Tanker Accident Rates and Expected Consequences in U.S. Ports and High Seas Regions

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ABSTRACT

As increasing amounts of hazardous materials cargo are transported by the marine mode, the associated risk to public safety and the environment has been a significant concern. The development of representative accident rates and consequences for marine transport has been hindered by difficulties in working with various data bases that are required to responsibly address this problem. A methodology that was developed to derive accident rates of hazardous materials marine transport in U.S. ports and high seas regions by using data collected from multiple sources is described in this paper. The focus of the study was tanker and tanker barge movements because these vessels are responsible for almost all hazardous materials movement by water. Several U.S. ports and high seas regions in the Gulf of Mexico and the Atlantic Ocean were selected for study. The resulting accident rates were coupled with conditional spill rates and consequences to derive expected release amounts for each geographic area. Several important findings emerged, including the relative risk of hazardous material movements in the Atlantic and Gulf regions. The paper concludes with a comparison of the research findings with other studies of domestic and international tanker transport.

As increasing amounts of hazardous materials cargo are transported by the marine mode, the associated risk to public safety and the environment has been a significant concern. The development of representative accident rates and consequences for marine transport has been hindered by difficulties in working with various data bases that are required to responsibly address this problem.

A methodology that was developed to derive accident rates of hazardous materials marine transport in U.S. ports and high seas regions is described in this paper. It is based on the use of empirical data on vessel movements and accidents; these data are maintained by various federal agencies. Detailed information on domestic vessel movements and aggregate data on foreign vessel movements in U.S. waters is maintained by the Corps of Engineers, U.S. Department of the Army, and was made available for use in this analysis. Data on shipping accidents, known as the Commercial Vessel Casualty File, are recorded by the U.S. Coast Guard and were also used in this study. Collectively, these data bases allow for the development of accident rates segmented by many different shipping characteristics.

The focus of the study was tanker and tanker barge movements because these vessels are responsible for almost all hazardous materials movement by water. Several U.S. ports and high seas regions in the Gulf of Mexico and the Atlantic Ocean were selected for study. They include Mobile Bay, Houston Ship Channel, Corpus Christi, Delaware Bay, and Providence. These ports were chosen because of their geographic locations and levels of tanker and tanker barge activity. In most cases, port definitions were expanded to consider the entire harbor or bay location to establish consistency between movement and accident records. Weighted averages of Atlantic and Gulf regions were also derived for comparison.

In addition to the estimation of accident rates, expected release rates were derived by using the accident rates, conditional spill rates, and associated consequences. The results of this project are also compared to findings from previous studies of domestic and international tanker transport.

ANALYSIS METHODOLOGY

The analysis was segmented according to the following geographic classification:

1. Vessel movements and related incidents in the harbors and bays where the ports are located, and
2. Vessel movements and related incidents in the high seas of the Gulf of Mexico and the Atlantic Ocean.

The analysis was also segmented according to the following accident types:

1. Collision,
2. Fire or explosion,
3. Grounding, and
4. Other (including structural failure).

For each geographic location-accident type pair, the following accident and damage statistics were compiled (including frequencies and histograms):

1. Number of accidents,
2. Number of fatalities and injuries, and
3. Monetary loss.

TABLE 1 Summary of Analysis Methodology

Data Base	Vessel Type	Weight of Vessel (grt)	Location	Accident Type	Data Available	Measures
Accident	Tankers and tanker barges	⩾500	Harbor or bay, or high seas	Collision, fire or explosion, grounding, other	1976-1980	No. of accidents; no. of fatalities and injuries; monetary loss
Movement	Tankers and tanker barges	⩾333	Harbor or bay, or high seas	-	1980	No. of vessel trips; no. of tons shipped; no. of vessel-miles; no. of ton-miles

For each geographic location, the following shipping volume measures were computed:

1. Vessel movements (trips),
2. Tons shipped,
3. Vessel-miles, and
4. Ton-miles.

These measures, combined with the accident measures previously described, serve as denominators from which to derive accident rates.

The analysis methodology is summarized in Table 1. Three aspects of the movement analysis should be noted:

1. A sample of Gulf and Atlantic port shipping records was analyzed for high seas measures; results were applied to the remainder of the shipping records.
2. Domestic shipping results were extrapolated to foreign shipping traffic by using aggregate foreign tonnage by commodity and domestic coastal travel only.
3. Extrapolation to the period 1976 to 1979 was done by using aggregate tonnage from previous years.

A more detailed description of this methodology is contained in the following discussion.

Establishing the vessel class to focus on requires identifying descriptors in both the volume and incident files that describe a consistent vessel type. The two factors considered were gross registered tons (grt) and vessel classification codes. Number of gross registered tons appears in the casualty file and can be derived for the movement file, which contains net registered tons. Vessels that weigh more than 500 grt were selected because vessels of this size would be indicative of cargo vessels that are seaworthy. The vessel classifications selected for the analysis were tankers and tanker barges.

For each harbor and bay, a frequency table was constructed of all shipping and receiving movements for tankers and tanker barges that weigh more than 500 grt; the table was segmented by type of commodity carried (see Table 2 for the Houston Ship Channel case). For every harbor and bay under consideration, with the segmentation just described, there remain a small number of shipments that are included in the shipping population that are carrying commodities that are not hazardous. The only three commodity types that are definitely known to be hazardous in this list are crude petroleum, petroleum products, and chemicals, in the limiting case. However, these three commodities together constituted more than 98 percent of all shipments transported by self-propelled tankers and tanker barges in and out of any of the ports; this validates the appropriateness of using this methodology to represent hazardous materials transport by tanker.

TABLE 2 Tonnage of Tankers and Tanker Barges Weighing More Than 500 grt, Segmented by Type of Commodity Carried, in the Houston Ship Channel

Type of Commodity (tons)	Self-Propelled Tanker	Tanker Barge	Total
Fish products	0	3,509	3,509
Crude petroleum	4,637,312	1,828,244	6,465,556
Non-metallic minerals	0	364,521	364,521
Food products	37,496	42,085	79,581
Chemicals	1,079,850	7,871,327	8,951,177
Petroleum products	14,590,835	16,582,345	31,173,168
Basic metals	0	3,427	3,427
Scrap materials	0	483,858	438,858
Total	20,345,488	27,179,312	47,524,800

It is important to note the relatively small population of self-propelled tanker movements. Ideally, self-propelled tankers would best represent ocean transport vessels. It is interesting to note, however, that several tanker barge trips were found to leave the ports and travel into ocean waters, suggesting that there may be little compromise in representativeness by including these vessels in the shipping population being considered. Apparently the use of a tanker barge in coastal ocean travel is common practice for shippers of hazardous materials because the regulations for barge movement are often less stringent on manpower requirements.

Similar vessel categories can be established for the casualty file to create consistency between movement analysis and accident analysis. Accident analysis was performed on all tanker and tanker barge vessels greater than 500 grt. To facilitate this, the following vessel types were included from the casualty file: (a) tanker ships, (b) tank barges, (c) public vessels-tanker, (d) flag vessels-tanker, and (e) tank barges-hazardous cargo.

It should be noted that the accident data base includes incidents involving both foreign and domestic vessels, whereas the movement records described previously involve only domestic vessels. However, aggregate movements of foreign vessels were also obtained and classified by commodity type, which allows for extrapolation across commodity type to derive total domestic and foreign movement measures.

The commodities to be used in the extrapolation process can be determined by looking at their relative share of the domestic tanker and tanker barge market and whether the commodity would be considered hazardous cargo. Previously in this paper it was shown that petroleum and chemical products constitute more than 98 percent of all tanker and tanker barge cargo transport; therefore, it would appear logical to extrapolate across these commodities. However, it must also be shown that by using these commodities, other vessel types are not being erroneously included in the extrapolation process.

To examine the question about extrapolation, all movements of vessels weighing more than 500 grt that carry petroleum and chemical products were identified (see Table 3 for the Houston Ship Channel case). In the limiting case of the harbor and bay sites under consideration, almost 97 percent of all petroleum and chemical movements are by self-propelled tankers and tanker barges. This confirms the

TABLE 3 Tonnage of Vessels Weighing More Than 500 grt That Carry Petroleum and Chemical Cargo in the Houston Ship Channel

	Type of Commodity (Tons)			
Vessel Type	Crude Petroleum	Petroleum Products	Chemicals	Total
Self-propelled cargo	0	2,149	54,625	56,774
Self-propelled tanker	4,637,312	14,590,835	1,079,850	20,307,984
Dry cargo barge	6,235	171,579	723,505	901,319
Tanker barge	1,828,244	16,582,345	7,871,327	26,281,904
Total	6,471,791	31,346,896	9,729,307	47,548,000

validity of using petroleum and chemical movements for extrapolation to foreign movements.

The process of identifying harbor and bay movements and high seas movements was based on using the data base previously defined. For the harbor and bay region, the movement file was searched for the different ports and waterways that constitute each region. Measures of high seas movement are the most difficult because the U.S. Army Corps of Engineers' data are not detailed for trips that move into these regions. Furthermore, the high seas is an area where vessels from many ports cross the same transport region. Finally, both the Gulf of Mexico and the Atlantic Ocean are geographically large areas that require some restrictive definitions in this project.

The boundaries of the high seas regions were defined by the Open Ocean Coding Chart that is used by the U.S. Coast Guard. This coding chart is a grid map that divides the world into reporting regions. In the Gulf region, there is a single rectangle in the grid that represents the Gulf longitudinally east of the Sabine River on the Texas-Louisiana border (94 degrees) and latitudinally north of Naples, Florida (26 degrees). In the Atlantic Ocean, the region is defined as a rectangle between 64 and 74 degrees longitude and 35 and 43 degrees latitude.

The method used to estimate movement measures in the high seas region was to take a random sample of movement records from all major Gulf ports from Port Isabel, Texas, to Charlotte Harbor, Florida, and from all major Atlantic ports between the Penobscot River, Maine, and Morehead City, North Carolina. For the sample selected, manual estimates were made of the travel distance into the high seas region. The travel distances were combined to form a trip length distribution that was subsequently applied to the remaining domestic trips and then to the foreign movements to arrive at total movement measures into the high seas region, starting from each port. The movement measures for each port were summed to reach a total movement estimate for the high seas region.

Because this process relies on both shipping and receiving activity in each port, if the trip has both the origin and destination in the high seas study region, it will be double-counted. To eliminate this problem, the total tonnage shipped between ports in the high seas region was also derived and taken into consideration. This problem is only present with domestic movements because foreign movements always have either the shipping or the receiving port located outside of the ports considered.

The process of identifying harbor and bay accidents and high seas accidents used a more direct approach. Harbor and bay accidents were selected based on casualty reporting codes that specify the body of water and nearest port to the incident. The high seas accidents were selected by searching for all accidents that occurred in the high seas region defined by the Open Ocean Coding Chart. The casualty file included a specific code to identify each rectangular region in the chart, which made the incident identification process simple.

One final aspect of the study methodology was to select a data base that was statistically large enough to use in analyzing accidents, given that far fewer accidents occur than do movements. A 5-year period from 1976 to 1980 was selected for this purpose. In contrast, a single year (1980) was used to analyze trip movements, and these results were extrapolated to 1976 to 1979 by using a comparison of movements for 1980 to aggregate tonnage handled in each port for 1976 to 1979, as reported by the U.S. Army Corps of Engineers. The extrapolation process was based on tonnage and used shipment information on whether trips were coastal, internal, or local to determine the appropriate values to use to derive an extrapolation factor.

In summary, the analysis methodology provided a consistent definition of vessel types, geographical regions, and other important shipment characteristics between the accident and movement files, while maintaining an analysis scenario that appears to represent marine transport of hazardous materials in harbor and bay areas and in the high seas. The results of these analyses are discussed in the following section.

ANALYSIS RESULTS

Movement Measures: Harbor and Bay Regions

By using the previously described methodology, the number of domestic vessel movements in each harbor and bay were derived for the period 1976 to 1980. The results are given in Table 4.

By applying the same process, measures of tons, vessel miles, and ton miles for harbor and bay movements from 1976 to 1980 were also estimated. The results are given in Table 5.

TABLE 4 Number of Domestic Vessel Movements, 1976 to 1980

	Coastal	Internal	Local	Total
Mobile Bay	1,722	20,202	2,862	24,836
Houston Ship Channel	16,134	92,691	39,112	147,937
Corpus Christi	8,438	27,109	9,639	45,186
Delaware Bay	43,254	47,214	4,822	92,290
Providence	8,623	662	528	9,813

TABLE 5 Total Tonnage, Number of Vessel-Miles, and Number of Ton-Miles for Harbor and Bay Movements, 1976 to 1980

	Total Tonnage	Total No. of Vessel-Miles	Total No. of Ton-Miles
Mobile Bay	45,105,041	621,081	1.33×10^9
Houston Ship Channel	377,608,725	4,483,966	1.36×10^{10}
Corpus Christi	164,887,581	555,838	3.41×10^9
Delaware Bay	475,613,382	4,354,818	3.31×10^{10}
Providence	36,044,763	87,136	3.31×10^8

Movement Measures: High Seas Region

By using the previously described methodology, the following high seas movement measures for the period 1976 to 1980 were derived.

	Gulf of Mexico	Atlantic Ocean
Trips	94,273	100,321
Tons	1,095,032,871	872,746,789
Miles	42,680,654	11,407,040
Ton-Miles	5.27×10^{11}	3.00×10^{11}

It should be noted that in the Atlantic movements, Long Island Sound was not considered part of the high seas because if an accident occurs there, it would be coded as a coastal rather than a high seas accident (according to the Coast Guard definition).

Accident Measures

Whereas derivation of the movement measures required use of a multistep process, accident measures can be derived directly from the casualty file.

Table 6 gives frequency counts and related statistics on fatalities and injuries, segmented by accident location and accident type for Gulf ports, and Table 7 gives the same information for Atlantic ports. The results show that crew fatalities and injuries are rare, and that, as expected, are most likely to occur because of fires and explosions and collisions. Because of the infrequent occurrence of fatalities and injuries, however, it is difficult to use this information as expected consequences that result from vessel accidents.

Tables 8 and 9 give the estimated monetary loss, also segmented by accident location and accident type, for Gulf ports and Atlantic ports. From the figures in the table, it is clear that in the Gulf region the expected consequence is more serious for a high seas incident than for harbor and bay incidents. However, this trend is not as apparent in the figures on the Atlantic region. Much of this problem is due to the high variation in the amount of cargo released when an incident occurs. Accepting monetary loss as a proxy for release amounts, the tables show that the Gulf region has a larger variation in monetary loss per incident, which suggests that there are a larger number of major incidents occurring in the Gulf region.

As expected, groundings are restricted primarily to harbor and bay areas, whereas collisions and structural failures ("Others") can occur in the harbor or bay area or on the high seas. Collisions are the most frequently cited occurrence, followed by groundings, other, and fires and explosions. This trend is consistent across all harbor and bay areas.

Concerning average monetary loss per incident, the largest number is for fires and explosions; the next largest numbers are for collisions, other, and groundings. This is an intuitively appealing result, because fires and explosions and collisions would be expected to result in more serious consequences. Earlier work substantiates this conclusion (1).

ACCIDENT RATES

By combining movement measures and accident measures, accident rates for ports and high seas regions can be derived. Table 10 gives estimates of the likelihood of an accident per unit measure for four movement measures and multiple accident locations. Weighted averages (based on movement volumes) are also reported for the Gulf and Atlantic harbor and bay areas. Table 10 was derived by using the column count totals from Tables 8 and 9 divided by the movement measures discussed previously in this paper.

The results show that the likelihood of a vessel accident is greatest in the Gulf harbor and bay areas, followed by the Atlantic harbor and bay areas, Gulf high seas, and Atlantic high seas. This order of accident likeliness remains consistent across all movement measures. It should be noted that for the measures that include tons or miles, the high seas accident rates are orders of magnitude lower than those for harbor and bay areas because of

TABLE 6 Fatalities and Injuries by Accident Location and Type in Gulf Ports and High Seas

Accident Type	Accident Location: MEAN / COUNT / SUM / STD DEV	MOBILE BAY 1	HOUSTON SHIP CH. 2	CORPUS CHRISTI 3	GULF HIGHSEAS 4	ROW TOTAL
COLLISIONS	MEAN	.0000	.0000	.0000	.2800	.0203
	COUNT	37	228	55	25	345
	SUM	.0000	.0000	.0000	7.0000	7.0000
	STD DEV	.0000	.0000	.0000	1.4000	.3769
FIRE/EXPLOSIONS	MEAN	.0000	.1667	.0000	.0000	.1111
	COUNT	1	6	1	1	9
	SUM	.0000	1.0000	.0000	.0000	1.0000
	STD DEV	.0000	.4082	.0000	.0000	.3333
GROUNDINGS	MEAN	.0000	.0000	.0000	.0000	.0000
	COUNT	34	80	25	6	145
	SUM	.0000	.0000	.0000	.0000	.0000
	STD DEV	.0000	.0000	.0000	.0000	.0000
OTHERS	MEAN	.0000	.0286	.0000	.0000	.0123
	COUNT	4	35	19	23	81
	SUM	.0000	1.0000	.0000	.0000	1.0000
	STD DEV	.0000	.1690	.0000	.0000	.1111
COLUMN TOTAL	MEAN	0.0	0.0057	0.0	0.1273	0.0155
	COUNT	76	349	100	55	580
	SUM	0.0	2.0000	0.0	7.0000	9.0000
	STD DEV	0.0	0.0756	0.0	0.9439	0.2964

TABLE 7 Fatalities and Injuries by Accident Location and Type in Atlantic Ports and High Seas

Accident Type	Accident Location: MEAN COUNT SUM STD DEV	DELAWARE BAY 1	PROVIDENCE 2	ATLANTIC HIGHSEAS 3	ROW TOTAL
		.0000	.0000	.0000	.0000
COLLISIONS		68	3	7	78
		.0000	.0000	.0000	.0000
		.0000	.0000	.0000	.0000
FIRE/EXPLOSIONS		.3750	.0000	.0000	.3333
		8	1	0	9
		3.0000	.0000	.0000	3.0000
		.7440	.0000	.0000	.7071
GROUNDINGS		.0000	.0000	.0000	.0000
		48	4	2	54
		.0000	.0000	.0000	.0000
		.0000	.0000	.0000	.0000
OTHERS		.0909	.0000	.0000	.0556
		33	1	20	54
		3.0000	.0000	.0000	3.0000
		.2919	.0000	.0000	.2312
COLUMN TOTAL		0.0382	0.0	0.0	0.0308
		157	9	29	195
		6.0000	0.0	0.0	6.0000
		0.2232	0.0	0.0	0.2007

the larger high seas cargo sizes and trip distances associated with each vessel movement.

The data in Table 10 also show clearly that the Gulf region is more accident prone compared with the Atlantic region, both in the harbor and bay areas and in high seas areas. This may be because of several reasons, including climatic conditions, vessel traffic, and navigability of the waterways.

The accident rates per trip compare favorably with a previous study of tanker casualties conducted by the Oceanographic Institute of Washington (2), which reported a tanker casualty rate per trip of 4.4×10^{-3}. Several other studies have been conducted worldwide on casualty rates per trip for harbor and bay areas, segmented by accident type (2,3). Table 11 gives these rates for several locations, includ-

TABLE 8 Estimated Monetary Loss by Accident Location and Type in Gulf Ports and High Seas

Accident Type	Accident Location: MEAN COUNT SUM STD DEV	MOBILE BAY 1	HOUSTON SHIP CH. 2	CORPUS CHRISTI 3	GULF HIGHSEAS 4	ROW TOTAL
		36.8108	30.2807	19.7455	621.7200	72.1594
COLLISIONS		37	228	55	25	345
		1362.0000	6904.0000	1086.0000	15543.000	14895.000
		133.9506	205.2086	54.2136	2234.7178	634.2164
FIRE/EXPLOSIONS		25.0000	1717.5000	2.0000	10.0000	1149.1111
		1	6	1	1	9
		25.0000	10305.0000	2.0000	10.0000	10342.0000
		.0000	4108.9414	.0000	.0000	3358.4333
GROUNDINGS		8.8235	1.9250	13.6000	41.6667	7.2000
		34	80	25	6	145
		300.0000	154.0000	340.0000	250.0000	1044.0000
		51.4496	6.5580	48.3589	102.0621	38.1360
OTHERS		24.5000	12.6857	3.9474	19.0000	13.0123
		4	35	19	23	81
		98.0000	444.0000	75.0000	437.0000	1054.0000
		37.0090	22.8226	8.2964	27.8666	23.1999
COLUMN TOTAL		23.4868	51.0229	15.0300	295.2727	64.3707
		76	349	100	55	580
		1785.0000	17807.0000	1503.0000	16240.0000	37335.0000
		100.0857	564.7766	47.1249	1520.3022	644.0237

TABLE 9 Estimated Monetary Loss by Accident Location and Type in Atlantic Ports and High Seas

Accident Type	Accident Location: MEAN COUNT SUM STD DEV	DELAWARE BAY 1	PROVIDENCE 2	ATLANTIC HIGHSEAS 3	ROW TOTAL
COLLISIONS		73.5441	26.3333	31.5714	67.9615
		68	3	7	78
		5001.0000	79.0000	221.0000	5301.0000
		285.0762	38.6954	46.5398	266.7153
FIRE/EXPLOSIONS		169.3750	50.0000	.0000	156.1111
		8	1	0	9
		1355.0000	50.0000	.0000	1405.0000
		368.6187	.0000	.0000	347.0996
GROUNDINGS		5.9792	6.2500	.0000	5.7778
		48	4	2	54
		287.0000	25.0000	.0000	312.0000
		29.6113	12.5000	.0000	28.0664
OTHERS		29.3333	2.0000	40.7000	33.0370
		33	1	20	54
		968.0000	2.0000	814.0000	1784.0000
		64.4043	.0000	101.7221	79.1373
COLUMN TOTAL		48.4777	17.3333	35.6897	45.1385
		157	9	29	195
		7611.0000	156.0000	1035.0000	8802.0000
		209.2191	26.2202	87.1706	190.7405

TABLE 10 Accident Rates per Unit Measure by Accident Location

	Probability of an Accident per: Trip	Ton	Mile	Ton-Mile
Mobile	3.06×10^{-3}	1.69×10^{-6}	1.22×10^{-4}	5.71×10^{-8}
Houston Ship Channel	2.36×10^{-3}	9.24×10^{-7}	7.78×10^{-5}	2.57×10^{-8}
Corpus Christi	2.21×10^{-3}	6.06×10^{-7}	1.80×10^{-4}	2.94×10^{-8}
Combined Gulf Ports	2.41×10^{-3}	8.94×10^{-7}	9.27×10^{-5}	2.87×10^{-8}
Delaware Bay	1.65×10^{-3}	3.30×10^{-7}	3.61×10^{-5}	4.75×10^{-9}
Providence	9.17×10^{-4}	2.50×10^{-7}	1.03×10^{-4}	2.72×10^{-8}
Combined Atlantic Ports	1.58×10^{-3}	3.24×10^{-7}	3.74×10^{-5}	4.97×10^{-9}
Gulf High Seas	5.83×10^{-4}	5.02×10^{-8}	1.29×10^{-6}	1.04×10^{-10}
Atlantic High Seas	2.89×10^{-4}	3.32×10^{-8}	2.54×10-6	9.67×10^{-11}

ing the Gulf and Atlantic harbor and bay areas. The table indicates that the collision and grounding rates are relatively high for the Gulf and Atlantic locations, particularly for collisions in the Gulf region.

SPILL RATES

Accident rates for vessel movements in the regions of interest were identified in the previous discussion. However, most reported accidents do not result in cargo spills. To derive estimates of the release expected, spill rates must also be computed, in addition to accident rates. The data used to derive accident rates did not include release amounts; therefore, spill rate estimates are based on previous literature that is not specific to the Gulf and Atlantic regions.

Studies that have examined spill rates include work conducted by J.J. Henry Company, Inc. (1), Porricelli and Keith (4), and Meade, LaPointe, and Anderson (5). Unfortunately, the first two studies stratified spill rates only by cause of accident and not by location. The latter study examined spill rates by both cause of accident and location. Regarding cause of accident, the studies found that the percentage of accidents that result in spills does not vary considerably according to the cause of the accident (see Table 12).

There is, however, a discrepancy between the absolute spill rate when comparing results of the J.J. Henry Company, Inc., study with the results of the Meade et al. study. Because the Meade et al. data are considerably more recent, and because the Porricelli and Keith results are consistent with Meade et al., the Meade et al. figures were selected for use in this study.

TABLE 11 Tanker Collision and Grounding Rates for Several Locations

	Collisions per Harbor Transit	Groundings per Harbor Transit
Thames	4.6×10^{-5}	3.6×10^{-5}
Holland	5.0×10^{-5}	1.7×10^{-5}
North Sea	6.7×10^{-5}	4.0×10^{-5}
J.J. Henry Study	4.6×10^{-5}	3.9×10^{-5}
IMCO Study	7.1×10^{-5}	9.1×10^{-5}
Washington State Study	6.2×10^{-4}	4.8×10^{-4}
Tanker Fleet Analysis	4.7×10^{-4}	8.3×10^{-4}
Mobile	1.49×10^{-3}	1.4×10^{-3}
Houston Ship Channel	1.54×10^{-3}	5.4×10^{-4}
Corpus Christi	1.26×10^{-3}	5.5×10^{-4}
Combined Gulf Ports	1.47×10^{-3}	6.4×10^{-4}
Delaware Bay	7.15×10^{-4}	5.0×10^{-4}
Providence	3.06×10^{-4}	4.0×10^{-4}
Combined Atlantic Ports	6.76×10^{-4}	5.0×10^{-4}

TABLE 12 Percent of Accidents Resulting in Spills

	Groundings	Collisions	Fires and Explosions	Other
J.J. Henry Company, Inc.	29.4	21.7	39.6	17.8
Porricelli and Keith	19.0	–	–	–
Meade et al.	14.9	13.5	14.7	14.5

Meade et al. reported the following spill rates by location:

	Percent of Accidents Resulting in Spills
Piers and Harbors	10.1
Coastal	22.2
At Sea	17.2

The locations analyzed in the Gulf and Atlantic regions study are best described in the Meade et al. study by "piers and harbors" for the harbor and bay area and "at sea" for the high seas area. It is assumed that "coastal" is more closely related to the Gulf Intercoastal Waterway and other movements of this kind that are within several miles of the shoreline.

If these spill rates were to be accepted, a comparison could be made of the Gulf and Atlantic study, discussed in this paper, and an earlier study conducted by Froelich and Bellantoni (6) that examined spill rates in four U.S. Coastal regions, which included Delaware Bay, the Louisiana Coast (including Mobile), and the North Texas Coast (including Houston Ship Channel). To make this comparison, the accident rates reported in the Gulf and Atlantic study are multiplied by the locational spill rates used by Meade et al. (5). The comparison of spill rates is given in Table 13.

Estimates by both studies of Delaware Bay spill rates are in general agreement. In the Gulf regions, the Froelich estimates generally lie between the harbor-bay area spill rates and the high seas spill rates, which was expected because the Froelich regions include harbor and bay areas, high seas, and coastal waterways.

SPILL SIZE

The amount of substance released is not reported in the Commercial Vessel Casualty File; therefore, statistics on spill size were not available for analysis of spills that have occurred specifically in the locations of interest. However, studies of spills from tankers have been conducted by the U.S. Coast Guard (7) and the Oceanographic Institute of Washington (2). The U.S. Coast Guard study uses the data base of the pollution incident reporting system, which records polluting incidents in and around U.S. waters. Average spill sizes are tabulated by vessel type (tank ships, tanker barge), but not by location. Furthermore, information on the spill size distribution is not reported. This is an important measure because the consequence of a rare (catastrophic) event is so significant.

The Oceanographic Institute study divides spills into four classes according to location: (a) piers,

TABLE 13 Comparison of Spill Rates of Abkowitz and Galarraga Study and Froelich and Bellantoni Study

Region		Spills per 1,000 Trips		Spills per 1,000,000 Tons	
Abkowitz	Froelich	Abkowitz	Froelich	Abkowitz	Froelich
Delaware Bay	Delaware Bay	0.17	0.12	0.03	0.02
Mobile Bay	Louisiana Coast	0.30	0.04	0.17	0.03
Houston Ship Channel	North Texas Coast	0.24	0.03	0.09	0.02
Gulf High Seas		0.10		0.01	
Atlantic High Seas		0.05		0.01	

(b) harbors, (c) entrances, and (d) coastal areas. The following results were reported:

	Mean Spill Size (gal)	Standard Deviation of Spill Size (gal)
Piers	24,785	33,496
Harbors	46,807	14,457
Entrances	114,954	80,312
Coastal areas	416,099	4,074,309

The most obvious conclusion that can be drawn from these figures is that the spill size increases as the distance from land increases; this is probably due to the severity of incidents in open waters and the duration of time between when an incident occurs and when assistance arrives on the scene. The large standard deviation of spill size for coastal spills demonstrates the importance of considering rare events. It is likely that a single catastrophic coastal spill resulted in such a large mean spill size and standard deviation.

To compare the Oceanographic Institute Study with the Gulf and Atlantic study, pier and harbor estimates (in the Oceanographic Institute study) were combined to correspond to estimates for the harbor and bay areas (in the Gulf and Atlantic study), and coastal estimates were used to represent the high seas. Thus, the average spill size in harbor and bay areas is 35,796 gal and in the high seas is 416,099 gal.

It is reported in the Oceanographic Institute study that exponential distributions are often used to represent spill size because this distribution can handle high variance conditions well. Furthermore, the exponential distribution has computational advantages in cases in which the variance is a function of the mean.

$$F(x) = 1 - e^{BX}$$

where $\bar{x} = 1/B$ and $\mathrm{var}(x) = 1/B^2$. Using this cumulative distribution and the reported means allows for the determination of the frequency of spills larger than a certain volume, which is important for rare event analysis.

However, the outcome of hypothesis tests of whether the exponential distribution is suitable in replicating the observed data is not reported in the Oceanographic Institute study. To pursue this matter, histograms of monetary loss from the Commercial Vessel Casualty File were developed. When combined, the histograms show that less than 5 percent of the observed incidents are in the extreme tail of the distribution. However, hypothesis tests on the distributions reveal that the exponential distribution is rejected in every case at the .01 level. This leaves open the possibility that the exponential distribution is representative of spill size but not of monetary loss, although it is assumed that the two measures are highly correlated.

EXPECTED RELEASE

The expected release of a spill can be derived as follows:

$$ER_m = AR_m \times PS \times M$$

where

ER_m = expected release (gal) per unit measure,
AR_m = accident rate per unit measure,
PS = conditional probability that the accident results in a spill, and
M = average spill size (gal).

The following information was used to derive expected releases for the Gulf and Atlantic regions:

- Accident rates--see Table 10.
- Conditional spill probabilities: .101 for harbor and bay areas; .172 for high seas.
- Average spill size: 35,796 gal for harbor and bay areas; 416,099 gal. for high seas.

Table 14 gives estimates of the expected release per trip for the Gulf and Atlantic regions under consideration. As expected, based on the discussion presented previously in this paper, the expected releases are larger in the Gulf region than in the Atlantic region, and are larger in the high seas area than in the harbor and bay areas. Caution is advised, however, in using these results for extrapolation because the impact of a rare (catastrophic) event can alter these figures significantly.

TABLE 14 Expected Release of Spills per Trip by Location

	Expected Release per Trip (gal)
Mobile Bay	11.06
Houston Ship Channel	8.53
Corpus Christi	7.99
Combined Gulf Ports	8.71
Delaware Bay	5.96
Providence	3.32
Combined Atlantic Ports	0.71
Gulf High Seas	41.72
Atlantic High Seas	20.68

SUMMARY

Accident rates and expected consequences of hazardous materials marine transport in selected U.S. ports and high seas regions have been examined in this paper. The focus of the study was tanker and tanker barge movements because these vessels account for almost all hazardous materials movement by water. The analysis was based on empirical data of vessel movements and accidents; these data are maintained by various federal agencies.

Several significant findings emerged from this research effort. A vessel accident is more likely to occur in a harbor or bay area than in a high seas area, although the expected damage associated with a high seas accident is considerably larger than that in a harbor or bay accident. The Atlantic Ocean and its associated ports also appear to be safer for the transport of hazardous materials than is the Gulf of Mexico. The results, in general, compare favorably to previous studies of domestic and international tanker transport.

It is also apparent that amounts released are subject to significant variation, depending on the severity of the accident. This implies that any risk assessment that includes consideration of expected releases must recognize the significance of the rare (catastrophic) event in addition to the expected value of spill size.

In addition to providing insight into the risks associated with marine transport of hazardous materials, the research results can be used in policy analysis, as well as to determine safer routing and facility location, given both cost and public safety constraints. These results can also be used in comparative analysis of hazardous materials transport safety across modes to establish research priorities.

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Code of Practice for Warehouse and Terminal Facilities Storing Hazardous Materials

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ABSTRACT

Practical standards are needed to guide the construction and operation of Canadian warehouses and transport terminals in which packaged hazardous materials are stored. More than 800 agencies and firms throughout the world were contacted to discover existing codes and practices that currently address this need. Based on a 33-percent response rate, specific problems with the storage of hazardous materials are identified. Findings are summarized in terms of existing problems with dangerous goods storage, a review of government codes and regulations in the countries surveyed, and a summary of current industrial practices. Many government regulations and industrial guides were found to consider some commodities but not others. Some of the larger chemical firms have developed their own internal standards for storing their products. But those firms and others that have invested much time in promoting safety are reluctant to share their experiences with competitors. Small firms and those that lack the resources to develop standards have little specific guidance on design and management of interim storage facilities. The study concludes that a code of practice should be prepared to guide the storage of packaged hazardous materials. Ten objectives for a code of practice are recommended with a list of important elements that a workable code of practice should contain. A comprehensive outline for an interim set of guidelines on the safe warehousing of hazardous materials is suggested.

Packaged hazardous materials are currently being stored and handled in general warehouses and transport terminals throughout Canada without specific standards for building design or material handling. Some codes guide the design and construction of facilities in which explosives, flammable or combustible materials, and radioactive substances are stored. The design and operation features of facilities that handle other dangerous goods, however, have not been addressed from a safety perspective. In addition, storage of several classes of dangerous goods together has not been considered in Canada's design codes.

Truck and rail transfer and storage facilities