Distribution of Causes in Selected U.S. Aviation Accident Reports Between 1996 and 2003

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Abstract

This paper describes the results of an independent analysis of the probable and contributory causes of selected aviation accidents in the United States between 1996 and 2003. The purpose of the study was to assess the comparative frequency of a variety of causal factors in the reporting of these adverse events. Although our results show that more of these high consequence accidents were attributed to human error than to any other single factor, a large number of reports also mentioned wider systemic issues, including the managerial and regulatory context of aviation operations. These wider issues are more likely to appear as contributory rather than primary causes in this set of accident reports.

Introduction

Some critics of accident investigation organizations accuse investigators of being too quick to blame operators, and too reluctant to investigate deeply into underlying systemic issues that may affect how operators behave. In this paper, we report on a study designed to analyze the validity of these criticisms as applied to recent commercial aviation accident investigations by the National Transportation Safety Board (NTSB).

Background Theory: Many people believe that investigators must look beyond the immediate causes of an accident to identify the underlying or 'systemic' factors that create the conditions that make an accident likely to occur. For example, Reason (ref. 1) distinguishes between the *person* and the *system* approach to accident analysis. According to Reason, these two different perspectives imply a radically different view of causation. The "person approach focuses on the errors of individuals, blaming them for forgetfulness, inattention, or moral weakness." In contrast, the system approach "concentrates on the conditions under which individuals work and tries to build defences to avert errors or mitigate their effects."

Similarly, Cook and Woods (ref. 2), building on the earlier work of Mackie (ref. 3), argue that accidents occur through the concatenation of multiple small failures. Each of these failures is necessary; however, each is insufficient to cause the failure unless it occurs in combination with other failures. Often these small failures have roots that extend well back from the moment when the accident is triggered. Following Reason, Cook and Woods are careful to distinguish between the operators who often trigger an incident "at the sharp end" and the managers and regulators who often create the latent conditions for a failure "at the blunt end." Managerial and regulatory problems make it possible for combinations of minor failures to build up over time and hence create the preconditions for failure.

Identifying precisely which factors play a significant role in the latent causes of an accident or incident can be quite difficult (ref. 4). For example, the operational pressures of everyday tasks may influence operator behaviour. The causes of these pressures may be traced back to particular management decisions distributed throughout the tiers of responsibility within a company. Often the systemic causes of adverse event will ultimately trace back to the regulatory authorities and certification bodies that help to create the environment in which a management board operates. The proponents of the systemic view can reasonably argue that regulators must ultimately bear responsibility for accidents in the industries that they regulate. However, this ignores the legislative and political constraints that limit the regulators' scope for intervention. Similarly, it is important to question whether or not upper-levels of management can reasonably be expected to understand the detailed working practices that characterise the everyday operation of complex technology. For instance, previous studies of adverse events, including the Bristol Infirmary failures and the Challenger accident, have shown that middle and junior levels of management often find it difficult to pass bad news to their superiors (ref. 4).

Investigation Agencies: The regulations that govern the work of most accident investigation agencies do not explicitly distinguish between the 'person' or the 'system' view of failure. For example, 49 United States Code 1131 states that the "National Transportation Safety Board shall investigate or have investigated (in detail the Board prescribes) and establish the facts, circumstances and causes or probable causes" of accidents described for the different modes of transportation under the Board's jurisdiction. This requirement explicitly charges the organization with a requirement to investigate the probable causes of adverse events. The Code of Federal Regulations (CFR) describes the rules that govern the manner in which an agency will meet these obligations under the code. CFR Title 49 Part 845.40 requires that the U.S. National Transportation Safety Board (NTSB) "set forth the facts, conditions and circumstances relating to the accident and the probable cause thereof, along with any appropriate recommendations formulated on the basis of the investigation."

The NTSB's annual statistical reports provide further guidance on the nature of causes and contributory factors "the objective…is to discern the cause-and-effect relationships in the accident sequence. This could be described as *why* the accident happened. In determining probable cause of an accident, the Safety Board considers all facts, conditions, and circumstances. Within each accident occurrence, any information that contributes to the explanation of that event is identified as a finding and may be further designated as either a cause or factor. The term factor is used to describe situations or circumstances that contributed to the accident cause. The details of probable cause are coded as the combination of all causes, factors and findings associated with the accident. Just as accidents often include a series of events, the reason why those events led to an accident may be the combination of multiple causes and factors. For this reason, a single accident report can include multiple cause(s)" (ref. 5). In practice, this definition of factors has greatest relevance for field investigators involved in the analysis of less serious general aviation incidents. It is less seldom applied to guide the major investigations of air carrier accidents that are the focus of this paper.

Although these guidelines fail to distinguish between Reason's 'person' and 'system' approaches, many investigators are aware of the importance of the systemic causes of adverse events (ref. 4). However, a number of factors can prevent them from exploring the wide range of minor failures that together combine to create the preconditions for adverse events. In particular, resource constraints limit the scope of many investigations. Most investigation agencies operate with a relatively small core staff. They rely on external support to provide additional expertise. There are inevitable shortages of skilled personnel in several key areas, including human factors. Other areas, such as software forensics, have yet to be used in major accident investigations. Further problems are created because staff must choose among a plethora of analytical techniques that might guide the systemic analysis of adverse events.

A number of leading accident investigators have written on the importance of systemic factors in the causes of adverse events. For example, Strauch (ref. 6) argues that the "transformation of error perspective" from blaming the operator to identifying the contribution of system elements "has, I believe, led to profound changes in the way we investigate, consider, and respond to accidents." It is important to stress, however, that this argument refers to a much longer timescale than that normally associated with the debate between the 'person' and 'system' approaches. Strauch argues that the NTSB had moved away from a narrow view of human error well before 1996, which is the starting point of our analysis. The transition towards a systemic view of failure was the result of several factors that influenced the Board. These included wider changes in society, including a greater appreciation that adverse events can only be addressed by looking at the underlying causes rather than the immediate symptoms. Similarly, attitudes within the Board were affected both by academic research and human factors work within the aviation industry that led to a greater appreciation of Crew Resource Management. Senior individuals on the Board can also be credited with having influenced this change within the organization.

In the remaining pages of this paper, we describe a study to analyze the comparative frequency of causal factors in selected aviation accident reports. We make several observations about what this study can and cannot tell us about the relative importance of the 'person' and 'system' approaches within a particular investigative body, and we make suggestions for future work.

The NTSB Study

Difficulties: It can be difficult to measure the impact that a particular view of accident causation has on the working practices of an investigatory organization. The views of leading investigators need not be shared by all of their colleagues. Similarly, it can be difficult to identify methods that might be used to support the application of a 'system' or 'person' view to particular investigations. There are further methodological concerns. In particular, most investigatory organizations considered a range of causal factors well before authors such as Perrow (ref. 8) and Reason (ref. 1) articulated the systems view. It might be argued that these authors provided their greatest service in developing a vocabulary to describe changes that were already slowly affecting investigatory practice. It is likely, therefore, that the impact of systemic ideas can only be measured in terms of a relative change in the scope of an analysis rather than by a dramatic or sudden change in investigatory practices. Finally, it is difficult to know what to *measure* in order to determine whether there has been any movement from the 'person' view to the 'system' view of adverse events. Investigatory agencies such as the NTSB are responsible for several different modes of transportation ranging from pipelines through to aviation. The subsequent investigations produce many different forms of report that range from brief synopses of near-misses through to lengthy documents on major accidents. It is unclear how one would identify the impact of a systems view on such large and complex reports or across the mass of shorter documents on lower severity mishaps.

<u>Method</u>: The method that was adopted in this study involved the two co-authors performing an independent analysis of all of the major aviation accident reports published by the NTSB between 1996 and 2003. Each of us has more than a decade's experience in the development of safety-critical systems and has been active in the analysis of system failures for more than five years. Aviation accident reports were chosen because this transportation mode is widely perceived to drive much of the innovation in accident investigation (ref. 4). The start date was determined by pragmatism. Full-text, electronic accident reports beginning with 1996 are posted on the NTSB web site. Also, we believed that this start date provided a sufficiently large sample to support our analysis within the time available for our study. The sample yielded a total of 26 accident reports from the NTSB. The reports ranged from high profile, multiple fatality accidents such as the loss of ValuJet Flight 592 through to less-well-known, non-fatal accidents such as a Federal Express landing accident in Newark in 1997.

The analysis progressed by extracting the causal and contributory factors that were identified in the reports of each investigation. This preprocessing stage was necessary to insure that both of us focused on the same source prose, given that many of the documents were hundreds of pages in length. The identification of all relevant sections in each report was performed as a collaborative activity. Before July 1996, NTSB reports grouped this information in a section labeled "Probable Cause." After that date, we used the probable and contributory causes that were explicitly listed in the abstract of each report. For example, the opening sections of the NTSB's report AAR-00-01 into a crash in Guam contains the following statements, which clearly distinguish between probable and contributing causes:

> "The National Transportation Safety Board determines that the probable cause of the Korean Air flight 801 accident was the captain's failure to adequately brief and execute the non-precision approach and the first officer's and flight engineer's failure to effectively monitor and cross-check the captain's execution of the approach. Contributing to these failures were the captain's fatigue and Korean Air's inadequate flight crew training. Contributing to the accident was the Federal Aviation Administration's (FAA) intentional inhibition of the minimum safe altitude warning system (MSAW) at Guam and the agency's failure to adequately manage the system".

We then went on to independently assign each of the probable causes and contributory factors to categories. We decided not to use any pre-defined taxonomy but to independently assign our own terms to each of the causes. This approach forms a contrast with some previous studies, for example, Wiegmann and Shappell (ref. 9). Our decision was based on the observation that taxonomy techniques remain a research area in their own right. There is considerable controversy over the development and application of taxonomy-based analytical methods where it can be difficult to establish inter-analyst reliability.

The results of this process were then collated. There were some obvious differences in the terms used by the two analysts, but there were also strong similarities. For instance, one analyst identified 'human error' while another distinguished between 'aircrew error', 'ATM error' 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. For example, we agreed to use the more general term 'human error'. The term 'ATM failure' was used instead of 'ATM error' because it was often unclear whether a particular probable or contributory cause could be associated with the manager's actions or with design problems in their information systems. Distinctions were preserved between different terms where no agreement could be reached between the two analysts.

Raw Results: Table 1 summarizes the results of this classification process for the probable causes identified in the NTSB reports. The 26 accident reports yielded a total of 40 probable causes for the first analyst. The mean number of probable causes was 1.5 with a standard deviation of 1. The second analyst also identified 40 probable causes, with a mean of 1.5 and a standard deviation of 0.8. The mode was 1 for both analysts.

Table 1 — Frequency of Probable Causes over Time (numbers in parentheses represent number of different accident reports)

	1996		1997		1998		1999		2000	
	J	M	J	M	J	M	J	M	J	M
Human Error	3 (3)	3(3)	6 (5)	7(5)	0	0	0	0	5 (2)	3(2)
ATM Failure	0	0	0	0	0	0	0	0	0	0
Maintenance Problem	1 (1)	1(1)	0	0	1 (1)	0	0	0	0	0
Company Management	2 (2)	1(1)	3 (2)	3(2)	2 (1)	3(2)	0	0	0	0
Regulation	2 (1)	0	1 (1)	1(1)	3 (1)	3(1)	0	0	0	0
Equipment Failure	0	0	0	0	0	1(1)	1 (1)	1(1)	1 (1)	1(1)
Aircraft Design	0	1(1)	0	0	0	0	0	1(1)	0	0
Manufacturing	0	0	0	0	1 (1)	1(1)	0	0	0	0
Environment	0	1(1)	1 (1)	1(1)	0	0	0	0	0	0
Undetermined	0	0	0	0	1(1)	0	0	0	0	0
Total	8	7	11	12	8	8	1	2	6	4

	2001		2002		2003		Total	
	J	M	J	M	J	M	J	M
Human Error	2 (1)	3(1)	0	0	2 (2)	2(2)	18 (13)	18(13)
ATM Failure	0	0	0	0	0	0	0	0
Maintenance Problem	0	0	1 (1)	1(1)	1 (1)	1(1)	4 (4)	3(3)
Company Management	0	0	0	0	0	0	7 (5)	7(5)
Regulation	0	0	0	0	0	0	6 (3)	4(2)
Equipment Failure	0	0	0	0	0	0	2 (2)	3(3)
Aircraft Design	0	0	0	0	0	0	0	2(2)
Manufacturing	0	0	0	0	0	0	1 (1)	1(1)
Environment	0	0	0	0	0	0	1 (1)	2(2)
Undetermined	0	0	0	0	0	0	1 (1)	0
Total	2	3	1	1	3	3	40	40

Although both analysts had the same total number of probable causes, there are slight differences in the individual analysis of specific reports. At first glance, this might seem strange, since the NTSB explicitly labels probable causes. However, some probable cause statements described multiple problems. For example, the Guam report (AAR-00-01) contains the following conclusion: "The National Transportation Safety Board determines that the probable cause of the Korean Air flight 801 accident was the captain's failure to adequately brief and execute the non-precision approach and the first officer's and flight engineer's failure to effectively monitor and cross-check the captain's execution of the approach". Several different ways exist to classify the individual causes within this conclusion. Two instances of human error might be identified: "the captain's failure to adequately brief and execute the non-precision approach"; and "the first officer's and flight engineer's failure to effectively monitor and cross-check the captain's execution of the approach". Alternatively, this conclusion could be thought to identify three instances of human error, with the first officer's and the flight engineer's failures being considered separate errors.

This example also illustrates that a single incident can yield multiple instances of the same cause within our taxonomies. It is for this reason that Tables 1 and 2 provide the total number of different accidents involving a particular cause in parentheses. Hence an entry in either table of the form 2(1) indicates two instances of a particular cause from a single accident report. An entry of the form 5(2) indicates that two accident reports yielded five different instances of the associated cause for that particular year.

Table 2 summarizes the results of our classification process for the contributory factors identified in the NTSB accidents reports. The first analyst identified 52 contributory factors, with a mean of 1.9 and a standard deviation of 1.5. The second analyst identified 55 contributory factors, with a mean of 2 and a standard deviation of 1.5. The mode for all contributory factors was 2.

Table 2 — Frequency of Contributory Causes over Time (numbers in parentheses represent number of different accident reports)

	1996		1997		1998		1999		2000	
	J	M	J	M	J	M	J	M	J	M
Human Error	3 (3)	4(3)	4 (3)	5(4)	1(1)	1	0	0	2(2)	2(2)
ATM Failure	1 (1)	0	0	0	0	0	0	0	0	0
Maintenance Problem	0	0	0	0	0	0	0	0	0	0
Company Management	6 (4)	8(5)	3 (3)	3(3)	2(2)	2(2)	0	0	1(1)	1(1)
Regulation	3 (2)	6(3)	4 (3)	4(3)	2 (1)	2(1)	0	0	4(2)	4(2)
Equipment Failure	0	0	2 (1)	2(1)	0	0	0	0	0	0
Aircraft Design	0	0	2 (1)	1(1)	0	0	0	0	2(1)	1(1)
Manufacturing	0	0	0	0	0	0	0	0	0	0
Environment	1 (1)	0	0	0	0	0	0	0	0	0
Undetermined	0	0	0	0	0	0	0	0	0	0
Total	14	18	15	15	5	5	0	0	9	8

	2001		2002		2003		Total	
	J	M	J	M	J	M	J	M
Human Error	3 (1)	3(1)	0	0	0	0	13 (10)	15(11)
ATM Failure	0	0	0	0	0	0	1 (1)	0
Maintenance Problem	0	0	0	0	0	0	0	0
Company Management	0	0	2(1)	2(1)	0	0	14 (11)	16(10)
Regulation	0	0	2(1)	2(1)	0	0	15 (9)	18(10)
Equipment Failure	0	0	0	0	1(1)	0	3 (2)	3(2)
Aircraft Design	1(1)	0	0	1(1)	0	1(1)	5 (3)	3(3)
Manufacturing	0	0	0	0	0	0	0	0
Environment	0	0	0	0	0	0	1 (1)	0
Undetermined	0	0	0	0	0	0	0	0
Total	4	3	4	5	1	1	52	55

Given the fact that the analysis depended on a degree of subjective interpretation within the statements of probable cause and contributory factors, we believe that tables 1 and 2 indicate a high level of agreement.

Discussion: As mentioned, the majority of the reports identified a single probable cause; however, the mode for contributory causes was two. For instance, NTSB report AAR-96-05 contained the following summary:

> "The National Transportation Safety Board determines that the probable cause of this accident was the flight crew's failure to maintain the required minimum descent altitude until the required visual references identifiable with the runway were in sight. Contributing factors were the failure of the BDL approach controller to furnish the flight crew with a current altimeter setting, and the flight crew's failure to ask for a more current setting."

Both analysts identified the single probable cause as an instance of human error. They also agreed that there were two contributory causes. However, the first analyst identified one instance of an aircrew contributory failure and another associated with air traffic management. The second analyst categorised both under the heading of human error.

In contrast to this incident, the standard deviations can be explained by exceptions to the mode that were characterised by a much higher number of probable or contributory causes. For instance, the NTSB report AAR-02-01 into Alaska Airlines Flight 261 provided the following summary of probable and contributory causes:

> "The National Transportation Safety Board determines that the probable cause of this accident was a loss of airplane pitch control resulting from the in-flight failure of the horizontal stabilizer trim system jackscrew assembly's acme nut threads. The thread failure was caused by excessive wear resulting from Alaska Airlines' insufficient lubrication of the jackscrew assembly. Contributing to the accident were Alaska Airlines' extended lubrication interval and the Federal Aviation Administration's (FAA) approval of that extension, which increased the likelihood that a missed or inadequate lubrication would result in excessive wear of the acme nut threads, and Alaska Airlines' extended end play check interval and the FAA's approval of that extension, which allowed the excessive wear of the acme nut threads to progress to failure without the opportunity for detection. Also contributing to the accident was the absence on the McDonnell Douglas MD-80 of a fail-safe mechanism to prevent the catastrophic effects of total acme nut thread loss."

Both analysts identified one primary cause and five contributory causes. In both cases the probable cause was listed as maintenance error. They identified two regulatory failures, two management failures, and a problem of aircraft design as contributory factors. This illustrates the considerable agreement over the probable and contributory causes for each accident. As noted above, there were, however, minor differences in interpretation and classification. Given the limited sample size and the small number of analysts, it is difficult to draw any firm conclusions about the analysis of particular accidents.

Additional Results: Figures 1 and 2 illustrate the overall percentage of probable and contributory causes in each category identified by each analyst. These diagrams provide arguably the most important insights from our work. There is considerable agreement about the proportion of causes that can be classified in each category. Both analysts identified human error in 44% of all probable causes. There is no more than a 5% difference in any other category of probable cause. Analyst J identified regulatory issues in 15% of all probable causes compared to 10% for analyst M.

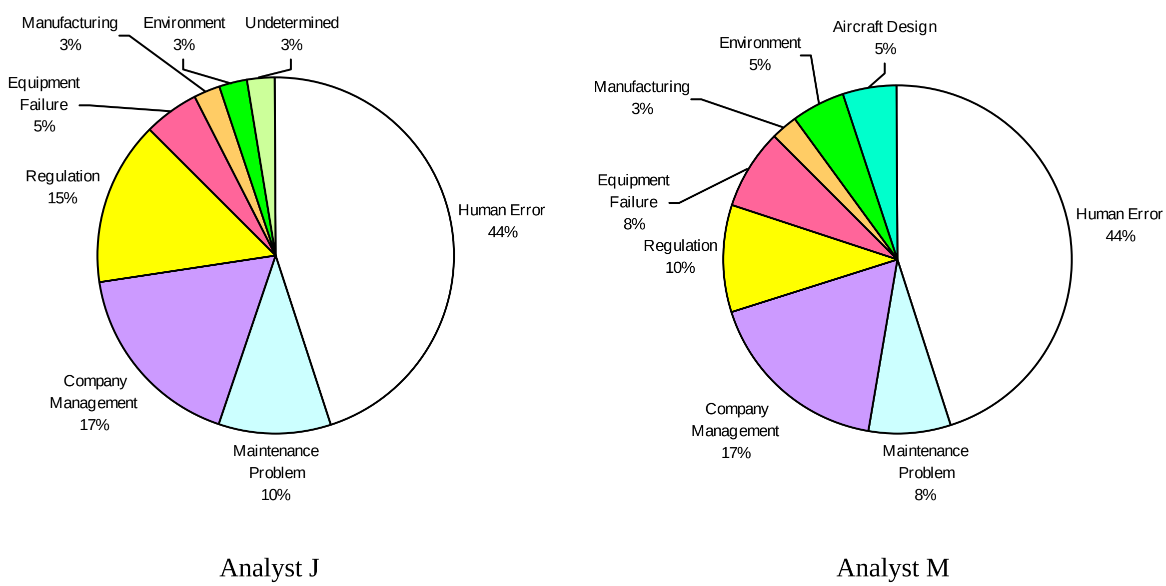

Figure 1 — Percentage of Probable Causes by Category

For contributory factors there is also much agreement. There is only a 2% difference in the proportion of contributory factors associated with human error at 25% and 27%. The proportion associated with regulation also shows considerable agreement at 28% and 34%.   Company management was identified in 27% of the contributory factors studied by analyst J, while analyst M identified it in 29% of the factors.

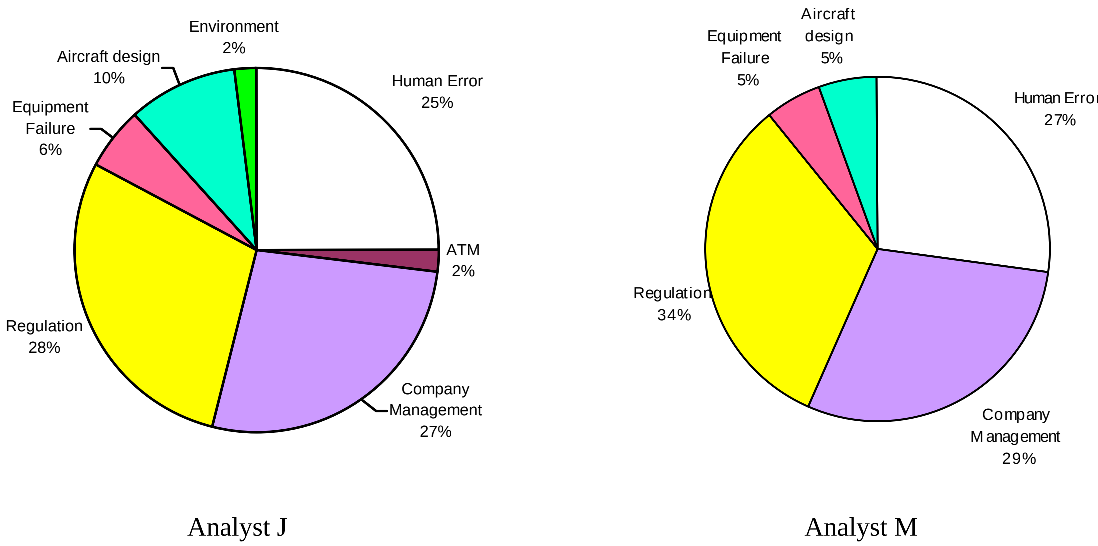

Figure 2 — Percentage of Contributory Factors by Category

There are some small differences in the classifications used by each analyst.   For example, analyst J identified Air Traffic Management error in 2% of the contributory causes while analyst M assigned these causes within a wider definition of human error.   Similarly, analyst J found environmental issues in 2% of contributory factors while several of these issues were classified as regulatory problems by analyst M. Overall, however, these differences seem remarkably small compared to the considerable agreement in the main categories of regulation, human error and company management.

Analysis: Table 3 shows a year-by-year breakdown of the number of citations of human error identified by both analysts.   The table shows no apparent bias towards "blaming the operator" in earlier reports; such a bias might be expected if there had been a move from a 'person' view of causality to a 'system' view during the period of our analysis.

Table 3 — Number of Citations of Human Error in Each Year

	probable		contributory	
	J	M	J	M
1996	3	3	3	4
1997	6	7	4	5
1998	0	0	1	1
1999	0	0	0	0
2000	5	3	2	2
2001	2	3	3	3
2002	0	0	0	1
2003	2	1	0	0

The apparent peak in 1997 is not due to any single accident with a high number of human errors. Instead, it is explained by a series of reports (AAR-97-05, 04, 03, 02, 01) that both analysts identified as attributing the accidents to human error.   A similar rise in human error identified during 2000 makes it likely that these are semi-random artefacts stemming from the types of accidents that happened to occur in those years.   It seems unlikely that these peaks can be directly attributed to a subtler acceptance of a 'person' view over what Reason terms the 'system' approach to causal analysis. This view is further justified by the observation that the rise in human error is largely explained by two accidents in 2000, which are documented in AAR-00-01 and AAR-00-02.

Our analysis of these diagrams and of the earlier tables also undermines accusations made by some safety researchers that accident investigations stop when someone is found to blame. Both analysts identified a large number of systemic causes and contributory factors throughout the sample of NTSB reports. Overall managerial failures were identified in approximately 17% of all probable causes and in 28% of all contributory factors. Similarly, regulatory issues account for 12% of all probable causes and 31% of all contributory causes. Managerial issues are the second most frequent classification for causal and contributory factors. Regulatory failures are the third most frequent probable cause and the *most frequent contributory factor* identified by both analysts.

It is true that in the reports we studied, fewer managerial and regulatory causes are identified after 1999. This might be argued as contradicting the hypotheses that the proponents of ‘system’ views have had an increasing impact on the work of investigatory organizations. It might also be argued that the residual 29% and 25% of contributory factors attributed to human error further illustrate a dominance of a ‘person’ view of blame. However, we believe that such arguments are overly simplistic and ignore the significance of managerial and regulatory factors found throughout our sample reports.

When we began this analysis, we were keen to determine whether or not the ‘system’ view of failure was having an impact on the reports issued by the U.S. NTSB. Our results have shown that the NSTB considered a wide range of causal and contributory factors in its reports. In particular, it seems clear that the Board has a long tradition of considering the regulatory and managerial precursors to accidents. However, human error continues to be the most prominent single factor identified in the reports.

One possible explanation for the prominence of human error is that many investigatory agencies rely on counterfactual definitions of root causes (ref. 4). These definitions are distinguished by arguments of the form “if the probable cause X had not occurred then the mishap also would not have occurred.” Several existing investigation techniques, including Multilinear Event Sequence and Events and Causal Factors Charting, embody counterfactual arguments within their associated analytical techniques. Investigators look at the events immediately preceding the failure. They then ask whether the accident would have been avoided if that event had not taken place. If the accident is still likely to have occurred even if that event had been prevented, then the investigation moves on to look at its precursors until a root cause is identified. One by-product of these techniques is that they are likely to identify direct operator errors as root causes, because these are often identified as immediate precursors to an adverse event. The current NTSB accident coding manuals recommend a sequence of events modelling matrix that is very similar to both of the techniques cited above. However, further work is required to determine whether or not counterfactual explanations account for the results that are presented in this paper. Alternatively, the relative frequency and recency of human factors causes in other investigations may help to create a reinforcement cycle in which these factors are more likely to be cited in the future because they have often been cited in the past.

Concluding Remarks

This study has shown us how difficult it can be to make inferences about the attitudes of complex, investigatory organizations from the reports that they produce. This should not be any surprise. It is, however, surprising that there have been so few previous attempts to conduct such a study. Without detailed evidence of the type presented in this paper, it is difficult to sustain or refute many of the criticisms that have been made about investigatory agencies and their attitudes towards the role of human error. Particular problems in our study stemmed from the difficulty of determining whether or not a particular cause was related to human error. Similarly, as we noted, it can be hard to determine whether certain paragraphs in a report described a single operator failure or a series of related errors. In practice, however, we were able to reach considerable agreement over these apparently intractable problems.

Further work is required to analyze the manner in which the use of investigatory techniques can influence the outcomes of a particular agency’s investigations. Such work must also acknowledge that every investigatory agency uses a range of different investigatory processes that vary according to the severity of the incidents under consideration. For example, NTSB field units typically consider less serious events, FAR Part 91 operations. In contrast, FAR Part 121 accidents tend to be handled by headquarters staff. The allocation of headquarters staff, typically, implies additional resources and the ability to probe deeper into the regulatory and organizational causes of an adverse event. We infer from the seriousness of the accidents under consideration in this analysis that these were subject to the most extended form of analysis.

The opening sections introduced Strauch's argument that the NTSB's had moved away from a narrow view of human error before the 1996 starting point for our research. Wider changes in society, partly as a result of the Three Mile Island accident, changes in the focus of human factors and Crew Resource Management, and the influence of senior management had all combined to increase the prominence of systems thinking within the Board. It can, therefore, be argued that a more pronounced contrast might have been obtained if we had extended our analysis into the early 1990s and beyond. This is possible because many previous reports are available in the digital archive held by the Embry-Riddle University. Such an analysis would raise a number of additional methodological concerns. In particular, it would be important to normalize the frequency of causal factors over time given the higher frequency of aviation accidents in the 1960s and 1970s.

Similarly, further work might extend our analysis to include the work of other similar agencies. As mentioned above, we have conducted a similar study of selected reports produced by the Canadian TSB (ref. 10). Although the results of that study are quite similar to those of the NTSB study, there are enough differences to suggest that it would be worthwhile to consider other agencies, too. In particular, the Australian Transport Safety Bureau has been heavily influenced by many of Reason's theories on the contextual nature of human error. An analysis for reports from this agency might yield very different findings. Additional further work that might yield different findings would be to extend the analysis to investigations of accidents that are outside the domain of transportation.

In this paper, we have described the results of an independent analysis of the primary and contributory causes of selected NTSB aviation accident reports between 1996 and 2003. The purpose of the study was to assess the comparative frequency of a range of causal and contributory factors in the reporting of adverse events in aviation. Our results show that more of these high consequence accidents were attributed to human error than to any other single cause; however, wider systemic issues, including the managerial and regulatory context of aviation operations, were also mentioned in a large number of reports. These systemic issues are more likely to appear as contributory rather than primary causes. 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. For NTSB aviation accident investigations at least, this is not true.

References

1. J. Reason. "Human Error: Models and Management." *British Medical Journal*, 320 (2000):768-770.

2. D. Woods and R.I. Cook. "The New Look at Error, Safety, and Failure: A Primer." Technical Report, US Veterans Association, National Centre for Patient Safety, 2004.

3. J.L. Mackie. *The Cement of the Universe*. Oxford University Press, Oxford, 1980.

4. C.W. Johnson. *The Failure of Safety-Critical Systems: A Handbook of Accident and Incident Reporting*. Glasgow University Press, Glasgow, 2003.

5. NTSB. "Annual Review of Aircraft Accident Data U.S. General Aviation, Calendar Year 1999." Washington, DC. Available from: http://www.ntsb.gov/publictn/2003/ARG0302.pdf

6. B. Strauch. "Normal Accidents: Yesterday and Today." In C.W. Johnson (editor), *Proceedings of the First Workshop on the Investigation and Reporting of Incidents and Accidents (IRIA 2002)*, Department of Computing Science, University of Glasgow, Scotland, 2002.

6. J. Reason. *Managing the Risks of Organizational Accident*. Ashgate Publishing, Hampshire, England, 1997.

8. C. Perrow. *Normal Accidents: Living with High-Technology Accidents*. 2nd Edition. Princeton University Press, Princeton, 1999.

9. D. Wiegmann and S.A. Shappell. *A Human Error Approach to Aviation Accident Analysis*. Ashgate Publishing, Hampshire, England, 2003.

10. C. W. Johnson and C. M. Holloway. "'Systemic Failures' and 'Human Error' in Canadian TSB Aviation Reports Between 1996 and 2002." To appear in *Proceedings of HCI-Aero 2004*, September 28 – October 1, 2004, Toulouse, France.

Appendix A: Reference List of Source Incident Reports

It is important in a study of this nature that others should be able to replicate or challenge the results of our work. For this reason we include a listing of all of the incidents that were considered in this study. All of these reports are available from the NTSB's web site: www.ntsb.gov. Our analysis considered the following NTSB reports: AAR-03-03, AAR-03-02, AAR-03-01, AAR-02-01, AAR-01-02, AAR-01-01, AAR-00-03, AAR-00-02, AAR-00-01, AAR-99-01, AAR-98-04, AAR-98-03, AAR-98-02, AAR-98-01, AAR-97-06, AAR-97-05, AAR-97-04, AAR-97-03, AAR-97-02, AAR-97-01, AAR-96-07, AAR-96-06, AAR-96-05, AAR-96-04, AAR-96-03, AAR-96-02, AAR-96-01.

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