to be a need for better navigational accuracy upon landfall (or terminal-fall in this case). LORAN-C may be sufficient but shore-based or fixed platform radar beacons bear consideration. The data indicates that conning errors and the related issue of location of pilot boarding point may be as important as navigational problems. The whole concept of a nearly self-policing, closed-shop, pilotage service might be scrutinized. The data indicates that collisions appear to be best handled by traffic separation and enforced bridge to bridge communication. The accident proneness of incoming as opposed to outgoing vessels suggests an ECAREG-like clearance system if for no other reason than to get the incoming crews on their toes.

REFERENCES

Anon (1975), International Petroleum Encyclopedia, 1975, Volume 7, The Petroleum Publishing Company, Tulsa, 1975.

Baratt, M.J. (1976) "Collision Avoidance Maneuvers in Restricted Visibility", J. Institute of Navigation. Vol. 29, No. 4, October, 1976.

Beyer, A.H., and Painter, L.J. (1977) "Estimating the Potential for Future Oil Spills from Tankers, Offshore Developments and Onshore Pipelines", Proceedings 1977 Oil Spill Conference, API-EPA-USCG Pub. No. 4284, Washington, D.C., API.

CAORF (1977), Proceedings 1st CAORF Symposium, June 23 and 24, 1977, National Marine Research Council, Kings Point, 1977.

Cockroft, A.N. (1976) "Statistics of Collisions at Sea", J. Institute of Navigation, Vol. 29, No. 3, July, 1976.

Crane, C.L. (1974) "Maneuvering Safety of Large Tankers: Stopping, Turning and Speed Selection", Maritime Reporter and Engineering News, 1 January 1974.

Devanney, J.W. III, and Stewart, R.J. (1974) "Primary Physical Impacts of Offshore Petroleum Developments - Analysis of Oil Spill Statistics" MITSG 74-20, MIT Sea Grant Program, Cambridge, 1974.

Devanney, J.W. III and Stewart, R.J. (1974) "Bayesian Analysis of Oil Spill Statistics", Marine Technology, Vol. 11, No. 4, October, 1974.

Devanney, J.W. III (1975) "A Brief Look at the Coast Guard 1969-1973 Tanker Casualty Data Base", Martingale Report to Environmental Protection Agency, Martingale Inc., Cambridge, 25 November 1975.

Fujii, Y. (1977) "Development of Marine Traffic Engineering in Japan", J. Institute of Navigation, Vol. 30, No. 1, January, 1977.

Fujii, Y., Yamouchi, I., and Mizuki, N. (1974), "The Probability of Stranding", J. Institute of Navigation, Vol. 27, No. 2, April, 1974.

Gray, W.O., Carven, C.J. and Becker, G.L. (1977) "International Regulation of the Tanker Industry", Proceedings 1977 Oil Spill Conference, API-EPA-USCG, API Pub. No. 4284, Washington, D.C.

Kemp, J.F. (1976) "Two Hundred Years of Collision Regulation", J. Institute of Navigation, Vol. 29, No. 4, October, 1976.

Kemp, J.F. (1977) "The Danger of Collisions with Merchant Vessels", J. Institute of Navigation, Vol. 30, No. 3, September, 1977.

National Transportation Safety Board (1969) "Collisions between Radar Equipped Ships", J. Institute of Navigation, Vol. 22, 454.

Offshore Oil Task Group (1973) "The Georges Bank Petroleum Study", MITSG 73-5, MIT Sea Grant, February, 1973.

Operations Research Inc. (1975) "Spill Risk Analysis Program, Volume I", ORI Technical Report 964, 7 October 1975.

Patell, J., Norrbin, N., Devanney, J., and Szasz, N. (1974) "Simulation of Vessel Encounters in Confined Waters", Hydrodynamics for Safety, Tenth Symposium, Naval Hydrodynamics, Office of Naval Research, ACR-204, October, 1974.

Stewart, R.J., and Kennedy, M.B. (1978) "An Analysis of U.S. Tanker and Offshore Petroleum Production Spillage Through 1975", Martingale Technical Report, MT-78-1, U.S. Department of Interior Contract No. 14-01-0001-2193, 10 May 1978.

Stewart, R.J. (1976) "A Survey and Critical Review of U.S. Oil Spill Data Resources with Application to the Tanker Pipeline Controversy" Martingale Report to the Department of the Interior, Martingale Inc., Cambridge, 7 October 1976.

Stewart, R.J. (1977) "The Tanker - Pipeline Controversy", Proceedings 1977 Oil Spill Confrerence, API-EPA-USCG, API Pub. No. 4284, Washington, D.C.

Tani, H. (1968) "The Reverse Stopping Ability of Supertankers", J. Institute of Navigation, Vol 21: 118.

TSC (1978) "Offshore Vessel Traffic Management (OVTM) Study, U.S. Department of Transportation, Transportation Systems Center, Cambrige, August, 1978.

U.S. Department of the Army, Corps of Engineers, "Waterborne Commerce of the United States, Calendar Year 1974" USGPO, Washington, D.C.

U.S. Department of Transportation, "Final Environmental Impact Statement 4(f), LOOP Deepwater Port License Application, Executive Summary, Deepwater Ports Project, Office of Marine Environment and Systems, Washington, D.C., 1976.

U.S. Geological Survey, "National Energy Transportation System, Total Petroleum Movements: 1974" (Maps), Reston, Virginia, 1977.

Van Berlekom, W.B., and Goddard, T. (1972) "Maneuvering of Large Tankers" Paper presented at the Society of Naval Architects and Marine Engineers Annual Meeting, New York, November, 1972.

Webster, W.C., (1974) "When is Collision Unavoidable?" Hydrodynamics for Safety, Tenth Symposium Naval Hydrodynamics, Office of Naval Research ACR-204, Arlington, 1974.

Wheatley, J.H. (1972) "Circumstances of Collisions and Strandings" Marine Traffic Engineering, Proceedings Royal Institute of Navigation and Royal Institute of Naval Architects Conference, 1972.

Wylie, F.J. (1977a) "Fully Automated Radar Plotting in the Context of Some Past Collisions, Part I" J. Institute of Navigation, Vol. 30, No. 2, May, 1977.

Wylie, F.J. (1977b) "Fully Automated Radar Plotting in the Context of Some Past Collisions, Part II" J. Institute of Navigation, Vol 30, No. 3, September, 1977.