# An Analysis of Recent Ship Collisions

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## INTRODUCTION

Ship collision data were compiled and analyzed as part of a U.S. Department of Energy project (SeaRAM) to characterize the risk of shipping radioactive materials by waterborne modes of transportation. The most significant results show that waterborne transport has the potential of being a very safe method of transporting nuclear materials. The work sought to identify means of estimating the risk associated with specific transportation campaigns. It has been determined that the risk of collision is directly related to activity in congested areas, such as entering and exiting ports or traversing narrow straits.

Further, the risk of fire is proportional to the time spent at sea - and not to the time traversing congested areas as is the case with collisions. Therefore, we believe that the probability of a fire is appropriately modeled as a constant multiplied by the time a trip takes. There is little evidence in the data examined to warrant more complicated models based on assigning specific probabilities to the specific geographic areas a route traverses.

Based on these initial results, it should be possible to build a generic model for assessing the risk of waterborne transport of radioactive material. By assigning the risk of collisions to the few small regions of the world's waterways where accidents actually occur with any frequency, it will be possible to calculate highly accurate estimates of probabilities of accidents associated with a specific route. Using the data, it would then be possible to develop a method to satisfy shipping requirements for specific campaigns.

## THE LLOYD'S MARINE CASUALTY DATABASE

The primary source of information for this analysis was the Lloyd's Marine Casualty Database. The database is organized into a series of tables accessible with most modern Relational Database Management Systems (RDBMS). For this project, the Informix system on a Hewlett-Packard 735 workstation was used for the data analysis. The period of time covered by the data analyzed was from 1977 through 1992. There were slightly less than 30,000 incident records in this data, with approximately 4,500 of the records relevant to this analysis that focused on fire and collision.

The organization of the database is that there is a record for each ship involved in an incident. Each ship is characterized with an unique Lloyd's registry number (called the *carolrno* in the data dictionary), and each incident is given a unique incident number (called the *caroinno* in the data dictionary).

A complicating factor in the analysis was that there was not a consistent relationship between the incidents and the number of records describing the incident in the database. In approximately 60% of the cases, there were two records, one for each ship involved in the incident. In about 39% of the incidents, there was only a single record. In many cases that record mentioned the other ship involved in the collision. In a very small percentage of the cases there were more than two records. Most of these incidents were related to ships breaking free in a harbor during a storm and then colliding with several other ships while adrift.

A second complicating factor, that considerably increased the time and labor to analyze the Lloyd's data, was that much of the information concerning the location and severity of the collisions and fires was located in text fields. Furthermore, the text fields were very brief. Thus, in many cases it was not possible to determine the severity of the damage to either of the ships, except in a very general way and which ship was the striking and which was the stuck ship (in many cases the damage was to the bow of both ships).

## ANALYSIS OF COLLISION LOCATION: DISTANCE FROM SHORE

Approximately 60% of the incident reports included specific geodesic coordinates that precisely identified the location of the incident. These coordinates were utilized to determine the point of closest proximity to land, which is plotted in Figure 1. The balance of the descriptions contained relative bearings (i.e., Off London, Off Wessen Light Vessel, etc.) that Lloyd's indicated generally meant distances of considerably less than the 5 mile cutoff used for the first bar in the histogram. (Note: these incidents are not included in Figure 1). A key result of this analysis was the identification of the strong correlation between crash frequency and proximity to land. This was demonstrated by two results. First, for the entire period of time covered in the study there were 865 collisions in harbors and restricted waters versus only 1135 outside ports and restricted waters.

Second, the number of collisions decreases rapidly as distance from shore increases (see Figure 1).

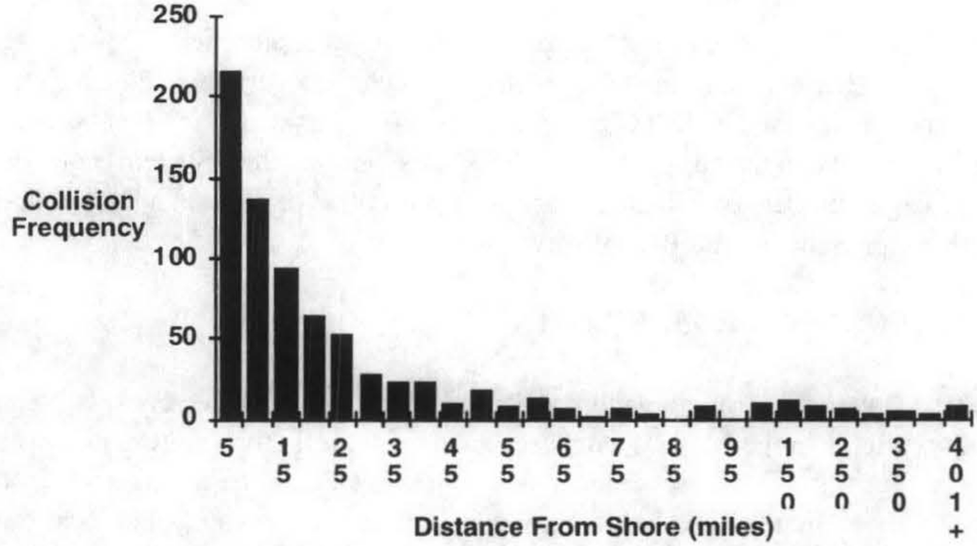


**Figure 1. Worldwide collision data (1977-1992)**

## ANALYSIS OF FIRE LOCATION: DISTANCE FROM SHORE

To compare the stochastic model for predicting collision and fire location, a similar histogram was computed plotting fire location versus distance from shore. This chart is shown in Figure 2. Based on this chart, it is clear that the best model for predicting risk of fire is with a model based on time at sea, rather than distance from shore. A second statistic supporting a preliminary assessment is that there are considerably more fires at sea than in ports or other restricted waters (1,572 fires at sea versus 975 fires in port).

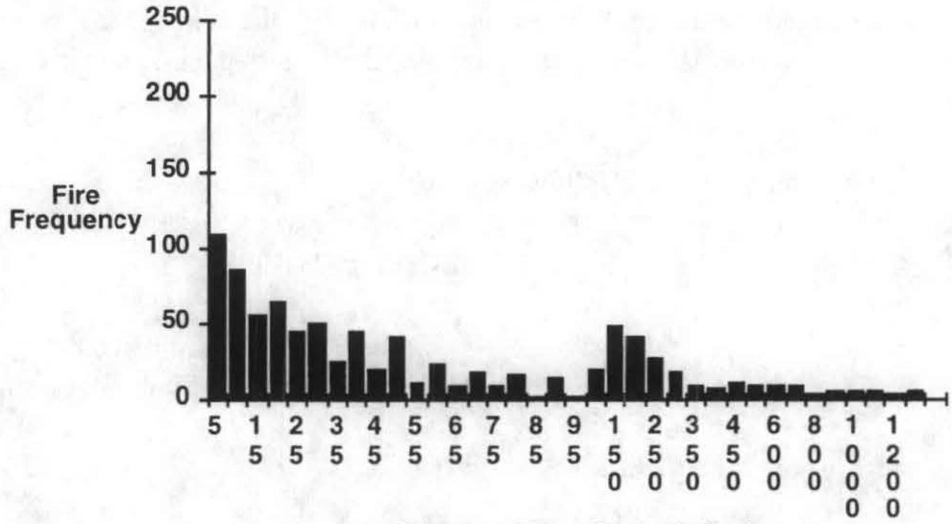


**Figure 2. Worldwide fire data (1977-1992)**

## ANALYSIS OF COLLISION LOCATION: CONGESTED REGIONS

Because most collisions occur near shore, all collisions were assigned to Marsden grid cells. It was determined that most ship collisions occur in a very few cells, for example, the cell that contains the English Channel and the North Sea. Collision locations were plotted for several congested regions in MES (Marsden Encoding System) cells that contained large numbers of collisions. Figure 3 presents typical results for a congested region, the approaches to the Port of New York.

## SEVERE ACCIDENT PROBABILITIES

Because the severity of collision and fire damage is at best incompletely specified by the data and text fields in the Lloyd's database, surrogate criteria for severe accidents had to be selected. For this study, a severe ship accident was taken to be any fire or any collision followed by a fire, that led to a beaching or a stranding. Fires enhance the release of volatile radioactive materials and fire plumes provide a transport mechanism for released radioactivity. Beaching and stranding suggest severe damage to the ship and also indicate that the accident occurred close enough to land to allow people to be subjected to radiation exposures should a release occur.

To estimate the probability of a collision that could lead to release of radioactivity, accidents were searched that fit these criteria, then divided by an estimate of the number of world-wide ship movements during the period in study. During the period of time the casualty data was analyzed, there were in excess of 16,000,000 ship movements world-wide, based on the number of movements in 1988 (the year that we have now begun to study). We did not include collisions where the ship sank because in these cases the incident did not present an airborne transport mechanism, although a more pessimistic estimate could be made based on the argument that some of the collisions, where a fire occurred and then the ship sank, could have remained afloat long enough to provide transport.

During this period, there were the following casualties:

**Table 1. Ship Collisions 1978-1993**

| | | Collision & | | Collision & Fire & | |
|---|---|---|---|---|---|
| | Collisions | Sunk | Beached | Sunk | Beached |
| In-port | 865 | 87 | 83 | 2 | 3 |
| At-sea | 1135 | 362 | 68 | 5 | 5 |

Thus, the Lloyd's data analyzed indictate (1) that there are about

$$\frac{2,000}{16,000,000} = 1.3x10^{-4} \text{ Collisions per sailing,}$$

(2) that the probability of a severe collision per sailing that does not lead to a fire is

$$\frac{6,000}{16,000,000} = 4x10^{-5} \text{ Severe collisions per sailing,}$$

and (3) that the probability of all three of the conditions for a severe collision plus fire incident being met would be about

$$\frac{8}{16,000,000} = 5x10^{-7} \text{ Severe collisions with fire per sailing.}$$

A second scenario that we investigated was the scenario that an all-consuming fire not caused by a collision might vaporize radioactive materials, cause the seals on a cask to fail, and transport the released radioactivity to land, thereby exposing the nearby population to radiation.

In the following table, the data are presented for the number of fires occurring in the studied period.

**Table 2. Fire not resulting from Collision 1978-1993**

| | Fires | Sink | Beached* |
|---|---|---|---|
| In-port | 1,572 | 19 | 119 |
| At-sea | 975 | 3 | 73 |

* includes groundings and part-submerged vessels

In the vast majority of the fires, the description indicates that the fire never threatened either the crew or the cargo. It was not possible to determine the number of times that the ship required personnel beyond the ship-board crew to extinguish the fire. The case that appears to lead to the greatest threat of radioactive release, if the fire is serious, is when the fire occurs in coastal waters away from ports and fire fighting equipment and is so severe that the captain decides to beach the ship rather than sail for dock-side assistance. Again, making the highly pessimistic assumption that all fires on ships are hot enough to fail the cask seals, yields the following estimate for the probability of fires and of a severe fire incident as:

$$\frac{2,547}{16,000,000} = 1.5x10^{-4} \text{ Fires per sailing}$$

$$\frac{192}{16,000,000} = 1.2X10^{-5} \text{ Severe Fire Incidents per Sailing}$$

**A ROUTE-SEGMENT BASED RISK ASSESSMENT**

Even thought there are a very small number of collisions and fires in the historical record on which to base risk calculations, it is apparent that the risk is concentrated in and around ports. Further, our preliminary analysis indicates that there is more than two orders of magnitude difference between accident frequencies of various ports (the difference is between $10^{-3}$ and $10^{-5}$). Based on these observations, a new tool for assigning discrete probabilities to ports, entries to ports, congested areas, and at sea will be constructed. This should allow very accurate and defensible estimates of the accident risk of shipping collisions.

Because most accidents occur in a few congested regions, average ship collision probabilities are not expected to provide a good estimate of the probability of a ship collision when a specific route is sailed. Better estimates can be developed by summing the probabilities of ship collisions for route segments. To do this, collision probabilities should be developed for ports, congested regions (e.g., the North Sea, the Strait of Gibraltar), and open ocean. Specifically, if a shipping route is defined to be a set of regions {Region 1, Region 2, . . . . . . , Region n} that the RAM transport ship traverses, then if this route is sailed, the accident probability for the route ($P_{route}$) is

$$P_{\text{route}} = \sum_{i=1}^{n} \frac{N_{Ci}}{N_{Ti}} \qquad \text{where}$$

$N_{Ci} =$ Number of Collisions per year in Region i
$N_{Ti} =$ Number of Transits per year of Region i

Values for $N_{Ci}$ have been developed. Values for $N_{Ti}$ are being developed. Preliminary analysis suggests that even though most ship collisions occur in a few congested regions, because the number of transits of these busy regions is very large, collision probabilities are probably lower in these high-traffic regions then in lower traffic regions, perhaps because most of the ships that traverse these regions are modern ships that are well equipped and manned by well-trained crews.

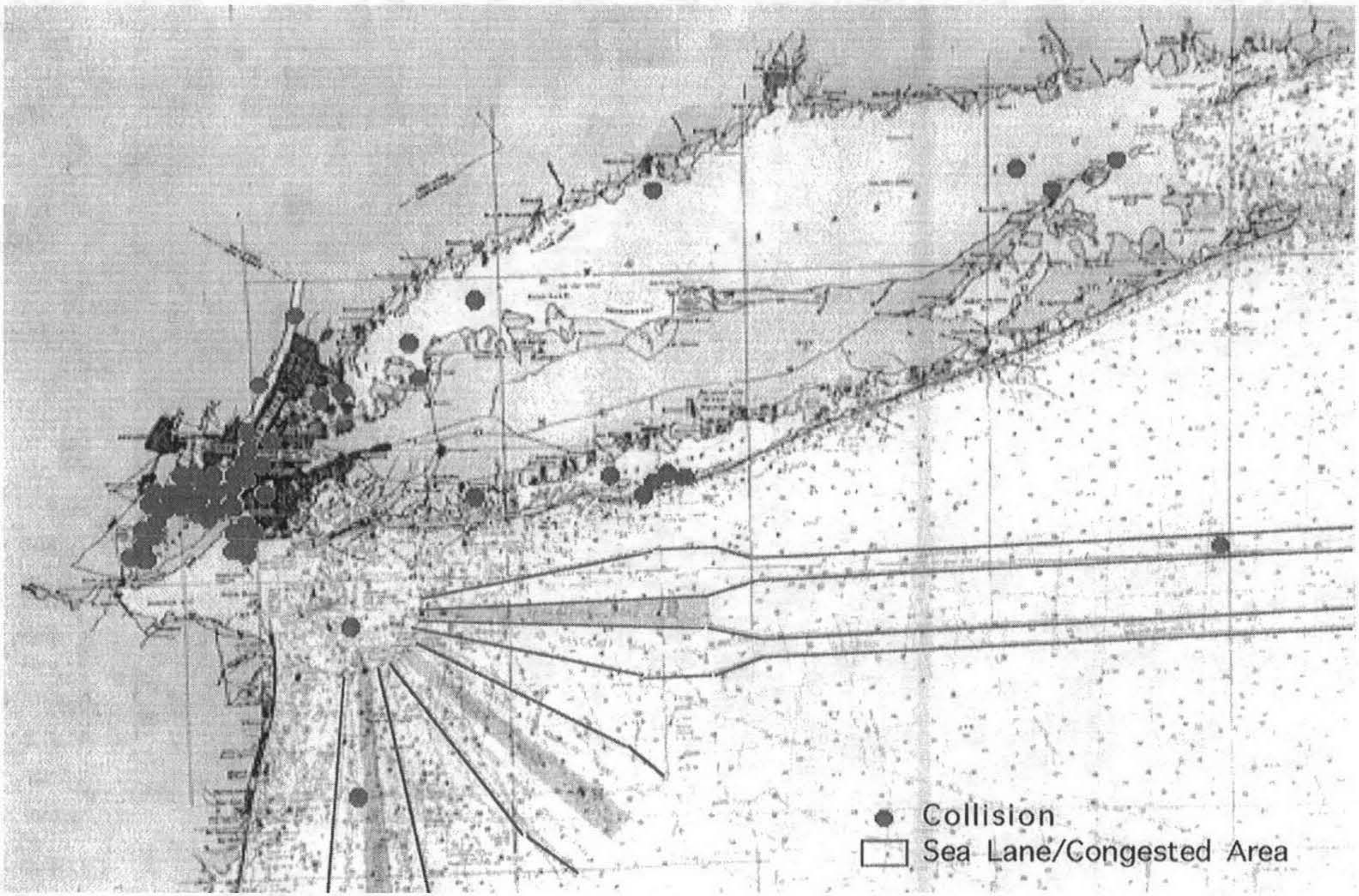


Figure 3. Typical congested area: the Port of New York