# TANK VESSEL PETROLEUM TRANSPORTATION AS A PREDICTOR OF MARINE OIL SPILLS

*Daniel R. Norton, LCDR, USCG*
*Commandant (G-MOR-3)*
*2100 Second Street, SW*
*Washington, D.C. 20593*

## ABSTRACT

*The annual volume of oil spilled into the marine environment by tank vessels (tank barges and tankships) is analyzed against the total annual volume of oil transported by tank vessels in order to determine any correlational relationship. U.S. Coast Guard data was used to provide the volume of oil (petroleum) spilled into the marine environment each year by tank vessels. Data from the U.S. Army Corps of Engineers and the U.S. Department of Transportation's (US DOT) National Transportation Statistics (NTS) were used for the annual volume of oil transported via tank vessels in the United States. This data is provided in the form of tonnage and ton-miles, respectively. Each data set has inherent benefits and weaknesses. For the analysis the volume of oil transported was used as the explanatory variable (x) and the volume of oil spilled into the marine environment as the response variable (y). Both data sets were tested for correlation. A weak relationship, r = –0.38 was found using tonnage, and no further analysis was performed. A moderately strong relationship, r = 0.79, was found using ton-miles. Further analysis using regression analysis and a plot of residuals showed the data to be satisfactory with no sign of lurking variables, but with the year 1990 being a possible outlier.*

## DISCUSSION

Each year tank vessels transport huge amounts of petroleum products over the United States' waterways. Such tank vessels are responsible for the majority of oil spilled into our marine environment according to the National Research Council which found that "Tankers and tank barges were responsible for 82% of the total spillage", for accidental spills during the period 1990-1999 for vessels in U.S. waters (National Research Council, 2003). What connection, if any, exists between the volume of oil transported by these tank vessels and the volume of oil that these vessels spill into the marine environment? For this study the term tank vessel is defined as "all vessels that carry oil in bulk and include tankships and tank barges". Also for this study, the term marine or maritime is defined as "of or pertaining to shipping or navigation", and includes the Great Lakes and inland rivers.

Data on the volume of oil spilled by tank vessels is readily available from the U.S. Coast Guard. The Coast Guard's Polluting Incident Compendium breaks down marine oil spills into the number of spills and the volume spilled. Under spill volume, spills are listed by source and include tankships, tank barge, all other vessels, facilities, pipelines, all other non-vessels, and other. For this study the tankship and tank barge data were combined and listed as tank vessel. The Coast Guard spill volume data includes spill volumes from foreign and domestic (U.S. flagged) tank vessels that occur on U.S. waters which include the Great Lakes and inland rivers.

Data on the volume of oil transported by tank vessels is available from the U.S. Army Corps of Engineers (USACE) and the U.S. Department of Transportation (US DOT), and is provided using two different measures: tonnage and ton-miles, respectively. Tonnage, listed in short tons equal to 2000 pounds, is a relatively simple measure and captures both domestic and foreign cargos. Ton-miles are defined as one ton of freight shipped one mile, and reflects both the volume shipped (tons) and the distance shipped (miles). Ton-miles are calculated as the distance between the shipment origin and destination ZIP codes (US DOT, 2003). Ton-miles, however, is limited in that the data is only gathered for domestic freight. The US DOT defines domestic freight (water) as: "All waterborne commercial movement between points in the United States, Puerto Rico, and the Virgin Islands, excluding traffic with the Panama Canal Zone. Cargo moved for the military in commercial vessels is reported as ordinary commercial cargo; military cargo moved in military vessels is omitted." (US DOT, 2003). Even without foreign freight data, the U.S. Department of Transportation believes that ton-miles are valuable and states that "Ton-miles provides the best single measure of the physical volume of freight transportation services."(US DOT, 2003). Since both tonnage and ton-miles measures allow for different benefits, this analysis of oil volume transported versus tank vessel volume spilled was calculated twice, once using tonnage and then using ton-miles.

A review of U.S. Coast Guard statistics shows a significant decrease in the annual volume of marine oil spills over the last quarter century. This decrease in spill volume has occurred while the total (foreign and domestic) maritime annual tonnage of oil products, are steadily increasing in the U.S. (USACE, 2001). However, the annual domestic oil product ton-miles for waterborne commerce are falling (US DOT, 2004). Increased dependence upon foreign oil and therefore an increased use of foreign flagged tankers may be the reason for the decreasing trend in ton-miles.

Both data sets were graphed and then analyzed for any correlational relationships. Any strong relationship(s) were then further examined using a scatterplot and regression analysis. Scatterplots display the relationship between two variables with one variable 'x' as the explanatory variable and 'y' as the response variable. The scatterplot graphically shows how well values of the explanatory variable predict the response variable. The relationship between the two variables is then displayed as a straight line, called the regression line. The regression line has an equation of: $y = a + bx$. The difference between an observed value of the response variable and the value predicted by the regression line is called a residual.

Residuals are plotted and examined to determine possible patterns or discover potential lurking or confounding variables that might cast doubt upon the result. For this analysis, tonnage and ton-miles are used as the explanatory variables and the volume of oil spilled by tank vessels is used as the response variable.

## OIL TONNAGE

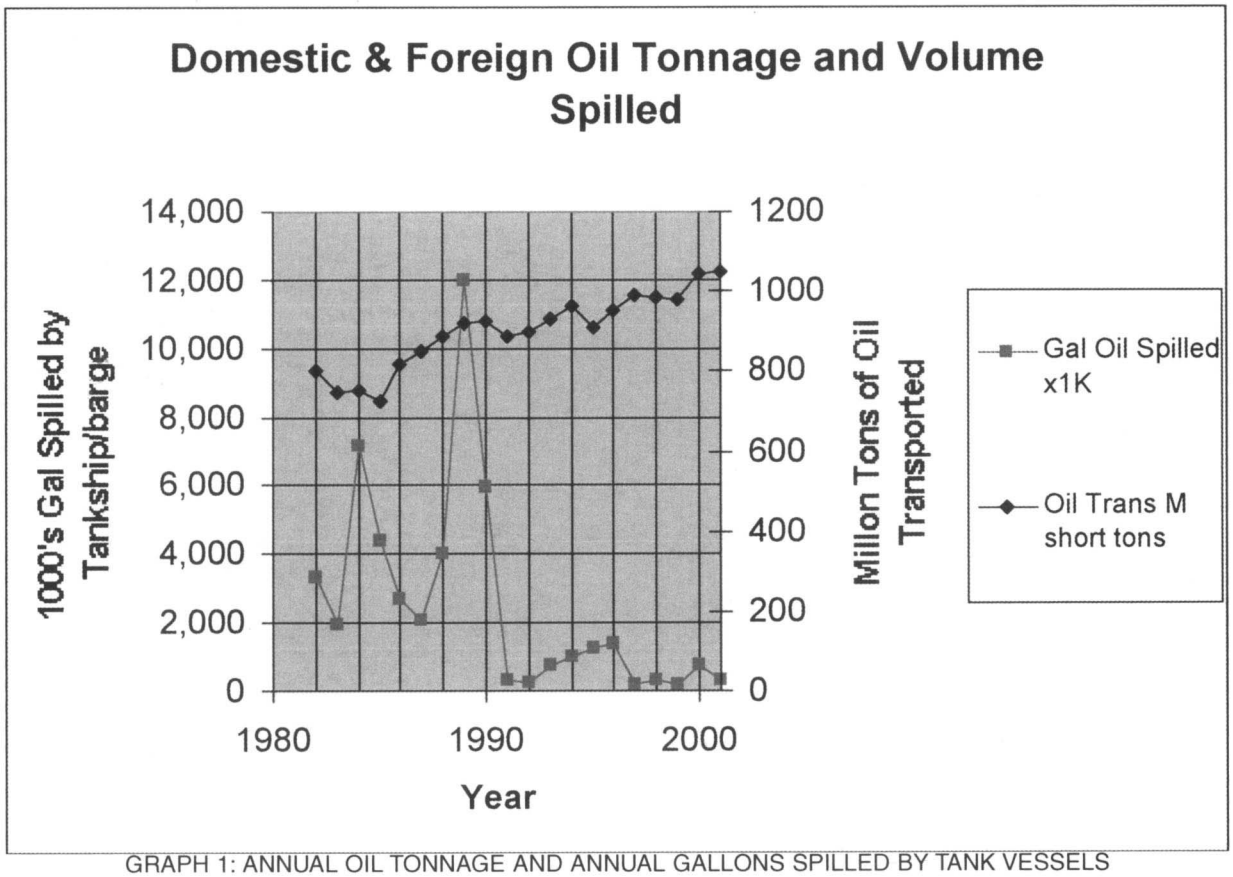
The first analysis used annual oil tonnage (domestic and foreign) transported in the U.S. The data is displayed in table #1. The data shows that over the twenty-year period starting with 1982 that the overall tonnage of oil (displayed in millions of tons) has steadily increased while the volume of oil spilled from tank vessels has been erratic but has decreased, most notably during the period from 1991-2001. Note that the U.S. Coast Guard (USCG) spill volume data used did not discriminate the vessel nationality, thus USCG spill data includes spills from foreign and domestic (U.S. flagged) tank vessels.

Data from table 1 is plotted on Graph #1 and visually displays the trends of these two variables over the twenty-year period.

The data from table #1 was statistically analyzed for any correlational relationships. Results of the correlation are displayed in table #2. For the twenty data sets examined from 1982 to 2001, an average of 2,520,900 gallons were spilled by tank vessels transporting an average of 900,600,000 tons of petroleum. This comes to 2,790 gallons spilled for every 1 million tons transported.

**Table 1: Annual U.S. oil tonnage and annual gallons spilled by tank vessels in U.S. waters.**

| **Year** | **1982** | **1983** | **1984** | **1985** | **1986** | **1987** | **1988** | **1989** | **1990** | **1991** |
|---|---|---|---|---|---|---|---|---|---|---|
| Oil Transported Million short tons | 799.6 | 748.5 | 753.5 | 726.4 | 815.6 | 847.7 | 887.7 | 922.7 | 923.5 | 886 |
| Gal Oil Spilled x1K | 3,335 | 1,953 | 7,148 | 4,415 | 2,675 | 2,098 | 4,016 | 12,019 | 5,969 | 334 |
| **Year** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** |
| Oil Transported Million short tons | 899.6 | 930.6 | 961.3 | 907.1 | 954.4 | 988.2 | 987.4 | 979.1 | 1043.9 | 1048.6 |
| Gal Oil Spilled x1K | 267 | 767 | 1,025 | 1,227 | 1,382 | 188 | 304 | 218 | 741 | 337 |




GRAPH 1: ANNUAL OIL TONNAGE AND ANNUAL GALLONS SPILLED BY TANK VESSELS

**Table 2: Observations, Mean, and Standard Deviation for Oil Tonnage data set**

| | n | Mean | SD |
|---|---|---|---|
| Oil Transported: Million short tons | 20 | 900.6 | 94.1 |
| Oil Spilled by Tank Vessels: Gallons x1K | 20 | 2520.9 | 3011.1 |

Correlation: r = –0.38
$R^2$ = 0.15

The correlation between tonnage of oil transported and volume spilled by tank vessels is negative, indicating the inverse relationship between the two data sets. The correlation of 0.38 indicates a weak correlation between these two data sets. Due to the weak correlation found, no further statistical analysis was performed on this data set.

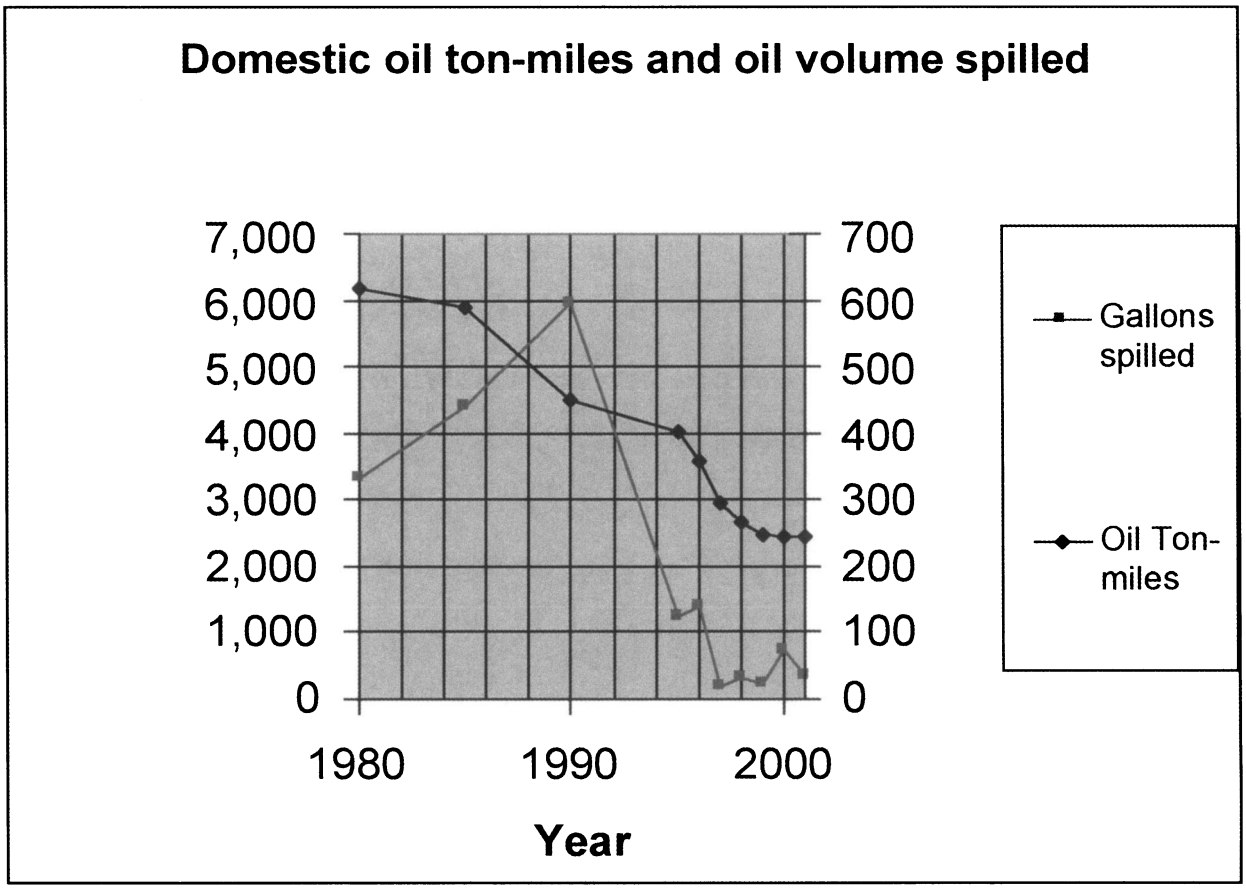
## OIL TON-MILES

The data sets used for this second analysis included the DOT's ton-miles for domestic (U.S. flagged) tank vessels (US DOT, 2004), and the U.S. Coast Guard's annual spill volumes for tank vessels (USCG, 2003). Note that the U.S. Coast Guard spill volume data used did not discriminate vessel nationality, thus spill data includes spills from foreign and domestic (U.S. flagged) tank vessels. The data for annual ton-miles and gallons of oil spilled by tank vessels are displayed in table #3.

The overall relationship is visible in graph #2, which plots domestic oil ton-miles against oil spilled by tank vessels. It is interesting to note that for the ten data sets examined from 1980 to 2001, an average of 1,811,600 gallons were spilled by U.S. tank vessels logging an average of 371,110,000,000 ton-miles. This is comes to only 4.8 gallons spilled for every 1 million ton-miles.

**Table 3: Annual domestic oil ton-miles and annual gallons spilled by tank vessels in U.S.**

| Year | 1980 | 1985 | 1990 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|---|---|---|---|---|---|
| Oil ton-miles (Billions) | 617.8 | 590.4 | 449 | 400.9 | 356.5 | 295.6 | 265 | 247.5 | 244.4 | 244 |
| Gal Oil Spilled x1K | 3,335 | 4,415 | 5,969 | 1,227 | 1,382 | 188 | 304 | 218 | 741 | 337 |




GRAPH 2: ANNUAL DOMESTIC OIL TON-MILES AND ANNUAL GALLONS SPILLED BY TANK VESSELS

Table #4 shows the basic statistical information for each data set of ton-miles and oil spilled. The correlation score, r = 0.79, indicates a moderately strong relationship. The square of the correlation, $r^2 = 0.62$ indicates that a majority of the variance is explained by the regression line.

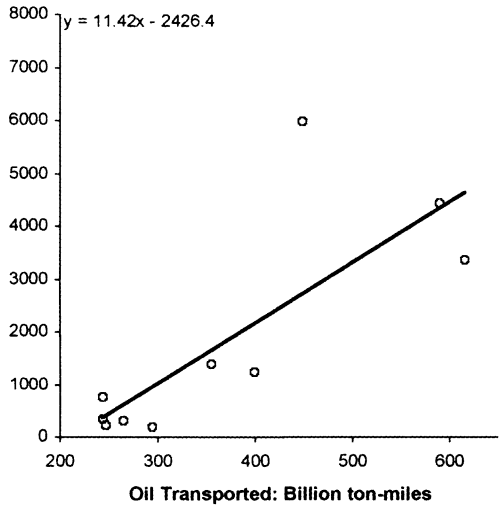
**Table 4: Observations, Mean, and Standard Deviation for Ton-miles data**

| | n | Mean | SD |
|---|---|---|---|
| Oil Transported: Billion ton-miless | 10 | 371.1 | 141.6 |
| Oil Spilled by Tank Vessels: Gallons x1K | 10 | 1,811.6 | 2,046.1 |

Correlation: r = 0.79
$R^2 = 0.62$

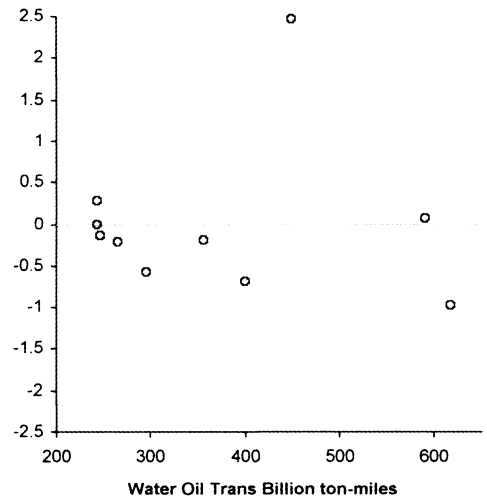
Graph #3 plots the ten observation using ton-miles on the x-axis as the explanatory variable and the volume of oil spilled in gallons on the y-axis as the response variable. A regression line is drawn which displays the strength of the linear relationship to the observations. The slope of the regression line equation is:

y = 11.42x – 2426.4




GRAPH 3: OIL TON-MILES VERSES OIL SPILLED DATA POINTS WITH REGRESSION LINE

Graph #4 provides a plot of the residuals for the ton-mile values, and displays no strong patterns that might indicate a lurking variable. The difference between an observed value of the response variable and the value predicted by the regression line is called a residual. Residuals are plotted and examined to determine possible patterns or discover potential lurking or confounding variables that might cast doubt upon the result. Lurking variables are defined as variables that may explain the relationship between the variables that were measured. A slight fan shape may be present, as more recent observations which have small ton-mile values also have smaller residuals. The residuals overall indicate a good fit of the regression line.




GRAPH 4: REGREGRESSION LINE RESIDUALS

The residual for the year 1990 with 449 Billion ton-miles and 5,969,000 gallons spilled could be a possible outlier, however the 1990 data set was considered valid and thus retained. Outliers are values that fall outside the overall pattern of the relationship for the scatterplot or the plot of residuals. If the correlation and regression are recalculated without the 1990 data the overall correlation improves to r = 0.95, and the slope of the regression line is slightly less steep with the slope equation at:

y = 9.79x – 2199.8

## CONCLUSIONS

The correlation of -0.38, between maritime oil transportation and the volume of oil spilled by tank vessels, indicated a weak correlation between the data sets. This result shows that there is little if any relationship between the marine transportation tonnage of oil and the volume of oil spilled by tank vessels. Due to the weak correlation found, this combination of data was not examined further. Thus, the tonnage of maritime oil transportation is not a good predictor of the volume of oil spilled by tank vessels.

A moderately strong correlation, r = 0.79, was found between tank vessel ton-miles and the volume of oil spilled by tank vessels. The amount of oil transported by tank vessels, as an explanatory variable, was therefore found to be a good overall predictor of the response variable, the volume of oil spilled into the marine environment by tank vessels, for the time period examined. The strength of the correlation and r-squared values are significant and maybe useful for predicting values of the response variable.

The possible causes for maritime oil spills are many and generally include human error, mechanical failure, and acts of god. The distance traveled by petroleum cargoes is not normally considered a significant factor in the causation of maritime oil spills. Rather, other event such as the number of transfers conducted, weather, crew experience, crew fatigue, and safety equipment are normally considered more important variables. The reason for the ton-miles to spill volume correlation may be explained by future examinations of additional factors that relate to tank vessel ton-miles. For example, should increased ton-miles relate closely to an increased number of product transfers and each product transfer averages to a spill error rate, then a more direct relationship to tank vessel spill volume may be confirmed. This analysis, however, did find for the time period examined, a strong correlational relationship between the volume of oil spilled

by tank vessels and the ton-miles of oil transported via these tank vessels that merits further consideration.

Potentially significant error sources to this analysis include: 1) the inherent limits of available data sources, including the limited number of data sets available for tank vessel petroleum ton-miles, 2) that the U.S. DOT data excludes the petroleum ton-miles of foreign vessels calling on U.S. ports, and 3) unknown or unreported oil spills that may have originated from tank vessels.

## BIOGRAPHY

LCDR Norton currently serves as the Response Management Section Chief at the U.S. Coast Guard Headquarters Office of Response in Washington, D.C. He holds a M.S. in Environmental Sciences from Johns Hopkins University. LCDR Norton has served at Marine Safety Offices in Honolulu, HI, and Corpus Christi, TX, and at the Eleventh District Office in Long Beach, CA. LCDR Norton is married with two children.

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