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A Cluster Analysis of Vessel Accidents

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Introduction

Several studies [3] [9] [11] have reported that the Port of New Orleans and the lower Mississippi River ranked first among the nation's ports and waterways in deaths and injuries and second in dollar loss resulting from vessel accidents. According to Carpenter [2] and based on historic casualty records for the Port of New Orleans, the average cost of each vessel accident was estimated at $545,000.

Accidents are, by definition, unplanned and unforeseen occurrences. Their causes are often circumstantial, with chance serving as a catalyst [9]. But accidents are not necessarily improbable occurrences. Indeed, circumstances may provide any degree of likelihood that they will occur [7]. This study investigates the circumstances surrounding navigational accidents and evinces some significant conclusions about the likelihood associated with such events. Its usefulness lies more in the realm of navigational policy for the lower Mississippi River than it does in the area of short term cause and effect inferences.

As applied in this research, clustering provides an analytical technique which can be used to develop meaningful subgroups of vessel accidents. Specifically, the objective of cluster analysis is to classify a sample of entities into a small number of mutually exclusive groups based on the similarities among the entities. Unlike discriminant analysis, the groups are not pre-defined (i.e., discriminant analysis requires a priori knowledge of group membership to derive the classification rule). Instead, a clustering technique is used to identify the groups.

Cluster analysis is also different from other multivariate statistical techniques in that it does not treat some variables as independent and some as dependent. Instead, cluster analysis attempts to identify interdependencies among a number of variables without treating any of them as dependent or independent, such as required by factor analysis. Based on cluster analysis, this study is an empirical characterization of the population of more than 900 vessel accidents which occurred on the lower Mississippi River from 1979 through 1987. By studying clusters of vessel accidents, the research can determine the characteristics or attributes that the casualties share, as well as those in which they differ.

Multivariate Methods

Multivariate methods refer to those statistical techniques which focus upon the structure of simultaneous relationships among three or more phenomena. Multivariate analysis emphasizes the examination of the simultaneous relationships among phenomena. Multivariate methods differ from simple univariate (single phenomenon) statistical techniques in terms of a shift of focus away from the levels (averages) and distributions (variances) of the phenomena, and instead concentrate upon the degree of relationships (correlations or covariances) among these phenomena. They also differ from bivariate (two phenomena) statistical techniques by shifting attention away from pairwise relationships to the more complex simultaneous relationships among phenomena.

Multivariate methods can be broadly categorized into two types: functional and structural multivariate techniques.

Functional multivariate methods are most appropriate for building predictive models with which the researcher can forecast, or explain one or more phenomena from the knowledge of other phenomena based on their relationships. In order to satisfactorily utilize the functional multivariate methods, it is essential that the researcher has considerable knowledge or theory about the phenomenon with which to properly conceptualize a realistic model.

Structural multivariate methods are more descriptive and less predictive in nature. They are essentially data reduction techniques which simplify complex and diverse relationships among phenomena in a manner which enables the researcher to gain insights into the underlying and nonintuitive structure of relationships.

Cluster analysis is a structural multivariate method which enables the researcher to classify, segment or disaggregate entities into homogeneous subgroups based on their similarities on a profile of information. The objective in cluster analysis is to meaningfully classify a group of entities into mutually exclusive clusters based on some judgmental or statistical rule. There are many different algorithms available for cluster analysis, and very few have any statistical inferential properties. Therefore, cluster analysis is more a heuristic than a statistical technique. However, it does provide insights into the typology or segments present in the data.

Cluster analysis usually involves at least two separate steps. The first is the measurement of similarity or association between the entities in order to determine how many groups really exist in the sample. The second step is to profile the variables in order to understand group composition.

The Nature of Clusters

The primary reason for the use of cluster analysis is to find groups of similar entities in a sample of data. These groups are conveniently referred to as clusters. There is no standard definition of the term "cluster." Despite the lack of a consistent definition of the term, it is clear that clusters have certain properties, the most important of which are density, variance, dimension, shape and separation [10].

Density is a property of a cluster that defines it as a relatively thick swarm of data points in a space when compared to other areas of the space that may have comparatively few or no points. There is no absolute measure of density, but the concept is intuitively obvious. *Variance* is the degree of dispersion of the points in this space from the center of the cluster (i.e., the relative nearness of points to one another in the space). Therefore, clusters can be said to be "tight" when all data points are near the centroid, or they may be "loose" when the data points are dispersed from the center. *Dimension* is a property closely related to that of variance; if a cluster can be identified, it is then possible to measure its "radius."

Shape is simply the arrangement of points in the space. While the typical conception of the shape of clusters is that they are ellipsoids, many different kinds of shapes, such as elongated clusters, are possible. If clusters are shaped in this manner, the concept of a radius or diameter is not useful. Instead, the "connectivity" of the points in the cluster, a relative measure of the distance between them, can be calculated. *Separation* is the degree to which clusters overlap or lie apart in the space. For instance, clusters may be relatively close to one another with no clear boundaries or they may be widely separated with large gaps between them.

Taken together, these terms can be used to describe any type of clusters within a space. From Everitt [5], clusters are "continuous regions of (a) space containing a relatively high density of points, separated from other such regions by regions containing a relatively low density of points." This definition does not restrict the conceptualization of clusters to any particular form before data analysis takes place, nor does it restrict the analysis to any specific clustering method.

Marine Casualty Database

In this research process, the choice of variables to be used with cluster analysis is the most critical step, i.e., to find that set of variables which best represents the concept of similarity. If important variables are excluded, poor or misleading findings may result. Ideally, variables should be chosen within the context of an explicitly stated theory that is used to support the classification [4]. The theory is the basis for the rational choice of the variables to be used in the study. In practice, however, the theory that supports any classification research is often implicit. For this study, recognized experts in maritime safety for the lower Mississippi River were surveyed to determine the most critical variables to use in this cluster analysis.

The terms "case," "entity," "object" and "pattern" denote the accident data being classified; whereas, "variable,' "attribute," "characteristics" and "feature" of the accidents are used to assess the cases' similarity.

The variables for this cluster analysis were identified as the result of discussions with members of the Port Safety Council, Port of New Orleans. Members of the Council include representatives from the following maritime groups: U.S. Coast Guard (Captain of the Port, Marine Inspection Office, Commanding Officer of NOLA-VTS); U.S. Army Corps of Engineers; dock and harbor authorities (Ports of Baton Rouge and New Orleans); steamship companies; barge lines and towing firms; pilot associations; and shippers (Exxon Shipping Co., Texaco, Inc., Chevron U.S.A.). All maritime parties who were interviewed agreed that the following variables concerning vessel safety were most important for any study of accidents on the lower Mississippi River.

The New Orleans Vessel Traffic Service (NOLA-VTS) monitors vessel traffic on the lower Mississippi River from Devil's Swamp near Baton Rouge south to the Gulf of Mexico beyond New Orleans - a distance of about 250 miles [12]. As a voluntary vessel movement reporting system, NOLA-VTS provides ocean-going ships, large barge tows, and other river traffic with pertinent information to aid in making decisions as to the proper navigation strategy in plying the lower Mississippi River. In addition, the NOLA-VTS audits vessel accidents and records them on a daily log.

This database was arranged so as to be consistent with the six operational sectors of the lower Mississippi River as delineated by NOLA-VTS, the primary data source. Table 1 shows the six VTS sectors and their respective mile marks.

Table 1. Vessel Traffic Service Sector Boundaries

Sector	Ports	Description - Mile Marks
I	Port Sulphur	Southwest Pass - 75.5 AHP
IA		MS River Gulf outlet - MRGO 50.7
II	New Orleans	75.5 AHP - 113.0 AHP
IIA	Avondale	MRGO 50.7 mile - Industrial Lock
III	Destrehan Grammercy St. Rose Good Hope	113.0 AHP - 159.5 AHP
IV	Baton Rouge	159.5 - 242.0 AHP

Note: Mile marks are posted at each tenth of a mile and refer to the lowest Mississippi River or the Mississippi River Gulf Outlet (MRGO) above Head of Passes (AHP).

The data set for this research study is comprised of 936 cases of vessel accident data occurring between 1979 and 1987 on the lower Mississippi River. Each accident record consists of the following attributes: 1) whether or not the vessel(s) involved in an accident were participating in the vessel tracking; 2) accident type; 3) river stage; 4) traffic level; 5) utilization rate of the U.S. Coast Guard's vessel tracking service; 6) accident location; 7) weather; and, 8) time of the accident. Table 2a and Table 2b provide descriptive statistics about the following variables used in the cluster analysis of vessel accidents.

Participation - This dichotomous variable [6] indicates whether or not a vessel, which was involved in an accident, was participating in the vessel tracking service. This indicates communication between vessel and NOLA-VTS's control center and the exchange of pertinent information to aid navigation efforts.

Accident Type - According to NOLA-VTS, casualty types include: 1) collisions; 2) rammings; and, 3) groundings. A *collision* is defined as any contact between vessels which are underway, anchored, moored, or in the process of docking or undocking. A *ramming* is the collision of a vessel with a fixed object such as a wharf, dock, pier, bridge, submerged object, or aid to navigation. *Groundings* represent vessel contact with the river bottom, and may or may not result in damage to the vessel. [6]

River Stage - The stage of the river (height above sea level measured in feet) is a very critical element of vessel safety, because river stage directly determines the velocity of the current. The hazardous conditions that often accompany the changes in the river stage (hence, river current) precipitate many vessel casualties on the lower Mississippi River between Baton Rouge and the Gulf of Mexico. River stage is a continuous variable.

Traffic Level - According to maritime authorities, traffic level is another major element influencing the occurrence of accidents in the study area. The measure of traffic includes ocean-going ships, barge tow assemblies, tugs, as well as excursion craft. Traffic level, as measured by the number of vessel movements, represents the number of vessel transits on the day of the accident. Traffic level is a continuous variable.

System Utilization - The system utilization variable is defined as the percentage of total vessel movements which were VTS-supported on the day of the accident. The U.S. Coast Guard calculates the level of utilization for the NOLA-VTS at the hour of peak daily traffic. System utilization is a continuous variable.

Location - Indicator variables provide the area of the lower Mississippi River where the accident happened. Six areas, each with a different physical geography, were employed. (Refer to Table 1 for definition of sectors and Table 2b for frequencies of where accidents occurred.) The percentages of accidents occurring in each location category were used as indicators of the relative strength of the areas in determining accidents.

Weather - Meteorological conditions that are hazardous to navigation in the study area are those which produce strong winds, heavy rainfall, and fog. Indicator variables were constructed to model these seasonal weather patterns which affect navigational safety on the lower Mississippi River (i.e., Dec-Jan, Feb-Mar, Apr-May, Oct-Nov, Jun-Sep). The percentages of accidents occurring in each weather category were used as indicators of the relative strength of the weather groupings in determining accidents. The percentages of accidents occurring in each time category were used as indicators of the relative strength of the time groupings in determining accidents.

Time - The time that a vessel casualty occurs is recorded by the U.S. Coast Guard using the standard military clock. For purposes of this analysis, the time of an accident was indicated by one of four categories: between midnight and 6:00 AM, between 6:00 AM and noon; between noon and 6:00 PM, and between 6:00 PM and midnight.

Table 2a. Descriptive Statistics - Continuous Variables

	Frequency	Percent	Mean	Min	Max
<u>River Stage</u>					
.1 - 4.5	309	33.0	9.2	.1	17.2
4.5 - 9.2	180	19.2			
9.2 - 13.2	128	13.7			
13.2 - 17.2	319	34.1			
<u>Traffic Level</u>					
3 - 130	6	.6	256	3	466
130 - 256	474	50.6			
256 - 361	373	39.9			
361 - 466	82	8.8			
<u>Utilization</u>					
3.0 - 18.4	7	.7	33.8	3.0	65.0
18.4 - 33.9	469	50.1			
33.9 - 49.4	449	48.0			
49.4 - 65.0	11	1.2			

Table 2b. Descriptive Statistics - Categorical Variables

	Frequency	Percent
Accident Type		
Collision	207	22.1
Ramming	422	45.1
Grounding	297	31.7
Time		
0:00 - 5:59 AM	266	28.4
6:00 - 11:59 AM	178	19.0
12:00 - 17:59 PM	230	24.6
18:00 - 23:59 PM	262	28.0
Participation		
Non-Participant	505	54.0
Participant	428	45.7
Weather		
Dec - Jan	172	18.4
Feb - Mar	120	12.8
Apr - May	295	31.5
Oct - Nov	92	9.8
Jun - Sep	257	27.5
Location		
I - Miss River	194	20.7
IA - Gulf Outlet	14	1.5
II - Miss River	228	24.4
IIA - Gulf Outlet	9	1.0
III - Miss River	169	18.1
IV - Miss River	322	34.4

The Cluster Procedure

There are many methods available for cluster formation. For a particular problem, selection of a technique depends not only on their features but also on the data set to be analyzed.

An algorithm based on nearest centroid sorting [1] was employed to efficiently cluster this large number of cases. Unlike other clustering algorithms, which result in a series of solutions corresponding to different numbers of clusters, this procedure generates only a single solution for the number of clusters requested. The number of groups must be designated by the analyst.

With this algorithm, a case is assigned to the cluster for which the distance between the cases and the center of the cluster (centroid) is smallest. The actual mechanics of the procedure depend on the information available. If the cluster centers are known, they can be specified in advance and case assignment is based on them. Otherwise, cluster centers are estimated from the data.

Table 3, giving the final cluster centers, contains the average values of the variables for each cluster but provides no evidence of the variability or correlation between variables. The number of accident cases assigned to each of the four groups is also shown.

In this analysis, solutions ranging from two to six clusters were tested by discriminant analysis. Discriminant models were built using the same variables which were used to cluster the groups. The discriminant criterion used to determine the optimum cluster solution was the percentage of cases correctly classified into clustered groups by the discriminant model. This criterion indicated that the four-group cluster solution was optimal, with 96 percent of cases being correctly classified. All variables were standardized to "Z" scores prior to clustering to prevent number sizes of the different measurements from affecting the analysis.

Table 3. Group Means for Accident Clusters (N = 923)

	Group 1	Group 2	Group 3	Group 4	Total
# Cases	224	226	133	340	------
Participation	1.000	.677	.368	.000	.462
Accident Type	1.906	2.535	2.068	1.950	2.099
River Stage	6.255	14.115	7.022	8.409	9.084
Traffic	229.204	335.487	235.986	227.239	255.481
Utilization	32.578	37.529	34.035	32.177	33.852
Location	28.475	25.813	20.537	25.174	25.464
Weather	21.188	30.397	21.129	21.095	23.400
Time	26.169	25.604	20.176	27.209	25.551

Table 4. Description of Accident Clusters

	Group 1	Group 2	Group 3	Group 4
Cases	224	226	133	340
V1	1.00000	.67699	.36842	.00000
V2	62% Ram[a] 86% C&R[b]	66% Ground[c]	53% Ram 73% C&R	49% Ram 77% C&R
V3	Slow Current[d] 69% < 7 Feet	Fast Current 73% > 14 Feet	Slow Current 58% < 7 Feet	Slow Current 48% < 7 Feet
V4	Moderate	Heavy	Moderately Heavy	Moderate
V5	Moderate	Heavy	Moderately Heavy	Moderate
V6	Concentrated Sector IV	Scattered	Scattered	Scattered
V7	36% Bad Weather	74% Apr-May Bad Weather	43% Bad Weather	45% Bad Weather
V8	Dispersed	Dispersed	83% Mornings 94% Daylight	0 Mornings 73% Night

[a]Ram is abbreviation for ramming.
[b]C&R represents collisions and rammings combined.
[c]Ground refers to a grounding of a vessel on the river bottom.
[d]Speed of current is directly related to river stage (i.e., the lower the river stage the slower the current and vice versa.

V1 = Participation; V2 = Accident Type; V3 = River Stage; V4 = Traffic; V5 = Utilization; V6 = Location; V7 = Weather; and, V8 = Time.

Description of Clusters

The resulting clusters will be discussed and compared in an order which emphasizes the apparent general impact of the VTS participation rate across the four groupings. Despite their obvious influence, the other seven features of the accident cases had varying effects on particular clusters.

Group 4 - Group 4 may be characterized as *Accidents that Shouldn't Have Happened*. This cluster consists of 340 accident cases, the largest cluster containing more than one-third of the sample of 923. By inspection of the descriptive information in Table 4, which was prepared by reviewing cross-tabulations of attributes by group membership, the attribute values of this group describe generally good navigational conditions, such as slow current, moderate traffic levels, and moderate (i.e., not low) utilization levels of the VTS along the lower Mississippi River. Other characteristics of these entities include a preponderance of collisions and rammings which usually occurred at night and not concentrated in any particular sector of the river. Forty-five percent of accidents occurred during months enduring bad weather (i.e., December, January, April and May), indicating that bad weather as expected contributed to casualties [8].

The most distinctive property of this group was that **none** of these vessels involved in an accident was participating in the NOLA-VTS at the moment of the incident. This phenomena, added to the serious nature of collisions and rammings along with moderate levels of VTS utilization by mariners plying the river at the time of the accident, indicates a powerful influence to ascribe these accident cases to Cluster 4. These accident cases reveal potentially serious casualties, despite reasonable navigational conditions and in conjunction with no mariner in this group partaking of the tracking service.

Group 2 - Group 2 may be characterized as *Bad Conditions for Good Navigators*. This cluster represents a dramatically different set of attribute values than does group 4. In general, group 2 is characterized by relatively poor circumstances for navigation, such as fast current, heavy traffic and the bad weather conditions of April and May (i.e., 73 percent of these cases occurred in these two months). The location and time attributes were not concentrated in any particular category but were distributed across these respective dimensions. The distinguishing attribute values for this group were: the high utilization levels (i.e., 80 percent of the cases were at "high" utilization rates) of the tracking service by mariners across the system at the time of these accidents; the high participation rate (67 percent) in the VTS for these accident cases in group 2; and, that the majority (66 percent) of accident types was a grounding.

A grounding is not a serious marine casualty like a collision or ramming. A grounding is defined as the vessel touching the river bottom, without regard to damage to the craft or whether the vessel was immobilized. Despite poor or even treacherous conditions, these accident cases in group 2 were most likely to be a non-serious casualty. Coupled with the high participation rate, these attribute values indicate that these mariners were doing a good job during the most trying of conditions, in contrast to the accident cases in group 4.

Group 3 - Group 3 may be characterized as *Probably Preventable*. This cluster exhibits attribute values that lie between the initial two groups already discussed. These intermediate characteristics depict mediocre conditions for navigation and associated accidents. This group of entities, with the least number of assigned cases (e.g., 133 entities or 14 percent), manifested slow river current and moderately heavy traffic. System-wide utilization of the NOLA-VTS was moderately heavy, while the location of accidents was scattered along the lower Mississippi River and not concentrated in any particular sector. About 43 percent of these accidents occurred during the months with bad weather for navigation. Of particular interest, 83 percent of these accidents materialized during the morning hours between 6:00 AM and noon, and 94 percent of all accidents happened during the usual daylight hours (e.g., 6:00 AM to 6:00 PM). Collisions and rammings accounted for 73 percent of all accidents in group 3, while the participation rate was about 37 percent.

Group 3 is relatively similar to group 4. A distinct property of both these groups was a relatively low (39 percent) in the former and the non-existent participation rate in the latter for NOLA-VTS at the moment of the incident. The serious nature of collisions and rammings, combined with moderate or even higher levels of VTS utilization as well as tolerable maritime conditions, suggests similar but nevertheless different groups. Group 3 is distinct because of the higher participation feature and the very high percentage of accidents that occurred during the morning hours. Group 4 experienced 73 percent accidents at night.

Group 1 - This cluster is another very interesting and unique group, especially in reference to group 4. Group 1 may be characterized as *Danger Zone*. Group 1 experienced a 100 percent participation rate, while group 4 had zero participation. Group 1 contains about 25 percent of the accident cases. As for attribute values in cluster 1, rammings comprise 62 percent of accident types, while collisions add another 24 percent. Together, these potentially serious casualties total 86 percent of accident types. There is no particular time segment when these accidents are more likely to occur. Thirty-six percent of the casualties happen during bad weather, slow current, moderate traffic levels, and moderate (i.e., not low) utilization levels of the VTS along the lower Mississippi River.

However, the *location* of the collisions and rammings is a very distinctive feature of this cluster. Fifty-six (56) percent of the accident cases are located in Sector IV of the lower Mississippi River. This section of river is especially dangerous for vessel traffic because of the myriad of narrow twisting turns, making navigation very hazardous for large ships and barge tows which are destined for the heavy concentration of petrochemical refineries and grain elevators in this area of the Mississippi River. This group can be characterized by river mariners attempting to provide safe passage for their vessels, cargoes and crews in treacherous waters as evinced by the 100 percent participation rate, but experiencing more than half of their accidents (typically collisions and rammings) in a most dangerous sector of the lower Mississippi River.

Table 5. Pooled Within-Group Correlation Matrix

	V1	V2	V3	V4	V5	V6	V7	V8
V1	1.000							
V2	.046	1.000						
V3	-.077	-.158	1.000					
V4	.004	.106	-.229	1.000				
V5	-.031	-.063	.006	.003	1.000			
V6	-.144	-.029	.064	-.100	-.036	1.000		
V7	-.029	-.105	.226	-.494	-.018	.008	1.000	
V8	.107	-.031	-.049	.045	.019	-.231	.021	1.000

As shown in Table 5, the pooled within-groups correlation matrix indicates if there is any substantial association between the various attributes. The highest correlation coefficient is -.229 between river stage (the proxy for speed of current) and traffic. This maximum correlation level indicates a minimum association between two variables and suggests that these attributes are very independent features of the accident cases.

Table 6 contains F-ratios for examining differences between the clusters. The F statistics represent the ratio of between-clusters mean square to within-cluster mean square. Large ratios (with 3 and 919 degrees of freedom) and small observed significance levels are associated with variables that differ between the clusters. However, the F tests should be used only for descriptive purposes since the clusters have been chosen to maximize the differences among cases in different clusters. The observed significance levels are not corrected for this, and thus cannot be interpreted as tests of the hypothesis that the cluster means are equal. Nevertheless, all variables had highly significant F statistics, indicating that the mean values of the attributes could be decidedly different and account for the assignment of cases to unique groups.

Table 6. Analysis of Variance

Variable	F-Ratio	Significance
Participation	568.00	.0000
Accident Type	41.69	.0000
River Stage	122.90	.0000
Traffic	188.40	.0000
Utilization	35.77	.0000
Location	35.09	.0000
Weather	104.50	.0000
Time	225.70	.0000

Summary and Conclusions

For this large sample of accident cases, cluster analysis generated four groupings that are relatively unique in their respective attribute values. These categories are logical groups, giving the realities of navigating the lower Mississippi River.

The most interesting conclusion is that for individual vessel participation in the NOLA-VTS; and, the most interesting comparison is that between Group 4, *Accidents that Shouldn't Have Happened* and Group 2, *Bad Conditions for Good Navigators*. The former group, with *none* of the vessels participating, consisted of relatively severe accidents occurring in relatively good navigating conditions. The latter group, with two-thirds of vessels participating, consisted of relatively non-severe accidents occurring only in the worst of conditions. In addition, Group 1 (*Danger Zone*) accidents, with 100 percent of vessels participating, were characterized primarily by their location in the most treacherous area of the river. Finally, Group 3 (*Probably Preventable* accidents), with their low participation rate, also included relatively severe accidents occurring in average or good conditions. In brief, heavy participation rates were associated with less severe accidents occurring in the worst of conditions, whereas low participation rates were associated with more severe accidents occurring in relatively good navigating conditions.

The individual participation rate of the VTS measures the linkage between specific mariners, the vessel tracking technology, and the system performance dimension of accidents. Accidents serve as an operational measure of marine safety, and specifically the safety of vessels, crews and cargoes. Significant incremental participation rates for the marine tracking technology across the accident clusters effectively distinguishes between casualty groups. From a risk and insurance perspective, these findings might provide justification to require participation in the vessel tracking service, either by governmental agencies or private insurers.

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