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Determinants of crew injuries in vessel accidents

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This study investigates determinants of the number of non-fatal crew injuries, fatal crew injuries and missing crew in freight ship, tanker and tugboat vessel accidents based upon individual accidents investigated by the US Coast Guard for the 1991–2001 period. Poisson and negative binomial regression estimates suggest that: (1) freight ship and tanker non-fatal injuries are higher when the vessel is moored or docked and during high winds and cold temperatures; (2) tugboat non-fatal injuries are higher during poor visibility; (3) freight ship fatal injuries increase with vessel age and tanker and tugboat fatal injuries are higher for fire and capsize accidents, respectively; and (4) freight ship missing crew increase with vessel age and tugboat missing crew are higher for fire and lake accidents.

1. Introduction

A vessel accident is an unintended happening. Its severity may vary from no vessel damage to the complete loss of the vessel, no cargo damage to loss of the entire cargo, and no crew injuries to deaths. Between 1980 and 2000 the loss of commercial vessels around the world ranged between 0.15% to 0.55% per year; crew losses, i.e. deaths and missing crew, averaged 700 or 0.06% per year [1].

Vessel safety rules (or regulations) and their enforcement seek to prevent and reduce the severity of vessel accidents. National vessel safety rules are enacted and enforced by flag and flag-of-convenience states. Uniform international vessel safety rules are established when countries adopt safety conventions of the International Maritime Organization (IMO). Each ratifying member country is obligated to enact the convention into national law, thus standardizing the safety rules among the ratifying countries. The ineffective enforcement of international safety rules by flag and flag-of-convenience states has led some countries to establish port state control (PSC) systems—inspecting vessels of all flags that enter their ports for safety rule violations—and to insist, by detention if necessary, on deficiencies being rectified. For further discussion of port state control, see [2–4].

Prior to 1998 the focus of ratified IMO safety conventions was the vessel, e.g. its construction and equipment, rather than human actions aboard the vessel. On 1 July 1998 the IMO's International Management Code for the Safe Operation of Ships

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and for Pollution Prevention took effect. It requires shipping lines to document their management procedures for detecting and eliminating unsafe human behavior. This shift towards regulating human actions aboard a vessel was motivated by the fact that: (1) most vessel accidents are caused by human error; (2) vessel accident claims are often attributed to human error; and (3) it is less expensive to change human behavior than it is to redesign vessels for safety. Nearly 80% of vessel accidents are caused by human error, a human action or omission identifiable as the immediate cause of the event from which the liability arises [5]. For further discussion of human error in shipping, see [6–8].

From a survey of 1,500 insurance claims for shipping accidents around the world between 1987 and 1996, the UK Thomas Miller P & I Club found that 90% of the accidents were caused by human error. Two-thirds of the accidents involving personal injury claims were due to human error, e.g. carelessness or recklessness under commercial pressures, a misplaced sense of overconfidence, or a lack of either knowledge or experience. Temperamental human factors responsible for accidents include fatigue, discomfort, boredom, anger, unhappiness and illness [9].

In addition to states, classification societies are also active in enforcing vessel safety rules. Classification societies inspect vessels to ensure that they are seaworthy, meet national-flag requirements and conform to international safety rules. Since vessel insurers must be confident that vessels are seaworthy, only insured vessels are classed by classification societies. For further discussion of classification societies, see [1, 10].

The purpose of this study is to investigate the severity of vessel accidents from the standpoint of the crew, i.e. to investigate determinants of the number of non-fatal crew injuries, fatal crew injuries and missing crew in vessel accidents. The results, in turn, can be used by flag and flag-of-convenience states and classification societies to evaluate their vessel safety programs for reducing the number of vessel-accident crew injuries, and to develop related benefit–cost analyses of various safety-enhancing measures. Specifically, states and classification societies might evaluate whether their safety programs have an impact on the determinants of vessel-accident crew injuries found in this study. If not, then by revising their vessel safety programs to address these determinants, the programs could be made more effective in reducing vessel-accident crew injuries.

Determinants of the fatal and non-fatal crew injuries of individual commercial US and foreign flag bulk, container and tanker vessel accidents (investigated by the US Guard for the time period 1981–1991) have been analyzed by Talley [11]. The estimation results suggest that the number of fatal crew injuries are greater for: (1) tankers than for container or bulk vessels; (2) fire/explosion accidents than for other types of accidents; and (3) multiple- than for single-vessel accidents. Non-fatal crew injuries are also greater for fire/explosion and multiple-vessel accidents. In a study of towboat vessel accidents (based upon US Guard investigations for the time period 1981–1991), McCarthy and Talley [12] found that the number of both fatal and non-fatal injuries are greater for: (1) docked or moored vessels than for underway vessels; and (2) fire/explosion accidents than for other types of accidents.

This study extends the literature on determinants of vessel fatal and non-fatal crew injuries by estimating separate vessel-accident equations for freight, tanker and towboat vessel accidents and by utilizing more recent data, i.e. for the time period 1991–2001, for such an investigation. Further, it is the first study to appear in the literature, to the knowledge of the authors, that investigates determinants of missing crew in vessel accidents.

The study is structured as follows: a model of vessel-accident injured, deceased and missing crew is presented in Section 2, followed by a discussion of the data in Section 3. Estimation results are detailed in Section 4 and estimated marginal effects are discussed in Section 5. Conclusions are set forth in Section 6.

2. The model

The number of non-fatal crew injuries, fatal crew injuries and missing crew in a vessel accident (NUMIDM) is expressed as a function of the number of crew on board (CREW), vessel damage severity (VESSDAM) and vessel-injury prevention (PREVENT), i.e.

$$\text{NUMIDM} = g(\text{CREW, VESSDAM, PREVENT}) \tag{1}$$

The relationship between NUMIDM and CREW is expected to be positive—as the number of crew on board increases the greater the likelihood that a member of the crew will have a mishap (injury, death or missing) in a vessel accident, all else held constant. Vessel damage severity should have a non-negative effect on NUMIDM, given that a damaged vessel does not necessarily result in non-fatal injuries, fatal injuries or missing crew. Vessel-injury prevention is expected to have a negative effect on NUMIDM.

CREW, VESSDAM and PREVENT in turn are modeled as functions of other variables. The number of crew on board a vessel (CREW) varies with vessel age and size, i.e.

$$\text{CREW} = h_1(\text{VESSELAGE, VESSELSIZE}) \tag{2}$$

A positive relationship is expected between VESSELAGE and CREW, since older vessels tend to have more crew than newer ones. A vessel's size should have a non-negative effect on the number of crew, since a larger vessel does not necessarily require a larger crew.

The damage severity of a vessel involved in an accident (VESSDAM) is expected to vary with the type of accident (TYPEACCD), vessel characteristics (VESSCHAR), vessel operation phase (VESSOPER), weather/visibility conditions (WEAVIS), and type of waterway (TYPEWAT), i.e.

$$\begin{aligned}\text{VESSDAM} = h_2(&\text{TYPEACCD, VESSCHAR, VESSOPER,}\\ &\text{WEAVIS, TYPEWAT)}\end{aligned} \tag{3}$$

The type of accident includes an allision (ALLISION), capsize (CAPSIZE), collision (COLLISION), equipment failure (EQUIPFAIL), explosion (EXPLOSION), fire (FIRE), flooding (FLOODING), grounding (GROUNDING) or a breakaway or sinking accident as well as being described by the number of vessels involved in the accident (NUMVESS). An allision accident occurs when a vessel strikes a stationary object (not another vessel) on the water surface. A collision accident occurs when a vessel strikes, or is struck by, another vessel on the water surface. A grounding accident occurs when the vessel is in contact with the sea bottom or a bottom obstacle. The greater the number of vessels involved in an accident, the greater the expected number of injuries. Otherwise, the a priori relationship between type of accident and VESSDAM is indeterminate.

Vessel characteristics include VESSELAGE, VESSELSIZE and whether the vessel is a US flag vessel (USFLAG). The a priori signs of the relationships between VESSDAM and VESSELAGE and VESSELSIZE are indeterminate. Vessels built in different years vary in design, construction technologies and materials, and operation. For a specific accident, vessel damage severity does not necessarily increase or decrease with age. A negative relationship is expected between VESSDAM and USFLAG, since the US is a nation among nations with the highest vessel safety standards.

Vessel operation phase is described by whether the vessel was anchored (ANCHORED), moored or docked (MOORDOCK), towed/towing (TOW), underway (UNDERWAY) or adrift at the time of the accident. Underway vessels involved in allisions, collisions and groundings are expected to incur greater vessel damage (given the speed of impact) than vessels that are moored, docked or adrift. However, it is unclear whether underway vessels involved in equipment-failures, explosions and fires will incur greater vessel damage.

Weather is differentiated by whether high winds (HIGHWINDS), precipitation (PRECIPTN) and/or cold temperatures (COLD) exist at the time of the accident. Visibility is differentiated by whether the visibility was poor (POORVISIB) and by time of day, occurring at nighttime (NIGHT) versus daytime. Although adverse weather and visibility are expected to increase the risk of a vessel accident, the impact on accident vessel damage severity is unclear.

The type of waterway includes a river (RIVER), harbor (HARBOR), coastal (COAST), ocean (OCEAN), lake (LAKE) or a bay waterway. For allisions, collisions and groundings, VESSDAM is expected to be less in harbors than in rivers, lakes, bays, coastal or ocean waterways, since vessels generally travel at lower speeds in harbors. Otherwise the relationship between VESSDAM and type of waterway is unclear.

Vessel injury-prevention (PREVENT) will vary with respect to vessel safety regulations (SAFE) and the enforcement of these regulations (SAFENF), i.e

$$\text{PREVENT} = h_3(\text{SAFE, SAFENF}) \tag{4}$$

Positive relationships are expected between PREVENT and SAFE and SAFENF. Safety regulation of vessels is differentiated by the vessel's flag, i.e. the latter is used as a proxy for the former. Specifically, US flag vessels (USFLAG) are distinguished from non-US flag vessels. Since this study investigates non-fatal crew injuries, fatal crew injuries and missing crew of vessel accidents investigated by the US Coast Guard, the latter is the vessel safety regulation enforcement agency for this study, either because the vessels are US flag or because they are foreign flag but in US waters. The variability in the enforcement of the safety regulations of US flag and foreign flag vessels in US waters is measured by distinguishing among the years (Y_i, where $i = 91, 92, \ldots, 01$) and the ten US Coast Districts (DIST) where vessel accidents occurred, i.e. by DIST_j, where $j = 1$, 2, 5, 7, 8, 9, 11, 13, 14 and 17. The Coast Guard 1st District covers the New England and New York Atlantic coast; the 2nd District covers the Midwest; the 5th District, the mid-Atlantic coast (southern New Jersey to North Carolina); the 7th District, the southern Atlantic coast (South Carolina to Florida); the 8th District, the Gulf coast; the 9th District, the Great Lakes; the 11th District, the California coast; the 13th District, the Pacific northwest coast; the 14th District, Hawaii; and the 17th District, Alaska.

Replacing the variables in equations (2), (3) and (4) by the variables used to classify or measure them and then substituting these equations into equation (1), one obtains the reduced-form equation:

$$\begin{aligned}\text{NUMIDM} = G(&\text{ALLISON, CAPSIZE, COLLISION, EQUIPFAIL,}\\ &\text{EXPLOSION, FIRE, FLOODING, GROUDING, NUMVESS,}\\ &\text{VESSELAGE, VESSELSIZE, USFLAG, ANCHORED,}\\ &\text{MOORDOCK, TOW, UNDERWAY, HIGHWINDS,}\\ &\text{PRECIPTN, COLD, POORVISIB, NIGHT, RIVER,}\\ &\text{HARBOR, COAST, OCEAN, LAKE, DIST1, DIST2, DIST5,}\\ &\text{DIST7, DIST8, DIST9, DIST11, DIST13, DIST14, DIST17,}\\ &\text{Y91, Y92,} \ldots \text{Y01)}\end{aligned} \quad (5)$$

Equation (5) is estimated separately for the number of non-fatal injuries, heretofore referred to as injuries (INJURY), fatal injuries or deaths (DEATH) and missing crew (MISSING) in a vessel accident for each type of vessel—freight, tanker and tugboat.

3. Data

Estimates of equation (5) are obtained utilizing detailed data of individual vessel accidents of freight ships, tankers and tugboats that occurred during the 11-year time period 1991–2001 and investigated by the US Coast Guard. Vessel accidents of foreign flag vessels occurred in US waters; those of US flag vessels are not restricted to any body of water, although most occurred in US waters. Data for all variables were extracted from the US Coast Guard Marine Safety Management System (MSMS) database. Four MSMS data tables were merged to obtain the data set for this study. The four data tables include: the Marine Casualty and Pollution Master Table (cirt), the Marine Casualty Vessel Supplement Table (civt), the Vessel Identification Table (vidt), and the Marine Casualty Weather Supplement Record (cwxt).

Variables used in the estimations of equation (5) and their specific measurements appear in table 1. Descriptive statistics (mean and standard deviation) for these variables appear in table 2. The mean statistics for the dependent variables reveal that more injured and missing crew occur per vessel accident in freight ship than in tanker accidents, but the injured and missing of the latter are greater than those in tugboat accidents. Deaths per tanker accident are slightly higher than that per freight ship accident which is higher than that per tugboat accident.

The mean statistics for the explanatory variables reveal that for freight ship (tanker) accidents 36.7% (41.4%), 14.8% (10.9%) and 13.1% (10.7%) were equipment failure, allision and grounding accidents, respectively and for tugboat accidents 24.3%, 23.8% and 19.0% were grounding, allision and equipment-failure accidents, respectively. The average age for freight ships, tankers and tugboats are 18.1, 17.5 and 25.3 years respectively. The majority of accidents for each vessel type occurred while the vessel was underway. Further, over 87% and 90% of the accidents for each vessel type occurred when cold temperatures and poor visibility

Table 1. Variable definitions.

	Measurement
Dependent variables	
INJURY	Number of crew injuries in a vessel accident
DEATH	Number of crew deaths in a vessel accident
MISSING	Number of missing crew in a vessel accident
Explanatory variables	
Type of accident	
ALLISION	1 if an allision vessel accident, 0 otherwise
CAPSIZE	1 if a capsize vessel accident, 0 otherwise
COLLISION	1 if a collision vessel accident, 0 otherwise
EQUIPFAIL	1 if an equipment-failure vessel accident, 0 otherwise
EXPLOSION	1 if an explosion vessel accident, 0 otherwise
FIRE	1 if a fire vessel accident, 0 otherwise
FLOODING	1 if a flooding vessel accident, 0 otherwise
GROUNDING	1 if a grounding vessel accident, 0 otherwise
NUMVESS	number of vessels involved in a vessel accident
Vessel characteristics	
VESSELAGE	vessel age in years
VESSELSIZE	vessel size in gross tons
USFLAG	1 if a US flag vessel, 0 otherwise
Vessel operation phase	
ANCHORED	1 if vessel is anchored, 0 otherwise
MOORDOCK	1 if vessel is moored or docked, 0 otherwise
TOW	1 if vessel is towed/towing, 0 otherwise
UNDERWAY	1 is vessel is underway, 0 otherwise
Weather/visibility conditions	
HIGHWINDS	1 if high winds exist (greater than 20 knots), 0 otherwise
PRECIPTN	1 if precipitation weather, 0 otherwise
COLD	1 if cold temperature (less than 32 Fahrenheit degrees), 0 otherwise
POORVISIB	1 if poor visibility, 0 otherwise
NIGHT	1 if nighttime, 0 otherwise
Type of waterway	
RIVER	1 if river, 0 otherwise
HARBOR	1 if a harbor, 0 otherwise
COAST	1 if a coastal waterway, 0 otherwise
OCEAN	1 if an ocean, 0 otherwise
LAKE	1 if a lake, 0 otherwise
Coast Guard district	
DIST1	1 if district one, 0 otherwise
DIST2	1 if district two, 0 otherwise
DIST5	1 if district five, 0 otherwise
DIST7	1 if district seven, 0 otherwise
DIST8	1 if district eight, 0 otherwise
DIST9	1 if district nine, 0 otherwise
DIST11	1 if district eleven, 0 otherwise
DIST13	1 if district thirteen, 0 otherwise
DIST14	1 if district fourteen, 0 otherwise
DIST17	1 if district seventeen, 0 otherwise
Year	
Y91	1 if year 1991, 0 otherwise

(*continued*)

Table 1. Continued.

	Measurement
Y92	1 if year 1992, 0 otherwise
Y93	1 if year 1993, 0 otherwise
Y94	1 if year 1994, 0 otherwise
Y95	1 if year 1995, 0 otherwise
Y96	1 if year 1996, 0 otherwise
Y97	1 if year 1997, 0 otherwise
Y98	1 if year 1998, 0 otherwise
Y99	1 if year 1999, 0 otherwise
Y00	1 if year 2000, 0 otherwise
Y01	1 if year 2001, 0 otherwise

Table 2. Mean/standard deviation descriptive statistics.*

	Type of vessel		
	Freight	Tanker	Tugboat
Dependent variables			
INJURY	1.041 (24.877)	0.779 (20.794)	0.142 (0.658)
DEATH	0.021 (0.149)	0.023 (0.247)	0.012 (0.123)
MISSING	0.003 (0.088)	0.002 (0.039)	0.001 (0.037)
Explanatory variables			
Type of accident			
ALLISION	0.148 (0.355)	0.109 (0.312)	0.238 (0.426)
CAPSIZE	0.002 (0.047)	0.002 (0.048)	0.005 (0.070)
COLLISION	0.065 (0.247)	0.088 (0.284)	0.126 (0.332)
EQUIPFAIL	0.367 (0.482)	0.414 (0.493)	0.190 (0.392)
EXPLOSION	0.001 (0.033)	0.002 (0.048)	0.001 (0.035)
FIRE	0.020 (0.141)	0.018 (0.132)	0.019 (0.135)
FLOODING	0.016 (0.125)	0.006 (0.078)	0.013 (0.113)
GROUNDING	0.131 (0.338)	0.107 (0.309)	0.243 (0.429)
NUMVESS	1.292 (0.888)	1.319 (1.146)	2.153 (1.559)
Vessel characteristics			
VESSELAGE	18.119 (11.459)	17.465 (10.442)	25.288 (11.528)
VESSELSIZE	20640 (14324)	31458 (22974)	262.1 (266.4)
USFLAG	0.417 (0.493)	0.507 (0.500)	0.915 (0.279)
Vessel operation phase			
ANCHORED	0.038 (0.192)	0.049 (0.216)	0.005 (0.071)
MOORDOCK	0.146 (0.353)	0.153 (0.360)	0.065 (0.247)
TOW	0.018 (0.134)	0.007 (0.083)	0.006 (0.077)
UNDERWAY	0.588 (0.492)	0.596 (0.491)	0.738 (0.440)
Weather/visibility conditions			
HIGHWINDS	0.041 (0.198)	0.025 (0.157)	0.042 (0.200)
PRECIPTN	0.029 (0.168)	0.013 (0.114)	0.024 (0.154)
COLD	0.892 (0.310)	0.898 (0.303)	0.872 (0.334)
POORVISIB	0.906 (0.292)	0.919 (0.272)	0.908 (0.290)
NIGHT	0.060 (0.237)	0.038 (0.192)	0.067 (0.250)
Type of waterway			
RIVER	0.424 (0.494)	0.393 (0.489)	0.738 (0.440)
HARBOR	0.054 (0.225)	0.048 (0.215)	0.028 (0.165)

(*continued*)

Table 2. Continued.

	Type of vessel		
	Freight	Tanker	Tugboat
COAST	0.189 (0.392)	0.243 (0.429)	0.123 (0.329)
OCEAN	0.169 (0.375)	0.205 (0.404)	0.034 (0.181)
LAKE	0.060 (0.238)	0.005 (0.073)	0.006 (0.074)
Coast Guard district			
DIST1	0.062 (0.242)	0.122 (0.328)	0.051 (0.220)
DIST2	–	–	0.186 (0.389)
DIST5	0.119 (0.324)	0.057 (0.232)	0.074 (0.262)
DIST7	0.188 (0.391)	0.119 (0.324)	0.076 (0.266)
DIST8	0.222 (0.416)	0.398 (0.490)	0.492 (0.500)
DIST9	0.160 (0.367)	0.020 (0.140)	0.047 (0.212)
DIST11	0.118 (0.323)	0.143 (0.350)	0.029 (0.168)
DIST13	0.059 (0.236)	0.053 (0.244)	0.024 (0.152)
DIST14	0.020 (0.139)	0.022 (0.145)	0.004 (0.063)
DIST17	0.051 (0.221)	0.066 (0.249)	0.016 (0.127)
Year			
Y91	0.008 (0.090)	0.007 (0.083)	0.001 (0.037)
Y92	0.097 (0.296)	0.068 (0.253)	0.043 (0.202)
Y93	0.081 (0.273)	0.085 (0.278)	0.056 (0.230)
Y94	0.102 (0.303)	0.125 (0.330)	0.070 (0.255)
Y95	0.101 (0.301)	0.108 (0.310)	0.108 (0.310)
Y96	0.108 (0.311)	0.102 (0.303)	0.153 (0.360)
Y97	0.128 (0.334)	0.126 (0.332)	0.145 (0.352)
Y98	0.114 (0.318)	0.115 (0.320)	0.116 (0.320)
Y99	0.117 (0.322)	0.109 (0.312)	0.110 (0.313)
Y00	0.093 (0.291)	0.095 (0.293)	0.117 (0.321)
Y01	0.050 (0.219)	0.061 (0.239)	0.082 (0.275)

Note: *Standard deviations are in parentheses.

existed, respectively and more accidents occurred in a river than in any other type of waterway.

Among Coast Guard districts, the largest number of vessel accidents for each vessel type occurred in the 8th District (the Gulf Coast)—22.2%, 39.8% and 49.2% of total freight ship, tanker and tugboat accidents. The second highest number, 18.8%, 14.3% and 18.6%, for freight ship, tanker and tugboat accidents occurred in the 7th, 11th and 2nd (the southern Atlantic coast, South Carolina to Florida; the California coast; and the Midwest) Districts. Over time, the largest number of vessel accidents (12.8% and 12.6%) for freight ships and tankers occurred in 1997; for tugboats, the largest number (15.3%) occurred in 1996. The second highest yearly number, 11.7%, 12.5% and 14.5%, for freight ship, tanker and tugboat accidents occurred in 1999, 1994 and 1997.

4. Estimation results

Equation (5) could be estimated by ordinary least squares. However, vessel accidents with injured, deceased and missing crew are infrequent; also, if the latter occur, they are few in number. The preponderance of zeros and the small values and clearly discrete nature of the INJURY, DEATH and MISSING dependent variables suggest that the estimation could be improved, relative to ordinary least squares, by using the statistical technique Poisson regression analysis which accounts for these characteristics. For a discussion of Poisson regression see [13].

A restrictive assumption of the Poisson regression model is that the mean and variance of the dependent variable are equal. A test of this assumption was performed for the Poisson regression estimates of equation (5) for all three dependent variables. Based upon the Lagrange multiplier test of over-dispersion [13, pp. 938–939], this assumption was rejected for the freight ship and tugboat injury equation estimates and the tugboat death equation estimate and accepted for the remaining Poisson regression estimates. The former equations were re-estimated using negative binomial regression, the most commonly used alternative to Poisson regression, where the mean and variance of a dependent variable are not assumed to be equal. Possible estimation bias from omission of relevant explanatory variables is addressed by including yearly binary variables (see tables 1 and 2) in the estimations. The estimated equations contain statistically significant explanatory variables, constant terms and yearly binary variables.

Table 3 reports the injury estimation results—Poisson estimation results for tanker accidents and Negative Binomial estimation results for freight ship and tugboat accidents. Focusing initially upon the freight ship injury results, it can be seen that the model fits the data well. The chi-square statistic is 53.20, exceeding the 37.6 critical value necessary for significance at the 0.01 level for 20 degrees of freedom. The coefficients for COLLISION, EQUIPFAIL, FIRE and GROUNDING indicate that the expected number of injuries is 1.38%, 3.55%, 1.82% and 4.74% less for collision, equipment failure, fire and grounding accidents than for allision or flooding. (For interpretation of Poisson regression coefficients as percentages, the same holds for negative binomial regression coefficients, see McCarthy [14].) The coefficient for VESSELAGE indicates that the number of freight ship accident injuries is expected to decline by 0.033% per year of vessel age, all else held constant. The expected number of injuries is 1.13% higher when the vessel was moored or docked but 0.378% less when underway. Injuries are higher when high winds and cold temperatures exist and the accident occurs in a lake but less when precipitation weather exists and the accident occurs at nighttime. The latter possibly reflects a more safety-conscious crew given the reduced visibility from precipitation and at nighttime. The expected number of injuries is 0.392% higher in District 13 and 0.603%, 0.551% and 0.595% less in Districts 9, 11 and 14 than in other districts. In year 1999 the number of injuries was 1.09% higher than for the remaining years.

For the tanker injury estimate, the chi-square statistic is large and statistically significant at the 0.01 level. The results indicate that the expected number of tanker injuries is 1.79% and 5.25% less for collision and equipment-failure accidents than for other types of accidents. Unlike the freight ship injury results, tanker injuries are expected to increase with the age of the vessel—0.018% per year of vessel age. The expected increase in tanker accident injuries is 1.62% and 1.21% when the tanker is moored or docked and towed. As for freight ship injuries, tanker injuries are higher when high winds and cold temperatures exist and lower when precipitation weather and nighttime exist and the location of the accident is a river, harbor or coastal waterway. Unlike the freight ship injury results, the expected number of injuries in Districts 7, 8 and 11 are 0.637%, 0.746% and 0.723% higher than in other districts. As for freight ship injuries, the number of tanker injuries was higher in year 1999 than for the remaining years.

Table 3. Vessel-accident crew injury equation results.*

	Type of vessel		
Explanatory variables	Freight**	Tanker***	Tugboat**
Type of accident			
ALLISION	–	–	−3.5650 (−19.04)
COLLISION	−1.3768 (−6.08)	−1.7856 (−4.20)	−2.3920 (−15.96)
EQUIPFAIL	−3.5514 (−13.43)	−5.2479 (−5.23)	−3.6670 (−16.48)
FIRE	−1.8241 (−4.63)	–	−0.4493 (−2.41)
FLOODING	–	–	−3.9427 (−3.88)
GROUNDING	−4.7418 (−4.78)	–	−4.1151 (−19.41)
NUMVESS	–	–	0.1053 (6.27)
Vessel characteristics			
VESSELAGE	−0.0327 (−10.89)	0.0184 (2.95)	−0.0163 (−3.95)
VESSELSIZE	–	–	0.0003 (2.05)
Vessel operation phase			
MOORDOCK	1.1313 (12.82)	1.6228 (12.42)	0.3257 (2.83)
TOW	–	1.2094 (2.27)	0.7994 (3.88)
UNDERWAY	−0.3784 (−4.43)	–	–
Weather/visibility conditions			
HIGHWINDS	3.7534 (70.44)	4.7838 (26.27)	–
PRECIPTN	−3.6746 (−7.01)	−1.4307 (−2.80)	–
COLD	2.0564 (17.57)	1.6075 (5.38)	–
POORVISIB	–	1.3576 (4.22)	0.4574 (3.01)
NIGHT	−1.0013 (−7.18)	−2.9006 (−3.97)	–
Type of waterway			
RIVER	−1.6039 (−24.06)	−1.7774 (−10.65)	−0.2663 (−2.41)
HARBOR	−1.1416 (−8.11)	−1.4617 (−4.52)	–
COAST	−1.4788 (−15.69)	−0.8559 (−4.89)	–
OCEAN	−0.4688 (−5.22)	–	–
Coast Guard district			
DIST2	–	–	0.3377 (2.27)
DIST7	–	0.6367 (3.05)	–
DIST8	–	0.7462 (4.64)	–
DIST9	−0.6028 (−5.77)	–	–
DIST11	−0.5508 (−7.16)	0.7231 (3.67)	–
DIST13	0.3924 (4.48)	–	–
DIST14	−0.5950 (−2.15)	–	–
Year			
Y98	–	−0.5773 (−2.29)	–
Y99	1.0868 (18.26)	0.5329 (3.27)	–
Y01	–	−0.7674 (−2.05)	–
Constant	−1.6216 (−10.51)	−4.3626 (−12.97)	−0.7085 (−3.34)
No. of observations	2573	1225	6990
Chi-square statistic	53.20	9784.0	44.65

Notes: **t* statistics are in parentheses.
**Negative binomial regression estimate.
***Poisson regression equation.

The chi-square statistic for the tugboat injury estimate is 44.7, exceeding the 29.1 critical value necessary for significance at the 0.01 level for 14 degrees of freedom. The tugboat accident injury results suggest that the expected number of tugboat injuries is higher: for capsize and explosion accidents, for larger tugboats, when

Table 4. Vessel-accident crew death equation results.*

	Type of vessel		
Explanatory variables	Freight***	Tanker***	Tugboat**
Type of accident			
CAPSIZE	–	–	2.2062 (2.14)
FIRE	–	1.9253 (3.06)	–
GROUNDING	–	–	−3.1232 (−3.06)
NUMVESS	−1.1495 (−2.21)	–	–
Vessel characteristics			
VESSELAGE	0.0270 (2.46)	–	–
VESSELSIZE	-0.0004×10^{-1} (−3.51)	–	–
Vessel operation phase			
MOORDOCK	–	–	0.8938 (2.15)
UNDERWAY	–	−1.0920 (−2.80)	–
Type of waterway			
OCEAN	–	1.4247 (3.68)	–
LAKE	–	–	2.3487 (2.17)
Coast Guard district			
DIST8	–	–	−0.7433 (−2.57)
DIST9	−1.4680 (−2.59)	–	–
Constant	−2.1987 (−3.31)	−3.7923 (−13.19)	−4.1195 (−26.01)
No. of observations	2569	1301	7170
Chi-square statistic	39.10	23.21	31.36

Notes: **t* statistics are in parentheses.
**Negative binomial regression estimate.
***Poisson regression equation.

poor visibility exists and greater the number of vessels involved in the tugboat accident. As for tanker accidents, tugboat injuries are expected to be higher when the tugboat is moored or docked and involved in towing than for other phases of vessel operation. If the accident occurs in a river, the number of injuries is expected to be 0.266% less than in other types of waterways. The expected number of injuries in District 2 is 0.338% higher than in other districts.

Death estimation results—Poisson estimation results for freight ship and tanker accidents and negative binomial estimation results for tugboat accidents—are found in table 4. For the freight-ship death equation estimate, the chi-square statistic of 39.1 exceeds the 13.3 critical value necessary for significance at the 0.01 level for four degrees of freedom. The coefficient for VESSELAGE indicates that the number of freight ship accident deaths is expected to increase by 0.027% per year of vessel age, all else held constant. The coefficients for NUMVESS and VESSELSIZE indicate that the number of freight ship deaths is expected to decrease by 1.15% per vessel involved in the accident and 0.04% per 1,000 vessel gross tons. Among districts, District 9 is expected to have 1.47% less freight ship deaths than other districts.

For the tanker death estimate, the chi-square statistic is statistically significant at the 0.01 level. The coefficient for FIRE indicates that the expected number of tanker deaths is 1.93% higher for fire accidents than for other types of accidents. The expected number of deaths is 1.09% less when the vessel is underway and 1.42% higher when the tanker accident occurs in an ocean waterway.

Table 5. Vessel-accident missing-crew equation results.*

	Type of vessel	
Explanatory variables	Freight***	Tugboat***
Type of accident		
FIRE	–	2.5510 (3.22)
Vessel characteristics		
VESSELAGE	0.0433 (1.73)	–
USFLAG	−2.2152 (−1.94)	–
Type of waterway		
LAKE	–	2.9250 (2.77)
Constant	−5.9731 (−10.00)	−6.8727 (−18.72)
No. of observations	2573	7170
Chi-square statistic	4129.5	6951.6

Notes: **t* statistics are in parentheses.

The chi-square statistic for the tugboat death estimate is 31.4, exceeding the 15.1 critical value necessary for significance at the 0.01 level for five degrees of freedom. The tugboat accident death results indicate that the expected number of tugboat deaths is 2.21% higher for capsize and 3.12% lower for grounding accidents than for other types of accidents. The number of expected deaths is 0.894% and 2.35% higher when the tugboat is moored or docked and when the tugboat accident occurs on a lake, respectively. Among districts, District 8 is expected to have 0.743% less tugboat accident deaths than in other districts.

Missing-crew estimations results for freight ship and tugboat accidents only are found in table 5. No explanatory variables were found to be statistically significant in the estimated tanker missing-crew equation. For both the freight ship and tugboat estimations, the chi-square statistics are large and statistically significant at the 0.01 level. The coefficients for VESSELAGE and USFLAG for the freight ship estimate indicate that the number of missing occupants in a freight ship accident is expected to increase by 0.043% per year of vessel age and be 2.22% less for a US flag vessel, all else held constant. The coefficients for FIRE and LAKE for the tugboat estimate indicate that the expected number of missing crew in a tugboat accident is 2.55% and 2.93% greater in a fire accident and when the accident occurs on a lake.

5. Marginal effects

Ordinary least-squares regression coefficients for continuous variables are interpreted as partial derivatives, i.e. the marginal effects of explanatory variables on the dependent variable, all else held constant. In contrast, Poisson and negative binomial regression coefficients do not measure the correct regression coefficient for non-zero observations of the dependent variable. However, correct marginal effects of Poisson and negative binomial regression coefficients can be calculated [13] and are reported in tables 6, 7 and 8.

The injury marginal effects (see table 6) indicate that 3.4 (1.9) and 3.9 (1.3) crew injuries are expected for each freight ship and tanker accident when high winds (cold temperatures) exist, all else held constant. Further, 1.0 and 1.3 injuries are expected for each freight ship and tanker accident when the vessel is

Table 6. Vessel-accident crew injury marginal effects.

	Type of vessel		
Explanatory variables	Freight	Tanker	Tugboat
Type of accident			
ALLISION	–	–	−0.4940
COLLISION	−1.2510	−1.4431	−0.3315
EQUIPFAIL	−3.2269	−4.2412	−0.5082
FIRE	−1.6574	–	−0.0623
FLOODING	–	–	−0.5464
GROUNDING	−4.3086	–	−0.5702
NUMVESS	–	–	0.0146
Vessel characteristics			
VESSELAGE	−0.0297	0.0148	−0.0023
VESSELSIZE	–	–	0.0004×10^{-1}
Vessel operation phase			
MOORDOCK	1.0279	1.3115	0.0451
TOW	–	0.9774	0.1108
UNDERWAY	−0.3439	–	–
Weather/visibility conditions			
HIGHWINDS	3.4105	3.8661	–
PRECIPTN	−3.3389	−1.1563	–
COLD	1.8685	1.2991	–
POORVISIB	–	1.0972	0.0634
NIGHT	−0.9098	−2.3441	–
Type of waterway			
RIVER	−1.4573	−1.4365	−0.0369
HARBOR	−1.0373	−1.1813	–
COAST	−1.3436	−0.6917	–
OCEAN	−0.4259	–	–
Coast Guard district			
DIST2	–	–	0.0468
DIST7	–	0.5146	–
DIST8	–	0.6031	–
DIST9	−0.5477	–	–
DIST11	−0.5005	0.5843	–
DIST13	0.3565	–	–
DIST14	−0.5407	–	–
Year			
Y98	–	−0.4666	–
Y99	0.9875	0.4306	–
Y01	–	−0.6202	–

moored or docked. The death marginal effects (see table 7) indicate that 4.4 crew deaths are expected for every 100 fire tanker accidents and 2.7 deaths for every 100 capsize tugboat accidents. The missing-crew marginal effects (see table 8) indicate that 3.6 missing crew are expected for every 1,000 fire tugboat accidents.

6. Conclusion

This study has investigated determinants of the number of crew injuries and deaths and missing crew in freight ship, tanker and tugboat vessel accidents that occurred

Table 7. Vessel-accident crew death marginal effects.

	Type of vessel		
Explanatory variables	Freight	Tanker	Tugboat
Type of accident			
CAPSIZE	–	–	0.0265
FIRE	–	0.0444	–
GROUNDING	–	–	−0.0375
NUMVESS	−0.0242	–	–
Vessel characteristics			
VESSELAGE	0.0006	–	–
VESSELSIZE	-0.0009×10^{-3}	–	–
Vessel operation phase			
MOORDOCK	–	–	0.0107
UNDERWAY	–	−0.0252	–
Type of waterway			
OCEAN	–	0.0329	–
LAKE	–	–	0.0282
Coast Guard district			
DIST8	–	–	−0.0089
DIST9	−0.0309	–	–

Table 8. Vessel-accident missing-crew marginal effects.

	Type of vessel	
Explanatory variables	Freight	Tugboat
Type of accident		
FIRE	–	0.0036
Vessel characteristics		
VESSELAGE	0.0002	–
USFLAG	−0.0077	–
Type of waterway		
LAKE	–	0.0041

for the 1991–2001 time period and were investigated by the US Coast Guard. Injured-, deceased- and missing-crew equations were estimated using Poisson and negative binomial regression techniques. These determinants may be used by states and classification societies for evaluating the performance of their vessel safety programs, i.e. evaluating whether their safety programs have an impact on the determinants of vessel-accident crew injuries and deaths and missing crew, as found in this study. If not, then by revising their vessel safety programs to address these determinants, the programs might be made more effective in reducing vessel-accident crew mishaps. Specifically, the marginal effects found in this study may be used by states and classification societies for developing crew safety performance evaluation standards for specific vessel types, vessel characteristics, geographic locations and weather conditions. Further, they may be used in benefit–cost analyses of proposed vessel-crew safety enhancing proposals (e.g. requirements related to firefighting equipment and vessel stability).

The estimated freight ship injury equation indicates that the number of freight ship crew injuries is expected to decline by 0.033% per year of vessel age; the expected number of injuries is 1.13%, 3.75% and 2.06% higher when the freight ship was moored or docked and when high winds and cold temperatures existed, respectively. The tanker injury estimate indicates that the expected number of tanker accident injuries is 1.79% and 5.25% less for collision and equipment-failure accidents and 1.62%, 4.78% and 1.61% higher when the tanker is moored or docked and when high winds and cold temperatures exist, respectively. The number of towboat accident injuries is expected to be 4.12% less in a grounding accident, but 0.457% higher when poor visibility exists.

Freight ship accident crew deaths are expected to increase by 0.027% per year of vessel age. Tanker deaths are 1.93% higher for fire accidents (or 4.4 deaths for every 100 fire accidents), but 1.09% less when the vessel is underway. Tugboat accident deaths are 2.21% higher for capsize accidents (or 2.7 deaths for every 100 capsize accidents), 3.12% lower for grounding accidents and 2.35% higher when the tugboat is in a lake. Missing crew in a freight ship accident is expected to increase by 0.043% per year of vessel age. Tugboat missing crew is expected to be 2.55% higher in a fire than in other types of accidents (or 3.6 missing crew for every 1,000 fire tugboat accidents) and 2.93% higher in a lake.

The results suggest that policies that reduce the number of freight ship and tanker vessel accidents that occur when high winds and cold temperatures exist and the number of tugboat vessel accidents that occur when poor visibility exists are likely to be efficacious in reducing the vessels' crew injuries. Policies that reduce tanker fire and tugboat capsize and lake accidents are likely to be efficacious in reducing the crew deaths of tankers and tugboats. Finally, a policy of reducing tugboat fire and lake accidents is likely to be efficacious in reducing the number of tugboat missing crew.

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