A Method for Modeling Low-Probability, High- Consequence Risk Events: Vessel Traffic on the Lower Mississippi River

George Wooddell
University of Louisiana at Lafayette

Robert Gramling

Craig J. Forsyth

A Method for Modeling Low-Probability, High-Consequence Risk Events: Vessel Traffic on the Lower Mississippi River

GEORGE WOODDELL, ROBERT GRAMLING, CRAIG J. FORSYTH[*]

INTRODUCTION

On the afternoon of December 14, 1996, the motor vessel *Bright Field*, a 763 foot long, Liberian flagged, dry cargo carrier, was descending the Mississippi River passing under the Greater New Orleans Bridge and approaching the sharp right hand turn around Algiers Point. At 2:06 pm, she lost power and, since rudders on motor vessels steer almost entirely by deflecting prop wash, also lost steerage. The vessel was traveling at sixteen miles per hour and immediately began to drift toward the outside of the turn. Ultimately the *Bright Field* struck the New Orleans "River Walk," a densely populated tourist location, between two moored and occupied cruise vessels on one side and a gambling boat with approximately 800 people on-board on the other. The allision[1] destroyed a portion of the River Walk and badly damaged a number of shops and a portion of the New Orleans Hilton. The good news is that the *Bright Field* was loaded with corn instead of a more hazardous cargo and missed the nearby vessels loaded with people. No one died, but 116 people sustained injuries. Damages and losses have been estimated at half a billion dollars. The bad news is that similar sized ships carrying potentially volatile cargos (gasoline, liquid natural gas, ammonium nitrate) pass through the same route on a daily, sometimes hourly, basis.

A variety of commodities, from chlorine to corn and petroleum to passengers, are transported on the lower Mississippi River regularly. Corn,

    1. An "allision" is when a vessel strikes anything but another vessel also under way (a collision) or the bottom (a grounding).

85

wheat and coal are the most commonly carried commodities. From a human health and safety perspective, these are relatively benign products in that a vessel accident and spill of these are not directly hazardous to people, whatever other ecological disturbances may ensue. However, over eighty million tons of petroleum products are transported on the river annually. Over a million tons of liquid natural gas traverse the river through the center of New Orleans. Additionally, over 400,000 tons of ammonium nitrate[2] pass through the center of Baton Rouge annually. The potential for a technological disaster is certainly present.

In his chapter on marine accidents, Charles Perrow calls marine transportation an "error-inducing" system.[3] A variety of factors lead to this designation, including: language differences between officers, crews and pilots;[4] intense pressure on captains to meet (often unrealistic) schedules;[5] avoidance of realistic inspection procedures by registering vessels in countries that do not require them, i.e., flags of convenience;[6] fragmented managerial regimes (ship owned by a company in one country; registered in a second country and leased by a company in a third country);[7] lack of vessel control systems, such as those for air traffic;[8] and, also unlike airlines, few high status passengers to call attention to accidents. More recently, the transformation of the only federal authority with any real enforcement power, the Coast Guard, to a drug interdiction agenda, is probably also a factor.

Anyone who studies technological disasters knows that the best way to deal with them is to prevent them from happening in the first place. But to do this requires identification and modeling of the factors that cause them. The biggest impediment to this step is lack of data as Robert Gramling and Naomi Krogman (among others) have noted.

> Regulatory agencies generally purport to base their preventative measures on scientific evidence of risk. While some technological processes or activities may be subject to formal risk analysis, low

---

2. In mid April 1947, a ship loaded with ammonium nitrate (fertilizer as in Oklahoma bomber Timothy McVeigh's bomb) exploded at the dock in Texas City, Texas, killing 576, injuring 5,000 and causing $67 million in property damage.

3. Charles Perrow, *Normal Accidents: Living with High-Risk Technology* 172 (Princeton University Press 1984).

4. Allision of the Liberian Freighter Bright Field with the Poydras Street Warf, Riverwalk Marketplace, and New Orleans Hilton Hotel in New Orleans Louisiana December 14, 1996 (National Transportation Safety Board 1998).

5. Perrow, *supra* n. 3, at 179-184.

6. K. X. Li & J. Wonham, *Who Is Safe and Who Is at Risk: A Study of 20-Year-Record on Accident Total Loss in Different Flags,* 26:2 Mar. Policy and Mgt. 137 (1999).

7. Perrow, *supra* n. 3, at 170-231.

8. *Id.*

incidence, high consequence events such as technological accidents are extremely difficult to predict with any accuracy…little more than educated guesses. . . . One of the most significant problems with assessing the risk of a major incident is that these low-probability events provide few examples from which to extrapolate risk factors. . . . Waiting for a sufficient number of oil spills, toxic chemical leaks or refinery explosions is not, however, a reasonable tactic in the prevention of these high consequence events.[9]

Thus, the question becomes: In the absence of sufficient direct experience, are there data that can help us begin to address the causes of and predict these low-probability, high-consequence events? James March suggests that maximum information can be extracted from low-probability, high-consequence events through: (1) collecting rich histories of events; (2) using multiple observers and multiple interpretations of events; and (3) constructing hypothetical histories.[10] This paper provides an example of how, using the first two of these techniques, data collected from expert informants and inferences from existing data on both low-incidence serious accidents and more common less serious accidents can be used to construct an index of relative risk. The model focuses on vessel traffic traveling on the lower Mississippi River, the busiest waterway in the world, where over 350,000 recorded commercial vessel movements occur annually.[11]

The vast majority of the literature relevant to the question of vessel accident risk concerns the question of on-board causes of vessel accidents. It is assumed that the predictors of which vessel will have an accident are on-board the vessel (i.e., vessel and crew characteristics). The most commonly cited on-board hazards include: the size of the vessel; the age of the vessel; the length of the vessel; whether the vessel is single or double hulled; the maintenance of the vessel; the classification society under which the vessel is registered;[12] the type of ownership; the history of ownership; where the vessel is flagged (i.e., flag of convenience or traditional maritime nation); license qualifications of mates and engineers; the vessel's casualty history; the vessel's history of violations; whether the vessel has system (e.g., steering) redundancy; and personnel history (including

9. Robert Gramling & Naomi Krogman, *Communities, Policy and Chronic Technological Disasters*, 45 Current Sociology 41, 46 (1997).

10. James March, *A Primer on Decision Making: How Decisions Happen* 242-243 (Free Press 1994).

11. A "vessel movement" is defined as the trip between the loading of a single commodity and its offloading. Boats that do not have cargo, such as a tug boat that moves to assist a ship docking, are not recorded.

12. A "classification society" certifies that a vessel is seaworthy. While some classification societies are reputable, others are merely rubber stamps. Shipping interests are well aware of the integrity of the various classification societies.

manning levels and the comparison of the present levels of manning with that of the vessel in the past and with similar type vessels).[13]

Unfortunately, while experts on marine accidents are virtually unanimous in their assessment that vessels flying flags of convenience are more likely to be involved in accidents, or that ships with redundant systems are safer than those without, the data to test these assumptions usually do not exist. The fact of the matter is that data are not collected in such a fashion as to enable one to relate accidents to these on-board characteristics. In those few cases where accidents are serious enough to require an investigation, by the Coast Guard or the National Transportation Safety Board, these factors are noted only if they were assessed as contributors to the accident. This fact returns us to the same problem noted above, of too few cases from which to generalize. In addition, factors that were not presumed to be contributors to the accident are not noted, even if they are thought to be dangerous by experts. Finally, in order to know if an onboard characteristic raised the vessel's probability of accident, one would have to know how many miles the vessel traveled per accident. The actual history-of-vessel data required are proprietary and not released. Thus, for the present, hypotheses about onboard vessel characteristics cannot be tested.

Craig Forsyth, Robert Gramling and George Wooddell, have addressed a different question: Where will vessels have accidents?[14] These authors

---

13. Spill, The Wreck of the Exxon Valdez: Implications for Safe Marine Transportation (Alaska Oil Spill Commission 1990); Report of the Tanker Safety Study Group (Alaska Oil Spill Commission 1989); Report of the Tanker Safety Study Group (United States Coast Guard 1987); Investigating Human Factors in Marine Casualities (The Tavistock Institute of Human Relations; Center for Marine Conservation 1989); The Exxon Valdez Oil Spill: A Management Analysis (Center for Marine Conservation 1989); Craig Forsyth, Sea Daddy: An Excursus Into an Endangered Social Species, 13 Mar. Policy and Mgt. 53 (1986); Craig Forsyth, The American Merchant Seaman and His Industry: Struggle and Stigma (Taylor & Francis 1989); Craig Forsyth, The Future of the American Seaman, 17 Mar. Policy and Mgt. 249 (1990); Craig Forsyth, Factors Affecting Tanker Safety, 18 Mar. Policy and Mgt. 313 (1991); Craig Forsyth, Transnational Corporations: Problems for Study in the New International Order of Maritime Shipping, 20(3) Mar. Policy and Mgt. 207 (1993); Craig Forsyth & William Bankston , The Social Psychological Consequence of a Life at Sea: A Causal Model, 11 Mar. Policy and Mgt. 123 (1984); Barbara Herman, Screening for Acceptable Risk: Washington State's Program for Screening Cargo and Passenger Vessels (Office of Marine Safety 1994); The Parameters of the Psychological Autonomy of Industrial Trawler Crews, in Seafarer and Community: Towards a Social Understanding of Seafaring (P. Fricke ed., Rowman & Littlefield 1973); A Study of Human Resources in Ship Operations Phase 2 (Maritime Administration, U.S. Department of Commerce 1982); National Research Council, Research Need to Reduce Maritime Collisions, Rammings and Groundings (National Maritime Transportation Research Board, Academy Press 1981); Final Report, (States/British Columbia Oil Spill Task Force Olympia WA 1990); The Oil Pollution Act, H.R. Rpt. 3394 (1989); C. Whitehurst, U.S. Merchant Marine (Naval Institute Press 1983).

14. Craig Forsyth et al., *Modeling the Mississippi: Oil Spill Risk on Louisiana's Largest Waterway*, (Louisiana Oil Spill Research and Development Program 1996) [hereinafter *Oil Spill*]; Robert Gramling et al., *Modeling the Mississippi: Barge Traffic and the Transportation of Oil on Louisiana's Largest Waterway* (Louisiana Applied Oil Spill Research and Development Program 1998) [hereinafter

have developed hypotheses about the effects of known waterway characteristics on the spatial distribution of vessel accidents. It is the purpose of this research to test hypotheses about this second question; to test a risk index. Although the data are limited on major incidents and therefore do not provide enough examples from which to extrapolate risk factors from major incidents alone, it is reasonable to assume that the causes of minor accidents are also potential causes of major accidents. Had the same set of circumstances reported on the *Bright Field* happened in a different section of the river, the vessel might have hit a soft bank, extricated herself and continued. There would have been no National Transportation Safety Board investigation, but the pilot would have reported the incident and the location. Similarly, the cause of a grain barge allision might also cause a much more hazardous chlorine barge allision. The factors might be the same, but the direct effect on humans might be quite different. Accordingly, we will focus on the river characteristics presumed to be related to accidents in general under the assumption that when river conditions promote accidents – they do not discriminate in terms of potential damage.

RIVER RISKS

A relative risk index, in which each mile of the lower Mississippi River is assigned a risk rating relative to every other river mile, was developed by the authors.[15] Those data comprise the independent variables in the current research. The index was constructed from several sources. Interviews were conducted with seamen, river pilots, Coast Guard officials, National Transportation Safety Board officials, port authorities, and other experts to obtain information about hazards on the Mississippi River. Our initial interview was with two river pilots who had a combined experience of about thirty-five years. In our interview with these river pilots, we marked specific problems that they noted directly onto United States Corps of Engineers chart books for the Mississippi River. They spent several hours taking us, chart by chart, up the river from the mouth of Southwest Pass to Baton Rouge, marking the problems and discussing them. From this initial interview, factors believed to increase risk emerged. Interviews with other knowledgeable individuals added to this list. In general, there was a great deal of agreement that these factors were the ones that individuals who worked on the river were concerned about. Additional sources such as the risk literature and previous attempts at risk indices,

Barge Traffic]; Robert Gramling et al., *Expert Informants and Relative Risk: A Methodology for Modeling Waterways*, 18 Risk Analysis 557 (1998) [hereinafter *Expert Informants*].

15. *Oil Spill*, *supra* n. 14; *Barge Traffic*, *supra* n. 14; *Expert Informants*, *supra* n. 14.

Workboat Magazine, Coast Guard publications, and commerce statistics were reviewed. Eventually fourteen risk factors were identified: (1) a narrow channel; (2) blind turns; (3) dangerous docks; (4) anchorages; (5) floating anchorages; (6) barge fleeting areas;[16] (7) bridges; (8) waterway junctions; (9) channel crossings; (10) shallow channels; (11) ferry crossings; (12) dangerous currents; (13) night vision problems; and (14) congestion.

The specified hazards.

1. Narrow Channel. A narrow channel is obviously a place where the navigable portion of the river is not wide enough to be entirely safe under all conditions (such as when passing another vessel). The width of a river is determined largely by human activity (i.e., structures along the bank that make the river narrow).

2. Blind Turn. A sharp bend where even at the relatively slow speeds of waterborne traffic, one cannot see far enough ahead to safely respond to other traffic and river characteristics. Blind turns were the factor most noted by our informants.

3. Dangerous Docks. Dangerous docks are docks that, for a variety of reasons, informants say are difficult to navigate. They may be very busy or extend into the river at a point where one has just encountered another hazard (such as a blind turn).

4. Anchorage. Anchorages are designated places where ships ride at anchor waiting for dock space. The presence of other vessels temporarily narrows the river.

5. Floating Anchorage. These are buoys permanently moored in the River that ships tie up to for loading and unloading

6. Fleeting Areas. Fleeting areas are where barges are stored when not in use. When barges are tied together in huge moored rafts, they can constitute an obstacle to other navigation. These are also areas for frequent activity and vessel movement as barge tows are put together for travel up or down the river.

7. Bridges. Bridges narrow the useable waterway and so constitute a hazard to navigation.

8. Waterway Junction. A waterway junction is where one waterway joins another. As with intersections on the highway waterway junctions can be problematic.

---

16. Fleeting areas are where barge tows are frequently being put together to go up or down stream.
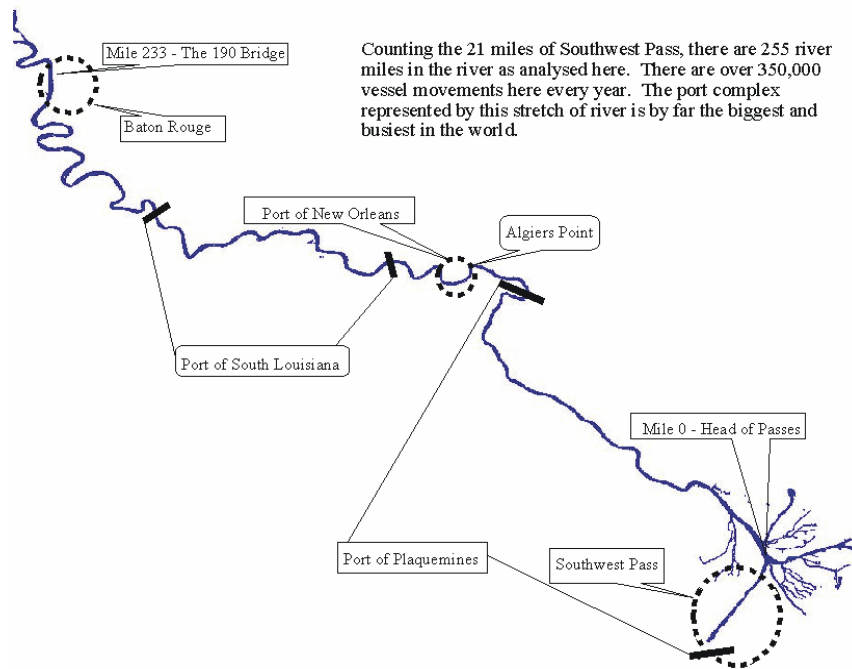
9. Channel Crossing. At various points along the river, the channel crosses from one side of the River to the other. Ships must follow the channel. Barges do not. Therefore, at these channel crossings, ship traffic crosses barge traffic.
10. Shallow Channel. If a ship drags bottom or has less than a meter clearance, steerage becomes a problem and greatly increases the chances of a mishap.
11. Ferry Crossing. Vessels whose routes carry them across rather than up or down the river should have a similar effect upon navigation as waterway junctions. Thus, ferry crossings are also potentially hazardous.
12. Dangerous Currents. On the outside of turns the current speeds up. In addition, other factors such as changes in river depth may produce large swirling eddies in the river. These situations affect steering.
13. Night Vision Problems. Blinding lights at docks and total darkness are the most commonly mentioned night vision problems.
14. Congestion. Congestion on the river operates much the same as congestion on the highway. All things being equal, it is more difficult to navigate a crowded waterway than an empty one.

Having delineated a set of risk factors, the next step was to determine where these factors occurred on the river. Some of these factors are quite easy to identify. Blind (sharp) turns, bridges, anchorages, channel crossings, waterway junctions and ferry crossings are marked on charts and maps, but others such as barge fleeting areas and night vision problems are not. The investigators drove to the levees for most of the area under consideration. We also used satellite photography and a video taken from a helicopter that flew down the east bank of the river from Baton Rouge to the mouth of Southwest Pass and back up the west bank.[17] Piloting charts of the River were taken to all informant interviews and every mile on the charts was labeled with notes. These were then arranged into the fourteen categories of hazards, such as "blind turn," "waterway junction," "dangerous current," and so on. All were entered into a table where each row was a river mile and each category of hazard was a column. If there was a waterway junction at mile ninety four, then the cell at that location received a

---

17. The video was shot the year before our research in an attempt to locate abandoned barges.

"1," and so on for each mile by each hazard column. Thus, all the river hazards so generated are dichotomous, present or absent (1s or 0s).

Figure 1: Lower Mississippi River Port Complex

Counting the 21 miles of Southwest Pass, there are 255 river miles in the river as analysed here. There are over 350,000 vessel movements here every year. The port complex represented by this stretch of river is by far the biggest and busiest in the world.

We focused our model on a 255 mile section of the Mississippi River between the mouth of Southwest Pass[18] and the U.S. Highway 190 bridge at Baton Rouge, which is too low for ships to pass under and thus constitutes the head of deep-water navigation. New Orleans is at about the middle of this section. This is the only section of the river which has both ship and barge traffic. There are four major ports located along this section of the river: the Port of South Louisiana (which is the largest, in terms of volume, in the U.S.); the Port of New Orleans; the Port of Baton Rouge; and the Port of Plaquemines. Taken together, over 400 million tons of cargo pass through these ports annually (see Figure 1).

---

18. The vast majority of the vessels enter or leave at Southwest Pass. Southwest Pass is the only pass maintained deep enough for ship traffic.

In order to test the effect of river traffic on accidents and construct accident rates of various kinds for use as dependent variables, measures of traffic per river mile are necessary. We obtained traffic data, which listed every commercial vessel movement for the year 1995 including the location of the vessel at the beginning and end of each trip.[19] There are over 350,000 cases in this database. Since some of the vessels that entered (or exited) the river were loaded (or unloaded) elsewhere, the place where they entered (or exited) the river was calculated using some likely assumptions. Ships must enter and exit via Southwest Pass. Barges enter via one of seven waterway junctions, Southwest Pass, or by coming downstream and passing under the Highway 190 bridge. Their loading (or unloading) location is known. The junction they entered (or left) is so indicated.

For example, barges loaded in St. Louis came downstream entering the section of the Lower Mississippi River we are studying at mile 233. Barges unloaded in Lake Borgne exited at the Mississippi River Gulf Outlet, and so on. These data were used in a computation that constructed 255 dummy variables (one for each river mile), where each vessel movement was a case (row). Judging from loading and unloading points, vessels either passed through a mile (a one (1) in that mile's column) or not (a zero (0) in that mile's column). Aggregation on vessel type (barge or ship, tanker or dry-cargo, all vessels) then produced the sum of all vessels passing through a river mile in 1995, by type of vessel. The resulting file was then transposed (changing the mile variables into cases of miles) and was merged with the risk factor table adding four new variables to it (number of tanker barges, number of dry-cargo barges, number of tanker ships and number of dry-cargo ships) to be used in the traffic rate calculations (explained immediately below), and one new variable (total traffic) to be used in some models as an independent variable and to calculate all-accident rates.

ACCIDENTS AND ACCIDENT RATES

The dependent variables in this investigation are various categories of vessel accident rates. The accident data were obtained from the U.S. Coast Guard.[20] Every vessel accident that the Coast Guard investigates is entered as a case. One of the variables in the data set specifies the river mile of the accident. Categories of vessel type (barge or ship, tanker or dry-cargo) and

19. U.S. Army Corps of Engineers, *Proprietary Individual Vessel Movements* (1995) (not published).
20. National Technology Information Service, *Marine Casualty and Pollution Database* (U.S. Coast Guard 1993, 1994, 1995, 1996, 1997).

type of accident (allision, collision, or grounding) were aggregated by river mile and merged with the database of hazards. A few definitions:

- *Allisions*: accidents in which a vessel hits anything but the bottom or another vessel that is underway. If a vessel underway hits a vessel that is not underway, that too is an allision.
- *Collisions*: accidents in which one vessel underway hits another vessel underway.
- *Groundings*: accidents in which a vessel enters waters that are too shallow for the vessel's draft, and "runs aground." Typically "bump and run" groundings, when a vessel is off the ground within a half hour or so under its own power, are not reported.

We also have an "all-accidents" figure, which includes categories of accidents other than allisions, collisions and groundings (such as explosions, equipment failures, and so on). The all-accidents variable also includes other vessels (such as party boats and casinos), in addition to the four types noted above (tanker barges, dry cargo barge, tanker ship, dry-cargo ship). The all-accidents figure, therefore, is higher than the sum of the accident types or the sum of accidents occurring to the four vessel types.

The models in this research, however, use accident *rates,* not raw accidents as the dependent variable. These were constructed as the number of accidents (by category) in a mile during the reporting period, divided by the number of vessels (by category) to pass the mile in 1995 multiplied by 100,000 (to avoid excessive decimal places).

Aggregation of the accident database yields the number of various types of accidents that occurred in each river mile in the years 1992 through 1997. Allision, collision and grounding rates are calculated from the Coast Guard accident data using Corps of Engineers traffic data as:

$$\textbf{\textit{(Accident type / total traffic) * 100,000 = Accident Type Rate}}$$

Accident rates occurring to the various vessel types are calculated as:

$$\textbf{\textit{(Accidents involving vessel type / that type of vessel traffic) * 100,000 = Vessel Type Accident Rate}}$$

Population Density

Since ultimately we want to discover the risk to human populations along the river, the units of analysis (miles along the river) are weighted by

population density. Population density is calculated by taking the number of persons in all census block groups within a half mile of the River,[21] and dividing that number by the number of square kilometers of dry land in those block groups,[22] for each of the 255 river miles.

The final database then has 255 cases of miles, navigational characteristics of each mile (the fourteen risk factors identified), vessel traffic for each mile, population densities for each mile, and categories of vessel accident rates for each mile.

MODELING THE RIVER

Predicting the combined effect of the hazards to navigation on accidents is accomplished by multiple regression (ordinary least squares). Ordinary least squares necessitate certain statistical assumptions. One of those assumptions is that the independent variables are not so highly intercorrelated that they are statistically indistinguishable.

Some of the independent variables in these regressions are correlated, a condition known as *colinearity*. (See Table 1). *Multicolinearity* occurs when independent variables are explained by other independent variables as a group. In a multiple regression, multicolinearity can cause unexpectedly large or small effects, or change the apparent direction of effects. Results for a regression with multicolinearity problems are not reliable, and some correction must be made. Problems with multicolinearity were diagnosed with the Tolerance statistic and independent variables were removed to decrease Tolerance to below 0.5. In the tables, variables that were eliminated as a corrective for multicolinearity have shaded cells.

21. U.S. Department of Commerce Bureau of the Census, *Twenty-first Census of the U.S.: Characteristics of the Population* (Government Printing Office 1990).
22. *Id.*

Table 1. Correlations Among Navigational Hazards
(Data Weighted)

	Narrow River	Blind Turn	Anchorage	Floating Anchorage	Barge Rafts	Bridges	Waterway Junctions	Shallow Channels	Ferry Crossings	Dangerous Currents	Night Vision Problems	Dangerous Docks	Congestion	Channel Crossings
Blind Turn	-0.011													
Anchorages	0.261**	-0.127*												
Floating Anchorages	-0.161*	-0.088	-0.048											
Barge Rafts	0.011	0.027	0.013	0.125*										
Bridges	-0.063	-0.1	-0.103	0.198**	0.131*									
Waterway Junctions	-0.094	-0.148*	-0.146*	0.071	0.211**	-0.091								
Shallow Channels	0.033	-0.029	0.11	0.274**	0.04	-0.031	0.14*							
Ferry Crossings	-0.103	0.328**	-0.014	-0.088	0.193**	-0.1	-0.148*	-0.065						
Dangerous Currents	-0.084	0.445**	0.163**	-0.071	0.188**	0.43**	-0.12	-0.053	0.444**					
Night Vision Problems	-0.036	0.31**	0.056	-0.024	-0.239**	-0.035	-0.051	-0.023	-0.057	-0.044				
Dangerous Docks	-0.068	0.145*	-0.537**	-0.296**	0.208**	0.007	0.165**	-0.194**	0.205**	0.233**	-0.122			
Congestion	-0.13*	-0.02	-0.134*	-0.12	0.34**	0.046	0.258**	0.016	0.2**	0.213**	-0.199**	0.436**		
Channel Crossings	0.236**	-0.111	0.017	0.568**	0.058	0.127*	0.021	0.206**	-0.112	-0.068	-0.039	-0.303**	-0.227**	
Traffic	0.116	-0.032	0.006	0.245**	-0.044	0.076	0.043	0.389**	0	-0.126*	-0.104	0.241**	0.269**	0.361**

Note: * p < .05, ** p < .01

FINDINGS

The list of delineated hazards to navigation does help predict accident rates on the Lower Mississippi. Some models are quite successful. The allisions model, for instance, accounts for more than half of the variance in allisions with seven of the fourteen hazards to navigation. Collisions are predicted by seven of these hazards, although less than half of the variance is explained (Table 2).

Table 2.
Models of Hazards to Navigation on Allision, Collsion,
Grounding and All Accident Rates
(Standardized Regression Coefficients)

	Allision Rates	Collision Rates	Grounding Rates	All Accident Rates
Narrow River	0.026	-0.069	.239**	-0.047
Blind Turn	-0.026	0.221**	.401**	-0.036
Floating Anchorages	-.138**	-0.057	-.181**	-.214**
Barge Fleeting Areas	.106**	0.178**	.135*	.283**
Bridges	.114*	-0.093	-0.036	-0.018
Waterway Junctions	0.009	.375**	.415**	.300**
Shallow Channels	.095*	-.121*	-0.054	-.129**
Ferry Crossings	.294**	-.321**	-0.095	0.081
Dangerous Currents	.452**			
Night Vision Problems	0.002	-.133*	-0.108	0.01
Dangerous Docks	-0.024	0.106	0.063	-0.031
Congestion	.317**	.126*	-.140*	.351**
Channel Crossings	0.016	-0.005	0.012	0.032
R² (Adjusted R²)	.717 (.702)**	.417 (.389)**	.370 (.339)**	.511 (.487)**

Note: * p < .05, ** p < .01

In the prediction of allision rates (adj. $R^2 = 0.702$), the model exhibits significant effects for dangerous currents, congestion, bridges, ferry crossings, shallow channels, and barge fleeting areas in the expected direction. Floating anchorages appear to depress allision rates (Table 2).

In Table 2, collision rates are predicted (adj. $R^2 = 0.389$) by barge fleeting areas, waterway junctions and blind turns. But, shallow channels, ferry crossings and night vision problems exhibit negative effects.

Grounding rates (Table 2) are predicted reasonably well (adj. $R^2 = 0.339$). Narrow river, blind turns, barge fleeting areas and waterway junctions all have their expected effects. Strangely, floating anchorages again predict fewer groundings as does congestion. All-accident rates are predicted at an adjusted $R^2 = .487$, nearly half the variance. All-accident rates, which include categories not specifically tested here as well, are predicted by barge fleeting areas, waterway junctions and congestion, in the expected directions. Shallow channels have a significant negative effect.

Table 3.
Models of Hazards to Navigation on Tanker Accident Rates
(Standardized Regression Coefficients)

	Tanker Ship Rates	Tanker Barge Rates	Dry-Cargo Ship Rates	Dry-Cargo Barge Rates
Narrow River	-0.025	-0.036	-0.117*	0.033
Blind Turn	-0.033	-.271**	-0.053	0.329**
Floating Anchorages	-0.12	-0.121	-0.186**	-0.11
Barge Fleeting Areas	0.023	.307**	0.288**	.165**
Bridges	-0.053	-.182**	-0.096	0.199**
Waterway Junctions	-0.055	-0.047	0.176**	.411**
Shallow Channels	-0.055		0.133*	
Ferry Crossings	-0.066	.245**	0.011	.155**
Dangerous Currents				
Night Vision Problems	0.052	0.083	0.053	-0.187**
Dangerous Docks	0.089	0.002	-0.094	.142**
Congestion	0.102	.198**	0.262**	-.124*
Channel Crossings	.200*	.161*	0.029	0.028
Traffic	.184*	0.062	0.241**	-.263**
R^2 (Adjusted R^2)	.066 (.016)	.296 (.261)**	.348 (.313)**	.462 (.435)**

Note: * $p < .05$, ** $p < .01$

Dry-cargo ship accident rates (Table 3) are predicted by barge fleeting areas, waterway junctions, shallow channels, congestion and traffic. A narrow river and floating anchorages tend to depress dry-cargo ship accident rates. Less than half of the variance is explained (adj. $R^2 = 0.313$). Dry-cargo barge accident rates are predicted (adj. $R^2 = 0.435$) by blind

turns, barge fleeting areas, bridges, waterway junctions and ferry crossings, all in the expected direction, but are counter indicated by night vision problems, congestion and traffic.

Tanker barge accident rates are predicted (adj. $R^2 = 0.261$) by barge fleeting areas, ferry crossings and congestion in the expected direction. Blind turns and bridges seem to depress the incidence of tanker barge accidents.   Tanker ship accident rates is the worst model of vessel type accidents (adj. $R^2 = 0.016$, not significant).   There are only significant effects for channel crossings and total traffic.

This is a fairly impressive showing for the risk index, conceived as the combined effects of all known river hazards, and might be generally taken as strong support for the hypotheses of Forsyth, Gramling and Wooddell,[23] and regarding their risk index's utility in prediction of vessel accidents.

DISCUSSION

Floating anchorages in this research seem to depress the incidence of every type of accident for which they have an effect. This is a difficult finding to explain. A closer look at the data, however, reveals that in every mile where there is a floating anchorage, there is also at least one barge fleeting area. As a result, floating anchorages are treated mathematically as a subset of barge fleeting, a circumstance that complicates analysis. Still, the negative associations for floating anchorages remain a mystery, as does the occasional finding that a narrow river, blind turns, bridges, shallow channels, ferry crossings, night vision problems, congestion and traffic make the River safer. The authors consulted with field informants, including Robert Ross, Chief of the Office of Vessel Traffic Management, United States Coast Guard, who suggested that when pilots approach widely known hazards, their level of alert ("pucker factor," as Ross called it) rises. This extra care, coupled with mitigation by the Coast Guard and the Corps of Engineers, might account for these unexpected negative effects. Other informants also suggested that generally agreed upon problem areas tended to raise stress levels and resulted in greater caution. This tends to support the idea that stress and the resulting greater caution, at least under some circumstances, may reduce risk.[24]

---

23. *Oil Spill*, *supra* n. 14; *Barge Traffic*, *supra* n. 14; *Expert Informants*, *supra* n. 14.
24. Todd LaPorte, *High Reliability Organizations: Unlikely, Demanding, and At Risk*, 4(2) J. of Contingencies and Crisis Mgt. 60 (1996).

These models do not fit tanker ship accident rates very well, partly because the sample size is the smallest for tanker ships. Examining the data for other reasons, however, reveals another interesting potential explanation. Tanker ship accidents, it turns out by reference to charts, seem to be clustered around tanker ship docks, particularly international tanker ship docks. Our data table does not distinguish between types of docks. But some of the most accident prone miles (232 and 118) are the locations of international tanker ship docks. Not only are these docks dangerous because they are crowded, but also because they draw a number of non-U.S.-flagged tanker ships, the most dangerous kind. Future research should categorize docks, if at all possible.

When more data become available, important sub-divisions of ship type by accident type rates might also be tested. The current data will not support categorization into sub divisions such as "tanker barge collisions" because of the small samples such subdivisions produce.

CONCLUSIONS

This index, as validated by its general effectiveness at predicting the location of actual vessel accidents, will be quite useful in various decision-making endeavors. Coast Guard officials, response crews, insurance brokers and local governments near or on waterways may want to take note of the predictive power demonstrated here. For those interested in developing techniques by which major but rare disasters might be predicted, this test demonstrates the utility of developing such predictions of risk by using expert informants and analyzing data that include all incidents, thus overcoming the problems associated with low-probability high-consequence events.

The data analysis also suggests possible practical solutions to potential accidents. Blind turns, barge fleeting areas, waterway junctions, and congestion are consistent predictors of at least some types of accidents. These factors inhibit the ability of pilots to know what is happening with other vessels around them. Having numerous vessels around, being unable to see what is coming around a turn or out of a waterway, or being in a fleeting area creates confusion. A way to address these types of issues is with a vessel traffic monitoring system. These systems consist of a transponder on each vessel similar to those on commercial airplanes, and a monitor that displays the position of other transponders in the area, similar to what an air traffic controller sees. Transponders vary with vessel types. Thus, sophisticated systems can monitor the types, travel direction and speed of vessels and display all of this to each vessel pilot. The Coast Guard has wanted to do this on the lower Mississippi River for some time, and it was

a topic of conversation in many of our interviews. A vessel traffic monitoring system would require owners to purchase equipment for each vessel and the Coast Guard to implement an expensive overarching system. Owners have resisted this expense, and congressional budgetary focus appears to date to be on more politically strategic issues than marine safety. It will be interesting to see if marine safety in general receives more attention as a result of the recent focus on terrorism and on ports and marine traffic as vulnerable areas. Pennsylvania is at least studying monitoring cargo from the port of origin, through ports in Pennsylvania, and then containers as they are unloaded and trucked across the country.[25] This type of attention might well mitigate some of the factors that make marine transportation problematic.

Although we have focused our attention here on river characteristics and the suggestion to reduce risk (a vessel traffic monitoring system) is a means to compensate for river conditions, we do not mean to detract from the ongoing focus of other researchers on vessel characteristics. The problems noted by such investigators are real and, though not rigorously tested by statistical means, do seem quite reliable as predictors of which vessels are more prone to accidents. It is also possible to take risk reduction actions based on these on-board characteristics. One of our informants stated that incidents like the *Bright Field* allision[26] could be largely prevented by not allowing flag of convenience ships (an on-board characteristic) into the river until they are inspected. This same informant acknowledged that pressure against such inspections would be intense from a variety of stakeholders. Indeed, much more sophisticated models for assessing vessel on-board potential accident risk have been developed[27] and research on, and implementation of, both of these approaches should be encouraged given the "risk inducing"[28] nature of marine transportation. Marine transportation problems are not going away. The *Bright Field* has changed only its name, being re-christened the *Bright Star*. Similarly, the *Exxon Valdez* was renamed the *Exxon Mediterranean.* Both actions are part of a process that makes testing of vessel characteristic hypotheses even more problematic.[29]

---

25. Interview by Jim Lehrer with Earl Freilino (Nov. 14, 2002) (television broadcast).

26. The *Bright Field* lost power because the number one oil pump for the engine failed. With a loss of oil pressure the engine automatically shut down to avoid engine damage. The switch that would switch to the number two oil pump was not operable. The log of the vessel indicated a long history of problems with the vessel's engine. The National Transportation Safety Board accident report found the probable cause of the accident was the failure of the vessel's owners to adequate maintain the vessel's engineering plant.

27. Herman, *supra* n. 13.

28. Perrow, *supra* n. 3.

29. Renaming vessels following high profile accidents is quite common.

102   *PIERCE LAW REVIEW*   Vol. 1, No. 1/2