A Longitudinal Analysis of the Causal Factors in Major Maritime Accidents in the USA and Canada (1996-2006)

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Abstract

Accident reports provide important insights into the causes and contributory factors leading to particular adverse events. In contrast, this paper provides an analysis that extends across the findings presented over ten years investigations into maritime accidents by both the US National Transportation Safety Board (NTSB) and Canadian Transportation Safety Board (TSB). The purpose of the study was to assess the comparative frequency of a range of causal factors in the reporting of adverse events. In order to communicate our findings, we introduce J-H graphs as a means of representing the proportion of causes and contributory factors associated with human error, equipment failure and other high level classifications in longitudinal studies of accident reports. Our results suggest the proportion of causal and contributory factors attributable to direct human error may be very much smaller than has been suggested elsewhere in the human factors literature. In contrast, more attention should be paid to wider systemic issues, including the managerial and regulatory context of maritime operations.

1 Introduction

This paper stems from a continuing study to validate assertions about the distribution of causes in adverse events. We are particularly concerned to establish whether or not the majority of accidents are 'blamed' on direct operator error. The results of an initial investigation into the causes of all major accidents and incidents in North American aviation from 1996 to 2003 cast doubt on previous studies that had asserted the importance of individual human factors in the immediate causes of adverse events (Johnson and Holloway, 2004). This work led to wider studies into accident reports across a range of other industries including rail and highway transportation (Holloway and Johnson, 2005, 2006). In contrast, this paper reports on our work to replicate the previous study and identify the proportion of causes and contributory factors associated with human error in the North American maritime industries across the decade from 1996 to 2006.

As mentioned, our initial work focused on the distribution of causal factors identified in aviation accident and incident reports. This decision was justified by the prominence of claims about human error in this industry. The first study focussed on all major adverse event reports issues by the US National Transportation Safety Board (NTSB) and the Canadian Transportation Safety Board (TSB) between 1996 and 2003 (Holloway and Johnson, 2004). This yielded a total of 26 US and 27 Canadian aviation investigations. Later sections will discuss the methods used in more detail. For now it is sufficient to observe that two analysts went through each of these reports developing their own independent classification scheme to distinguish between broad categories of causal and contributory factors. This identified approximately 40 causes and 53 contributory factors in the NTSB dataset and 50 causes with 53 contributory factors for the TSB. The subsequent classifications showed that only 37% of causal factors in the NTSB study related to individual human error. In contrast, 48% of causes and contributory factors can be categorized as organizational. 12% related to equipment. 'Other' causes accounted for 3%. In contrast, for the TSB 50% of the causes and contributory factors were related to individual error, 22% to organizational issues, 20% to equipment and 8% to 'other' factors. Although human error remains a significant factor in many of these accident reports, it is not true that investigatory agencies ignore the organizational issues that create the context for adverse events. It is also apparent from our study that the differences between the NTSB and the TSB reflect important differences in the types of air operations, and hence accidents, that occur in US and Canadian air space (Johnson and Holloway, 2004). The Canadian datasets contain far more incidents involving private pilots and technologically unsophisticated small aircraft. There are thus correspondingly fewer opportunities for organizational issues to intervene in these incidents, where single individuals will be performing most of the operations. We have recently extended these initial aviation studies by analysing the causes and contributory factors cited in NTSB reports for three different sample periods 1976-1984, 1996-2004 and 2004-2006. The preliminary results show considerable differences over this time period. The proportion of direct operator 'errors' diminishes as the proportion of organisational causes rises between the first and second samples. There is evidence that the proportion of causes due to human error has risen again in the most recent group of accident reports (Johnson and Holloway, in press).

The results of this initial study may not be typical of other safety-critical industries. The relatively high levels of training and regulatory control make it likely that organisational issues would be more prominent than human error in aviation when compared to other domains. Such caveats motivate the study, reported in this paper, of North American maritime accidents. Further motivation is provided by a recent survey commissioned by the UK Marine Accident Investigation Branch (2004). This examined 66 accidents. The report argued that one third of all the groundings involved a fatigued officer who was alone on the bridge at night. Two thirds of all the vessels involved in collisions were not maintaining 'a proper lookout'. An important strength of the MAIB study was that it published the methodology that was used to support these findings; 'Once selected, the accidents were then reviewed in detail by MAIB nautical inspectors in order to complete a questionnaire (Annex A) covering many aspects of bridge watch keeping practice, which had been developed for this study. The data gathered was input to a human factors database before analysis.' This scientific approach enables subsequent analysts to replicate their methods and, therefore, validate their results. Many previous studies have failed to provide readers with this methodological information. However, a number of caveats can be raised about the manner in which the accidents were selected for the MAIB study. The study excluded fishing and commercial vessels under 500 gross tons. Accidents involving vessels berthing, at anchor, or under pilotage, were also excluded. This reflected the study's focus on bridge watch-keeping during a passage rather than on navigation or maneuvering. The study also focused on the insights obtained by individual investigators looking at each accident. There does not seem to have been any attempt to conduct inter-analyst comparisons for individual reports.

2 Method

We were concerned to develop results that could be challenged or replicated by other researchers. All of the materials used in this study are available on-line and can be accessed by contacting the first author. We were also concerned to assess the validity of our results by comparing the insights obtained from different analysts. We, therefore, used two investigators to extract the causes and contributory factors from the accident reports that we studied. Each had more than a decade's experience in the development and analysis of safety-critical systems. Each studied the same sample of maritime accident reports. By choosing a ten-year window, the sample yielded a total of 22 accident reports from the NTSB and 160 from the TSB. This imbalance partly reflects the relative prominence of the Canadian maritime industries. It also reflects the way in which the TSB groups major and minor incidents within a single reporting framework. In contrast, the NTSB explicitly separates major accident reports from accident briefs, which were excluded from our study. Rather than impose our own arbitrary distinctions about the seriousness of each adverse event, we chose to analyse all of the TSB reports containing chapter headings presented within the period of our study. The reports ranged from high profile, multiple fatality accidents such as the Fire on Board the Panamanian passenger ship Universe Explorer through to less severe grounding incidents.

Our analysis progressed by extracting the causal and contributory factors that were identified in the aftermath of each investigation. This preprocessing stage was necessary to insure that each of the analysts focused on the same source, given that most of the documents were many pages in length. The identification of all relevant sections in each report was performed as a collaborative activity between the analysts. There were, however, important differences in the treatment of the documents. These stemmed from the way in which the Canadian and US agencies structure their findings. The NTSB provides a summary that distinguishes between probable causes and contributory factors in the following way:

> The National Transportation Safety Board determines that the probable cause of the collision between the Coast Guard patrol boat CG242513 and the small passenger vessel Bayside Blaster was the failure of the coxswain of the Coast Guard patrol boat to operate his vessel at a safe speed in a restricted-speed area frequented by small passenger vessels and in conditions of limited visibility due to darkness and background lighting. Contributing to the cause of the accident was the lack of adequate Coast Guard oversight of non-standard boat operations. (NTSB MAR-02/05)

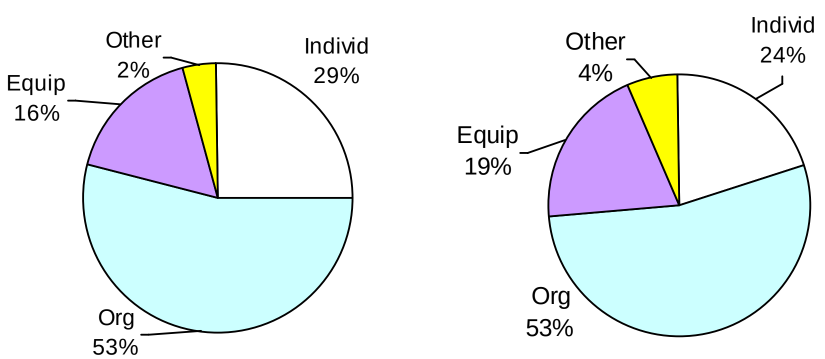
Canadian TSB reports contain a section entitled 'Findings as to Causes and Contributing Factors'. The analysis was less straightforward, however, because these documents did not explicitly separate causes and contributing factors. Each analyst, therefore, had to separate probable causes from contributory factors in TSB reports even though the distinctions were clearly presented in the NTSB reports. All subsequent stages were also performed in isolation until the results were available for comparison. We assigned each probable cause and contributory factor to a number of common categories. We did not use a pre-defined taxonomy. Each analyst created their own classification as they progressed through the incidents. As before, everyone involved in the project could assign any labels that they chose. The classification process raised several practical problems. For example, the following section is taken from an NTSB maritime report:

> Contributing to the amount of property damage and the number and types of injuries sustained during the accident was the failure of the U.S. Coast Guard, the Board of Commissioners of the Port of New Orleans, and International RiverCenter to adequately assess, manage, or mitigate the risks associated with locating unprotected commercial enterprises in areas vulnerable to vessel strikes (NTSB MAR-98/01)

This passage could yield three contributory factors; one associated with the U.S. Coast Guard, another with the Board of Commissioners of the Port of New Orleans and one with the International RiverCenter. Another analyst might identify three factors associated with a failure to adequately assess, manage, or mitigate the risks of vessel strikes. Conversely, this passage could yield the cross product of nine contributory factors where each agency failed in each of these three ways. We imposed no constraints on this issue except to agree that compound statements could be interpreted to yield several individual causes or contributory factors. It was left up to the reasoned judgement of each analyst on a case-by-case basis. The results of this process were then collated. There were some obvious differences in the terms used but there were also strong similarities. For instance, one analyst identified 'weather' as a contributory factor while another identified the 'environment' and so on. Where such disagreements occurred we used a process of discussion to agree on a common term to support comparisons between the classifications. Distinctions were preserved between different terms where no agreement could be reached between the analysts.

	Analyst C		Analyst M	
P – Probable Cause, C - Contributory	**P**	**C**	**P**	**C**
Design	**4**	**7**	**4**	**10**
Human Error	**11**	**7**	**9**	**7**
Maintenance	**2**	**2**	**2**	**0**
Company/Organisation	**12**	**6**	**15**	**6**
Regulatory	**7**	**9**	**4**	**15**
Weather	**1**	**0**	**2**	**0**
Equipment	**0**	**1**	**0**	**2**
Physical Structure	**0**	**0**	**2**	**0**
Industry	**0**	**0**	**0**	**1**
Unknown	**2**	**0**	**0**	**0**
Total	**39**	**32**	**38**	**41**

Table 1: Analysis of Causes and Contributory Factors in NTSB Maritime Accidents (1996-2006)



Analyst C

(22 Reports,

71 Causal & Contributory Factors)

Analyst M

(22 Reports,

79 Causal and Contributory Factors)

Figure 1: Pie-Charts of Causes and Contributory Factors in NTSB Maritime Accidents (1996-2006)

3 US National Transportation Safety Board Results

Table 1 and Figure 1 summarize the results of this classification process for both the probable causes and the contributory factors in the NTSB reports. The 22 incidents yielded a total of 39 and 38 probable causes for the two analysts. There were 32 and 41 contributory causes. Across all incidents, there was a mean of 1.75 causes per incident with a mean of 1.65 contributory factors per incident. The classification in Table 1 represents the product of an initial amalgamation, using the method described in the previous section. In contrast, Figure 1 uses an additional phase of generalisation that eases comparisons between the aviation data introduced in previous paragraphs and the results of the maritime analysis. This generalisation groups equipment failures and design issues. It also combines regulatory issues, maintenance problems, company specific factors and organisational issues. As can be seen, there are strong similarities both between the different analysts and between the NTSB maritime and aviation data sets. For example, the combined causal and contributory factors in the NTSB aviation study yielded 48% related to organisational factors, 37% to individual issues, 12% related to equipment and 3% to other factors (Johnson and Holloway, 2004).

The slight disagreement over the total number of contributory causes between the investigators might appear to be confusing given that the NTSB explicitly labels probable and contributory causes. As mentioned, however, some probable causes described several different problems. For example, the report into a collision between a US Coast Guard vessel and a small passenger boat contains the following argument;

> The National Transportation Safety Board determines that the probable cause of the collision between the Coast Guard patrol boat CG242513 and the small passenger vessel Bayside Blaster was the failure of the coxswain of the Coast Guard patrol boat to operate his vessel at a safe speed in a restricted-speed area frequented by small passenger vessels and in conditions of limited visibility due to darkness and background lighting. Contributing to the cause of the accident was the lack of adequate Coast Guard oversight of non-standard boat operations. (US NTSB MAR-02/05)

Analyst C classified the causes as human error and weather. Analyst M identified human error and the environment. The contributory causes were listed as ‘organizational’ by analyst C and regulatory by analyst M. As can be seen, this form of analysis depends upon a degree of subjective interpretation within the statements of probable cause and contributory factors. Hence Figure 1 indicates a surprising level of agreement between the analysts. Many NTSB reports yielded only a single probable cause. For instance, NTSB report MAR-02/03 contained the following summary:

> The National Transportation Safety Board determines that the probable cause of the grounding of the Finest was the failure of the vessel master to use appropriate navigational procedures and equipment to determine the vessel’s position while approaching the Shrewsbury River channel. Contributing to the cause of the grounding was the lack of readily visible fixed navigational aids.

> Also contributing to the cause of the grounding was the failure of New York Fast Ferry to require the use of installed navigation equipment and to set guidelines for operations in adverse environmental conditions. (US NTSB MAR-02/03)

Both analysts identified the single probable cause as an instance of human error. In contrast to this simple case, our analysis identified a small number of incidents that proved to be extremely complex at least in terms of the number of causes and contributory factors. For instance, the NTSB report into the ramming of the Eads Bridge by barges in the Admiral St. Louis Harbor in Missouri provided the following summary of probable and contributory causes:

> The National Transportation Safety Board determines that the probable cause of the ramming of the Eads Bridge in St. Louis Harbor by barges in tow of the Anne Holly and the subsequent breakup of the tow was the poor decision-making of the captain of the Anne Holly in attempting to transit St. Louis Harbor with a large tow, in darkness, under high current and flood conditions, and the failure of the management of American Milling, L.P., to provide adequate policy and direction to ensure the safe operation of its towboats. The National Transportation Safety Board also determines that the probable cause of the near breakaway of the President Casino on the Admiral was the failure of the owner, the local and State authorities, and the U.S. Coast Guard to adequately protect the permanently moored vessel from waterborne and current-related risks (NTSB MAR-00/01)

Analyst C identified six probable causes; three regulatory failures, two organisational failures and one instance of human error. Analyst M classified seven causes; one environmental problem; one organisational issue; three regulatory problems; one company issue and an instance of human error. Neither analyst identified any contributory factors. Such findings illustrate considerable differences in interpretation and classification. Given the limited sample size and the small number of analysts it is difficult to draw firm conclusions about the analysis of particular incidents. However, the growing body of evidence from this and previous studies does illustrate that such incidents are the exception rather than the norm. This methodology can yield a surprising level of agreement in the identification of causal and contributory factors in official investigation reports.

Both analysts identified a large number of systemic causes and contributory factors throughout the sample of NTSB reports. Overall managerial or organisational failures accounted for approximately 53% of all probable causes and contributory factors. Individual forms of 'human error' only represented 27% of the total. Equipment failures came to 17% and 3% fell into the 'other' classification. Even after the results from our previous aviation study, these findings came as a considerable surprise. In particular, we had anticipated a higher proportion of equipment related problems in the maritime industry. However, the NTSB reports seem to reveal the commitment that investigators within this agency have to look beyond immediate causes and investigate the organisational and regulatory issues contributing to incidents and accidents.

As mentioned, the 22 NTSB reports in our sample yielded approximately 70 causes and contributory factors for each analyst. This provided useful insights about individual and organisational factors when aggregated across the decade. However, the sample arguably yielded insufficient evidence to support clear conclusions about trends between 1996 and 2006. This point can be illustrated by the Bar Chart in Figure 2. The diagram provides a year-by-year distribution of causes and contributory factors for our sample of accident reports. The dates refer to the year in which the documents were published rather than to the accidents themselves, this follows the convention used in Appendix A and enables cross referencing with the NTSB library. The number of causal and contributory factors in each category is strongly influenced by individual accidents. Longer term trends are obscured by the characteristics of particular incidents. For example, a single accident in 2000 accounted for all of the regulatory and organisational causes in that year. Similarly, the same accident was caused by both instances of human error recorded in 2001.

The Bar Chart in Figure 2 also illustrates the difficulty of visualising the results of an analysis into the causal and contributory factors in major accident reports. Simple graphs cannot easily convey the changing proportions of causes in different categories when the number of factors is partly determined by the number of accident reports that are issued in each year. In our sample of NTSB reports, the frequency of particular causal factors is strongly determined by the number of reports which varies from none in 2003 to 5 in 2002. Figure 3, therefore, uses a J-H area graph to map the changing percentage of causes and contributory factors for each year from 1996 to 2006. This helps to ease the visualisation problems by normalising across accident frequencies, although the count is still shown on the X-Axis. As can be seen, the lack of any coherent pattern confirms our previous argument based on the Bar-Chart in Figure 2, that the individual causes and contributory factors of a small number of accidents obscures any longer term trends over the sample. Although this visualisation provides a normalised view of causes over time, it does not resolve the problems associated with a limited sample size. The following section, therefore, provides a more sustained analysis of 160 Canadian TSB maritime reports compared with only 22 in the NTSB sample.

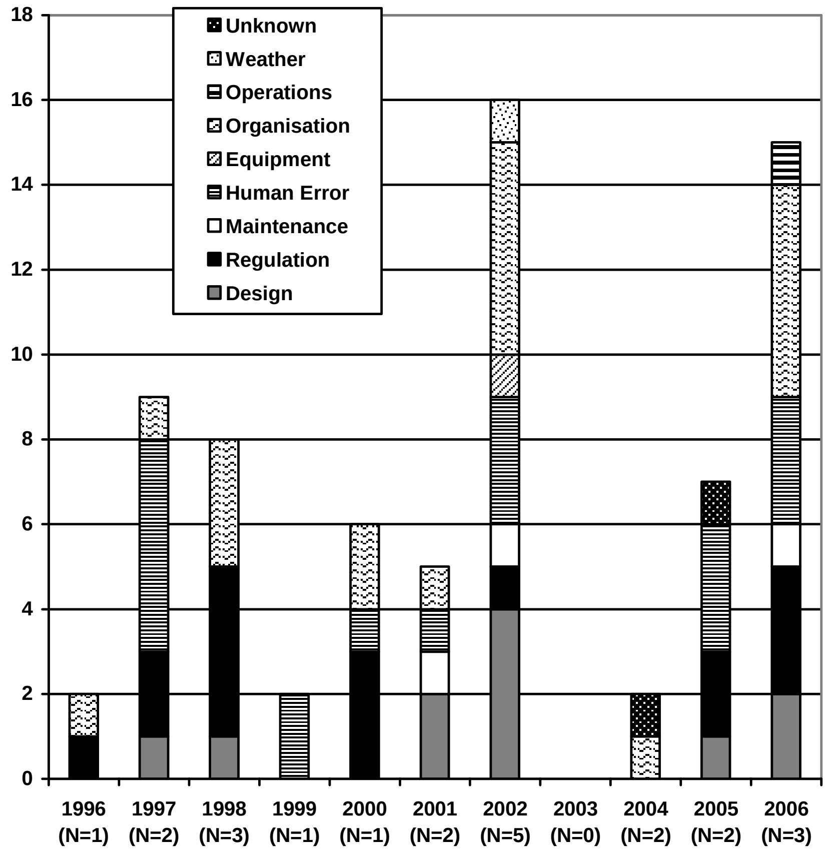


Figure 2: Distribution of Causes and Contributory Factors in NTSB Maritime Reports
by Year (Analyst C)

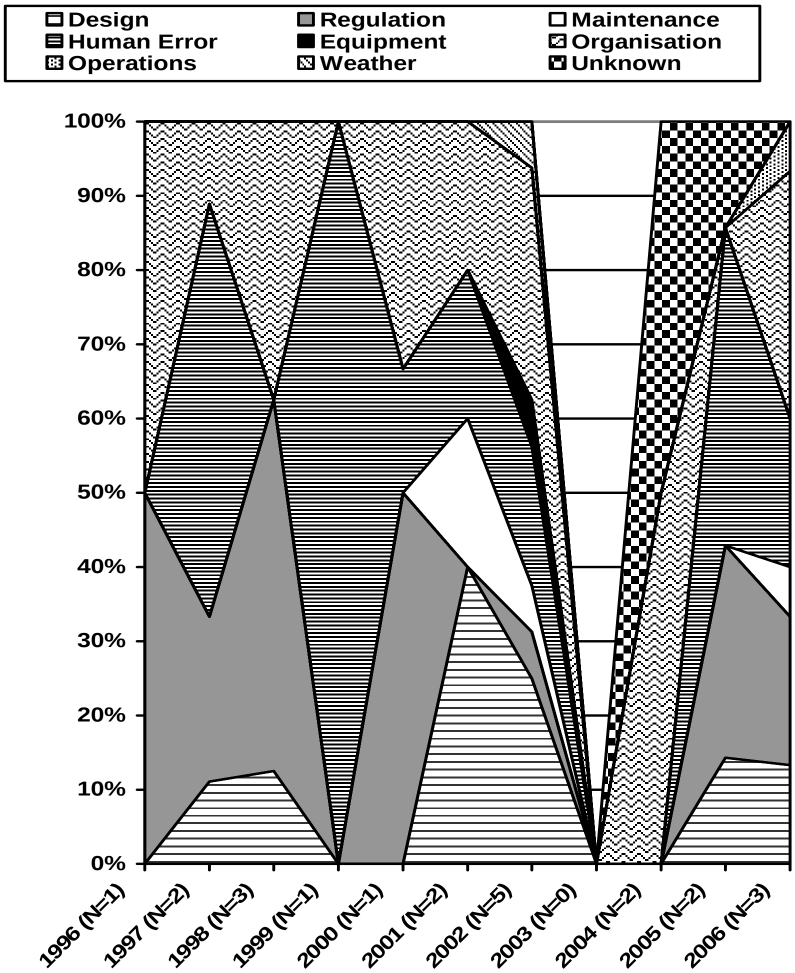


Figure 3: J-H Graph of Causes & Contributory Factors in NTSB Maritime Reports by Year (Analyst C)

4 Canadian Transportation Safety Board Results

We were anxious to determine whether the US NTSB was atypical in the prominence of regulatory and organizational factors in their major maritime and aviation accident reports. The results of our previous study had already identified some differences in the aviation data between Canada and the USA. As mentioned, these differences stem from the traffic patterns in each country. They may also be due to differences in the training of investigators and the reporting procedures used in each country (Johnson, 2003). We were, therefore, anxious to determine whether these patterns could also be seen in maritime accident reports. Our work proceeded in a similar manner to that of the NTSB sample. The first stage was to make our initial selection of incidents from the many thousands of adverse events that are reported to the TSB each year. We focused on the longer more sustained accident reports; that is, those containing numbered chapter headings. These did, however, include near miss incidents as well as events leading to multiple fatalities. We identified a far larger sample compared to either our aviation datasets or to the NTSB major maritime incident reports. In the previous studies, we had used a heuristic to cut down the TSB aviation corpus so that we only focussed on the most serious incidents and accidents. This left a total sample of 27 TSB aviation documents compared to 26 reports from the NTSB. In contrast, our more ambitious maritime study yielded 22 accident reports from the NTSB and 160 marine reports from the TSB. The problems of obtaining comparable samples might seem like a relatively trivial methodological issue. However, the different ways in which the NTSB and TSB group their major accident reports has important consequences for anyone attempting to identify patterns in the causes of adverse events across different countries. It can be hard to make comparisons between incidents in different countries and this can impair the exchange of lessons learned from previous failures.

The TSB documents included sections on "Findings as to Causes and Contributing Factors", "Findings as to Risk", and "Other Findings”. We focussed on the sections detailing causes and contributory factors. This task was complicated because some reports used a slightly different format with two sections entitled "Causes" and "Findings”. As might be expected, we focused on the section describing the causes of the adverse event. As before, we independently categorised the probable causes and contributory factors. There was no expectation that each analyst would use the same categories that had emerged from the analysis of the NTSB maritime reports. This posed several problems that had not arisen during the previous studies. For example, many hours of analysis were required to work through all of the 160 reports. It was difficult for analysts to ensure that they applied the same classification criteria at the end of the period as they had used at the start of their analysis. As we shall see, the very diversity of the incidents included in this larger sample also forced the analysts to develop a far wider range of categories for the TSB sample. Further problems stemmed from the way in which the TSB group together probable causes and contributory factors within their reports. For instance, the section of a report into the ‘Capsizing and Loss of Life on a Small Fishing Vessel *Cap Rouge II* off the Entrance to Fraser River, British Columbia’ contains the following list:

3.1 Findings as to Causes and Contributing Factors

1. Inherent transverse stability was progressively reduced by structural additions and the installation of more and heavier fishing gear, including the adoption of a "West Coast" seine net of 7.4 tonnes, all of which were located at or above the main deck level.
2. The installation of additional gear and its effects on stability were not monitored or assessed by a suitably qualified person, nor brought to the

attention of Transport Canada (TC) inspectors, between or during routine quadrennial inspections.

3. The watertight integrity of the main deck was compromised by the ineffective gaskets of five flush-fitting manhole covers, which resulted in extensive downflooding, a marked increase in after trim, and reduced transverse stability.
4. Because of their limited knowledge of basic principles of trim and stability, the additional weight of the seine net, the inherent heel to starboard, the routine presence of water on deck, and the towing resistance of the seine skiff were not considered by those on board the *Cap Rouge II* to present any undue risk to vessel operation.
5. The vessel lost transverse stability due principally to the cumulative free surface effects of water shipped and retained on the main deck and other liquids in four partially full fish holds, four fuel tanks, a freshwater tank, and the lazarette.
6. The rapidity of the capsizing precluded orderly abandonment of the vessel.

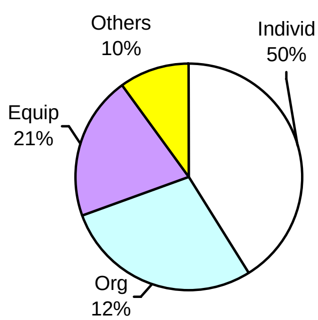
(TSB report M02W0147)

As can be seen, the TSB provide no explicit indication between causes and contributory factors in this list. Each analyst, therefore, had to arrive at this classification independently. In consequence, analyst C identified two causal factors of design and regulation. Analyst M identified design and equipment failure. Analyst C found four contributory factors. These included maintenance, human error, design and 'other'. Analyst M identified human error; environmental factors and regulatory issues.

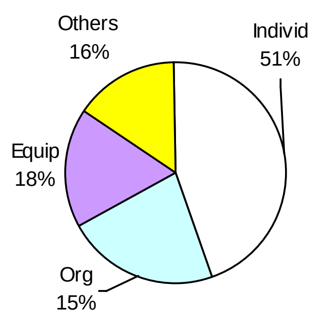
	Analyst C			**Analyst M**	
	Probable cause	**Contributory Factor**		**Probable cause**	**Contributory Factor**
Clothing	**0**	**0**		**1**	**2**
Company/Organisation	**16**	**54**		**15**	**60**
Design	**33**	**50**		**23**	**45**
Emergency responders	**0**	**0**		**0**	**3**
Environment/Weather	**30**	**20**		**35**	**27**
Equipment failure	**31**	**12**		**32**	**8**
Health	**0**	**0**		**0**	**1**
Human Error	**106**	**146**		**120**	**142**
Maintenance	**15**	**21**		**10**	**18**
Operations	**33**	**23**		**8**	**8**
Physics	**0**	**0**		**15**	**11**
Regulator	**3**	**9**		**2**	**12**
Unknown	**5**	**2**		**4**	**2**
Others	**0**	**4**		**0**	**0**
Total	**272**	**341**		**265**	**339**

Table 2: Causal Information in the TSB Maritime Dataset

The decision to allow each analyst to identify multiple causes and contributory factors within the lists presented by the TSB led to some differences in the analysis provided by each investigator. The 160 maritime reports yielded a total of 272 probable causes for analyst C and 265 for analyst M. Analyst C also identified 341 contributory factors while analyst M found 339. Table 2 provides a more detailed distribution of these causes and contributory factors within the various categories that were induced during our analysis. The variance between the investigators could have been reduced if a more formal method for distinguishing causes from contributory factors had been used. For instance, the PRISMA analysis technique provides a flow chart that investigators can work through to identify the role that various factors can play in an incident or accident (Johnson, 2003). At the start of the study, we decided not to use this approach because the development of appropriate root cause analysis techniques remains an active area for research. We are currently exploring the impact that more formal techniques might have on the results of our analysis.



Analyst C (160 reports, 613 causes/factors)



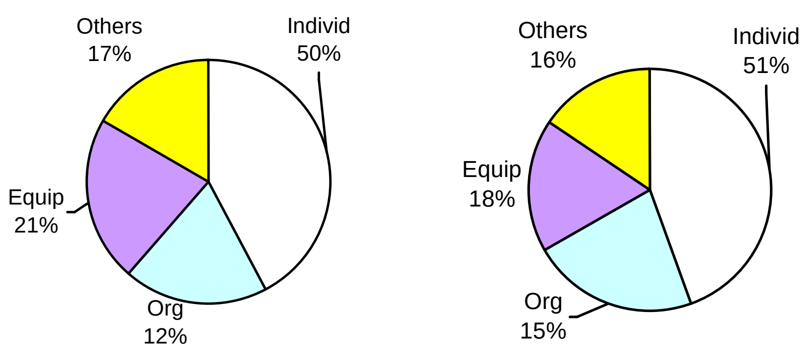
Analyst M (160 reports, 604 causes/factors)

Figure 4: Categorisation of Causes and Contributory Factors in the TSB Maritime Dataset

Figure 4 presents an overview of the more detailed classification illustrated in Table 2. By combining causes and contributory factors we can abstract away from some of the individual classification differences that were mentioned in the previous paragraphs. Company/organisational issues were grouped with regulatory factors, maintenance and operations. Equipment related causes and contributory factors were combined with design issues. ‘Others’ included environmental conditions, meteorological factors, unknown and other issues. As can be seen, the TSB maritime reports show a pattern that is very similar to the results from our previous studies of the TSB reports for major aviation accidents. Our earlier work on NTSB aviation reports showed that approximately 50% of all causes and contributory factors could be related to individual ‘error’ within our sample of aviation reports.

20% stemmed from equipment related issues, 22% to organisations and 8% to other factors. Here we can see a remarkably similar pattern in the maritime incidents, especially between analysts C and M. The initial analysis indicates that individual error plays a more prominent role in the TSB dataset than in the NTSB and that this pattern reflects the results from our previous aviation study. This can also be explained in similar terms. For example, the Canadian reports contain many incidents involving small charter vessels and owner-operators. In such cases, there is less opportunity for larger management structures and external organisations to create the preconditions for failure. Many of these incidents occur in remote locations well away from busy, regulated passages. Finally, it might also be argued that the prominence of individual error is an artefact of the different analytical techniques being employed by each agency (Johnson, 2003)

It is important not to exaggerate the prominence of human error in our study. The 50% of causal and contributory factors identified for individual failure in Figure 4 is relatively low compared to most estimates made in the wider human factors literature. It should also be remembered that this range is still much higher than our results for the NTSB dataset. Within the Canadian incidents, Figure 5 illustrates the consistency of the analysis by aggregating across both analysts but distinguishing between the proportion of causes and contributory factors in each of the four high level categories. This is an important analysis because it shows that there is no particular focus on individual error as a primary cause rather than a contributory factor nor can it be argued that the TSB investigators focus on organisational issues as contextual issues rather than more 'direct' causes.



Causes (Both analysts, 160 reports, 537 causes)

Contributory Factors (Both analysts, 160 reports, 604 factors)

Figure 5: Categorisation of Causes and Contributory Factors in the TSB Maritime Dataset

Figures 6 and 7 use 'J-H Graphs' to map the distribution of causes and contributory factors across the study period 1996-2004. This end-point reflects the latest collection of reports released by Transport Canada at the time of writing (late 2006). The y-axis shows the percentage of reports in each category, which is mapped as a percentage of the total causes for that year in Figure 6 and as a percentage of total contributory factors in Figure 7. As can be seen from the x-axis, this helps to normalise for a strong decline in the number of maritime reports issued; from 49 in 1996 to only 4 in 2004. A number of arguments can be used to explain this decline. The fall may reflect a genuine improvement in maritime safety over the period studies. This, in turn, may reflect changes in market structure as high-risk, single operator work has arguably decreased. Alternatively, the decline in major accident reports may reflect institutional changes in the investigation and reporting of major accidents by Transport Canada.

The increasing focus on organisational factors is readily apparent in Figures 6 and 7, from relatively small beginnings at the start of the sample to an increasing proportion of the causes and contributory factors in more recent reports. The focus on human error seems to have fluctuated from year to year. As with the NTSB results this may simply reflect the influence of particular adverse events on the totals for a particular year. However, there does appear to be a declining focus on individual error as a contributory factor over the study period even though Figure 3 shows that the proportion of contributory factors related to human error is comparable to the proportion of causes in this classification. Further work is required to determine whether this is part of a sustained trend within the TSB reporting of maritime accidents. In particular, it is important also to identify causal explanations for any patterns that are sustained. For example, Ayeko (2002) has described the influence that Reason’s (1997) work on organisational causes of accidents has had upon investigators’ training with the TSB. It could be argued that systematic changes in the causal analysis of major accidents should be apparent in the J-H graphs as increasing numbers of inspectors are exposed to these initiatives.

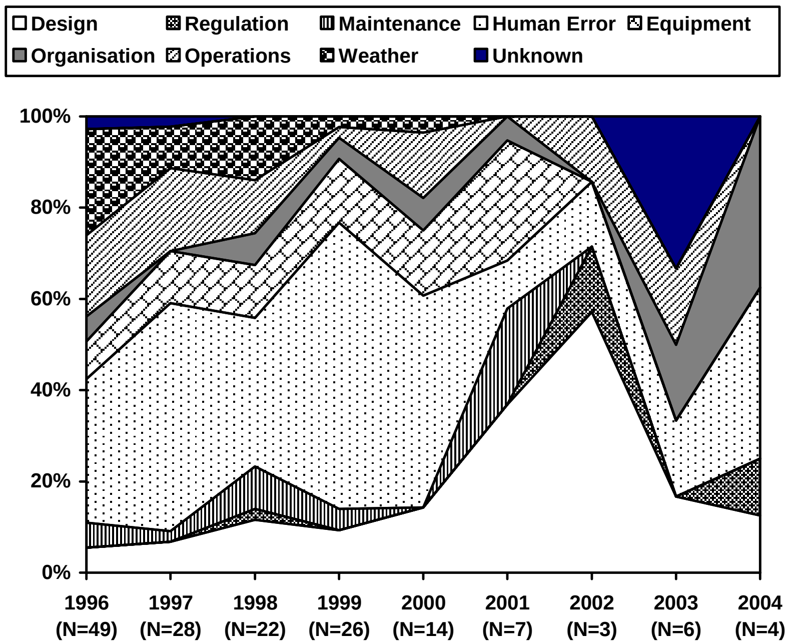


Figure 6: J-H Graph of Causes in TSB Maritime Reports by Year (Analyst C)

5 Conclusions

We have described the results of an independent analysis of the primary and contributory causes of maritime accidents in both the United States and Canada between 1996 and 2006. The purpose of the study was to assess the comparative frequency of a range of causal factors in the reporting of adverse events. Our results suggest that many of these high consequence accidents were attributed to human error. However, the overall proportion was very much smaller than has been suggested elsewhere in the human factors literature. A large number of reports also mentioned wider systemic issues, including the managerial and regulatory context of maritime operations. Based on these results we believe that is inaccurate to assert, as some have, that most investigations stop as soon as they find someone to blame, or that organizational causes are usually ignored. There are wider implications. For example, some have used the supposed predominance of human error as a primary cause in accidents to justify automation as a means reducing operator intervention. By restricting the scope for human 'error', it should be possible to reduce the overall accident rate (Johnson, 2003). This paper undermines these arguments by challenging the claimed prominence of human error in incidents and accidents.

In order to communicate our findings, we have introduced J-H graphs to visualise the proportion of causes and contributory factors associated with human error, equipment failure and other high level classifications in longitudinal studies of accident reports. These diagrams provide means of normalising across the causes and contributory factors that lead to rare and atypical events. The J-H charts show that our limited sample of NTSB reports could not be used to identify emerging patterns in the proportion of accidents associated with human error, equipment failure or organisational issues for twelve month intervals from 1996 to 2006. However, it is possible to discern a rise in the proportion of organisational issues that are identified as contributory factors in a broader sample of TSB maritime accident reports from 1996 to 2004, which includes the most recent publications.

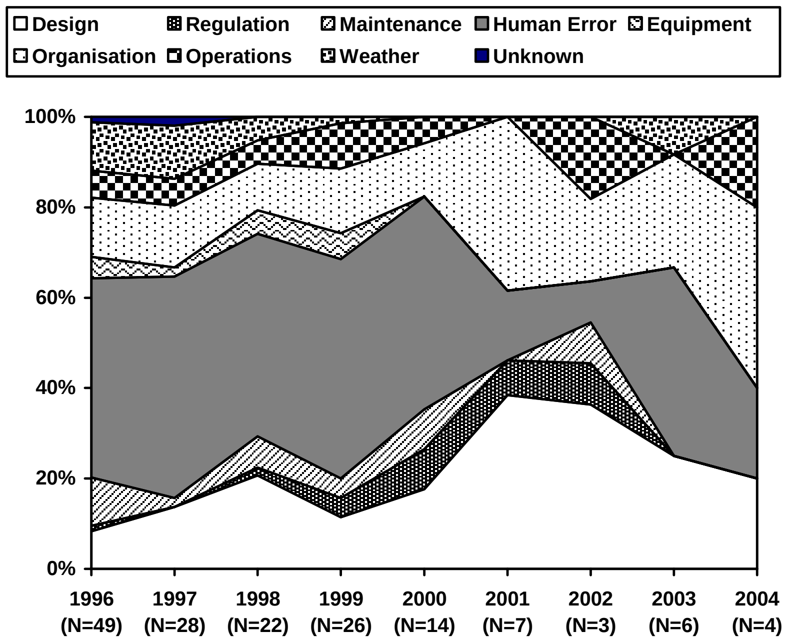


Figure 7: J-H Graph of Contributory Factors in TSB Maritime Reports (Analyst C)

A key finding from our research is that investigatory organizations show a similar distribution of causes and contributory factors between individual, organizational and equipment failures across different modes of transportation. Hence, there are strong similarities between the prominence of organizational factors in the NTSB reports in aviation and the maritime industries. Similarly, close comparisons can be made between the classifications for the TSB aviation and maritime reports. There are, however, considerable differences between the NTSB and TSB distributions in both modes. We conclude that these results are due to differences in the operational profile in each country. For instance, the TSB reports document a larger number of incidents involving private pilots and owner-operator vessels in remote areas than their NTSB counterparts. These differences may also be due to different analytical techniques, such as the TSB Integrated Safety Investigation Methodology approach (Ayeko 2002, Johnson 2003). Further work is required to more accurately trace the impact that investigator training has on the conclusions of accident and incident reports. Such studies must also consider the knock-on effects that these findings will have on the engineering of safety-critical systems across many different industries.

Acknowledgement

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Appendix A: Data Sources Used in the Study

An important aim of our study was to enable others to replicate our work. The NTSB and TSB documents in our data set included all major maritime reports between 1996-2006.

For the NTSB they were:

> MAR-96/01, MAR-97/01, MAR-97/02, MAR-98/01, MAR-98/02, MAR-98/03, MAR-99/01, MAR-00/01, MAR-01/01, MAR-01/02, MAR-02/01, MAR-02/02, MAR-02/03, MAR-02/04, MAR-02/05, MAR-04/01, MAR-05/01, MAR-05/02, MAR-06/01, MAR-06/02, MAR-06/03.

We also included the NTSB report into the allision between the tow boat *Robert Y. Love* with Interstate 40 on 26th May 2002. This document appears in both the marine and highways archive, following the NTSB's approach we use the highway identifier (HAR-04/05).

The TSB reports in our data set were:

> M96C0022, M96C0032, M96C0032, M96C0056, M96C0062, M96C008, M96C0090, M96C0093, M96F001, M96F0023, M96F0025, M96H0016, M96L0006, M96L0017, M96L0037, M96L0043, M96L0052, M96L0059, M96L0069, M96L0083, M96L0111, M96L0112, M96L0116, M96L0131, M96L0142, M96L0146, M96L0148, M96L0156, M96M0002, M96M0038, M96M0090, M96M0128, M96M0132, M96M0144, M96M0150, M96M0176, M96M0178, M96N0047, M96N0061, M96N0063, M96W0025, M96W0061, M96W0100, M96W0109, M96W0175, M96W0183, M96W0187, M96W0243, M96W0250, M97C0013, M97C0055, M97C0057, M97F0002, M97F0027, M97L0019, M97L0021, M97L0030, M97L0035, M97L0050, M97L0076, M97M0005, M97M003, M97M0094, M97M0141, M97N0067, M97N0071, M97N0073, M97N0099, M97N0129, M97W0022, M97W0044, M97W0048, M97W0152, M97W0194, M97W0197, M97W0236, M98C0004, M98C0015, M98C0026, M98C0040, M98C0046, M98C0066, M98F0009, M98F0023, M98F0039, M98L0097, M98L0120, M98L0139, M98L0149, M98L0165, M98M0003, M98M0061, M98M0078, M98N0001, M98N0064, M98W0019, M98W0045, M98W0245, M99C0003, M99C0005, M99C0008, M99C0016, M99C0019, M99C0027, M99C0048, M99F0023, M99F0038, M99F0042, M99L0011, M99L0098, M99L0099, M99L0126, M99M0062, M99M0142, M99M0161, M99W0033, M99W0058, M99W0078, M99W0087, M99W0095, M99W0116, M99W0133, M99W0137, M99W0145, M00C0026, M00C0033, M00C0053, M00C0069, M00H0008, M00L0034, M00L0114, M00N0098, M00W0005, M00W0044, M00W0059, M00W0230, M00W0265, M00W0303, M01C0033, M01C0054, M01L0080, M01L0112, M01M0100, M01N0020, M01W0006, M02C0030, M02W0147, M02C0064, M03L0026, M03C0016,

M03W0073, M03N0050, M03M0077, M03L0124, M04L0050, M04L0066, M04L0099, M04L0105.

Appendix B: Additional Graphs

Figure B-1 illustrates the year by year breakdown on causes and contributory factors for analyst C across the NTSB sample using the high-level classifications that were introduced in previous sections. As can be seen, this confirms the lack of any apparent pattern in the small number of reports (22) even though they yield more than 70 causal/contributory factors.

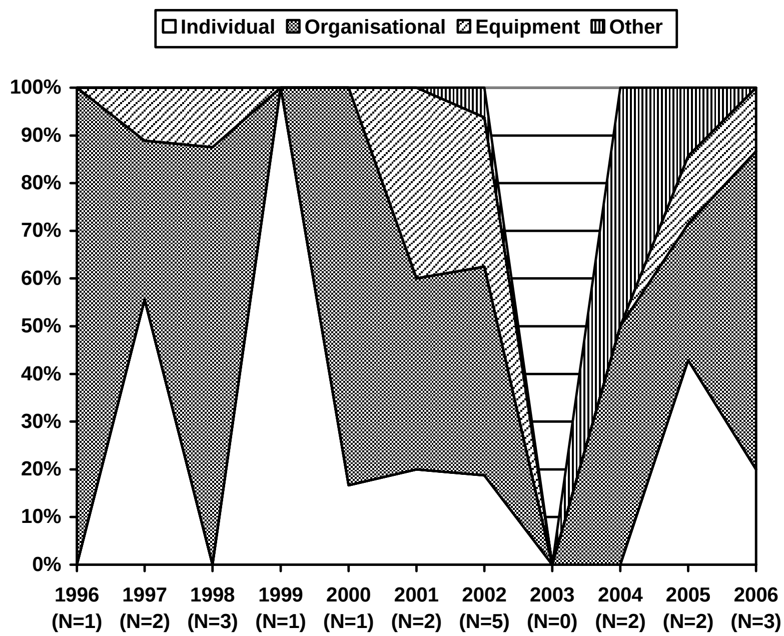

Figure B-1: J-H Graph of Causes & Contributory Factors in NTSB Maritime Reports by Year (Analyst C)