‘Systemic Failures’ and ‘Human Error’ in Canadian TSB Aviation Reports Between 1996 and 2002

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ABSTRACT
This paper describes the results of an independent analysis of the primary and contributory causes of aviation accidents in Canada between 1996 and 2003. The purpose of the study was to assess the comparative frequency of a range of causal factors in the reporting of these adverse events. Our results suggest that the majority of these high consequence accidents were attributed to human error. A large number of reports also mentioned wider systemic issues, including the managerial and regulatory context of aviation operations. These issues are more likely to appear as contributory rather than primary causes in this set of accident reports.

Keywords
Human error, accident analysis, incident investigation

INTRODUCTION
Reason [1] has recently distinguished the ‘person’ from the ‘system’ approach to accident analysis. Each of these perspectives implies 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 defenses to avert errors or mitigate their effects’. Similarly, Cook and Woods [2] argue that accidents occur through the concatenation of multiple small failures. Each of these causes is necessary. However, they are each insufficient to cause the failure unless they occur in combination with other potential causes. Often these small failures have roots that extend well back from the moment when the accident is triggered. This analysis is 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’. In particular, managerial and regulatory problems often make it possible for combinations of these minor failures to build up over time and hence create the preconditions for failure.

There is considerable controversy over this systemic view of failure [3]. It can be difficult to identify precisely which factors play a significant role in the latent causes of an accident or incident. For example, the operational pressures of their everyday tasks may influence operator behaviour. The causes of these pressures can 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 lead to the regulatory authorities and certification bodies that help to create the environment in which a management board will operate. The proponents of the ‘systemic’ view can reasonably argue that regulators must ultimately bare 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. In particular, previous studies of adverse events such as the Bristol Infirmary failures have shown that middle and junior levels of management often find it difficult to pass bad news to their more senior colleagues [3].

The regulations that govern the work of most accident investigation agencies seldom emphasize the importance of ‘systemic factors’. For example, the Canadian Transportation Accident Investigation and Safety Board Act, 1989, c. 3, the Transport Safety Board (TSB) must identify “causes and contributing factors” to identify “safety deficiencies as evidenced by transportation occurrences”. It is not the function of the Board “to assign fault or determine civil or criminal liability, but the Board shall not refrain from fully reporting on the causes and contributing factors merely because fault or liability might be inferred from the Board's findings. A number of further factors can prevent investigators from exploring the 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. However, there are inevitable shortages of skilled personnel in several key areas, including software forensics. Further problems are created by the lack of recognized analytical techniques that might be used to guide and validate the 'systemic' analysis of adverse events. From this it follows that it can be difficult to determine whether or not investigators have considered an adequate range of causal factors during any particular investigation.

A number of leading accident investigators have written on the importance of 'systemic' factors in the causes of adverse events. For example, Strauch [4] 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'. Similarly, Ayeko [5] has argued that 'to learn a lesson from an accident one must understand not only the immediate cause but also contributing factors and underlying conditions of the accident'. He goes on to state 'it is my belief that, when we seek "cause" rather than "information about cause" in an investigation of an accident, the direction of the investigation often veers towards elements that are more likely to be linked to blame rather than the mitigation of risks'. We were concerned to determine whether these 'systemic' views of complex, technological failure have had a discernable impact on the work of accident investigation agencies.

It can be difficult to measure the impact that a particular view of accident causation has upon the working practices of an investigatory organization. For example, most investigatory organizations analyzed a range of causal factors well before authors such as Perrow [6] and Reason [1] articulated the 'systems view'. It is likely, therefore, that the impact of 'systemic' ideas can only be measured in terms of a relative change in the scope of any analysis rather than a dramatic or sudden change in investigatory practices. It is also difficult to know what to *measure* in order to determine whether there has been any movement from the 'person' view to the 'systems' view of adverse events.

Method

The method adopted in this study involved the two co-authors performing an independent analysis of all of the major aviation accident reports published between 1996 and 2002 by the Canadian TSB. The investigators each had more than a decade's experience in the development of safety-critical systems. Each has been active in the analysis of system failures for more than five years. The decision to focus on Canadian accident reports was justified because this forms one part of a larger international study, a companion paper described the results of applying this technique to US NTSB investigations. The start date was determined by pragmatism. It was felt that this provided a sufficiently large sample to support our analysis within the time available to our study. This sample yielded a total of 27 accident reports. The most recent report available at the time of writing, February 2004, was published in 2002. The reports ranged from high profile, multiple fatality accidents such as the loss of Swiss Air Flight 111 through to less severe loss-of-separation incidents. The heuristic that we adopted was to investigate every aviation incident report that was composed of distinct numbered sections between 1996 and 2002. We also substituted a number of the less structured, reports for 2002. These were reports A02C0124, A02F0069, A02P0109, A02Q0130. This decision was justified by the need to avoid a gap in our sample for the last two years. We were also unable to determine whether this less structured format will provide a standard for future TSB reports. Even with these additions, our sample is relatively small compared to the 1,812 accidents and 1,374 incidents that were reported to the Candian TSB in 2002. A considerable process of filtering was used by the investigatory agencies to select the most serious of these incidents for investigation. In consequence, our sample focuses on those higher risk mishaps, including near misses, which were deemed serious enough to warrant a subsequent investigation and report.

The analysis progressed by extracting the causal and contributory factors that were identified in the aftermath of each investigation. Canadian TSB reports contain a section in their abstract that lists 'Findings As To Causes and Contributing Factors'. Once these sections had been extracted, the two investigators performed their analysis independently. All subsequent stages were also performed in isolation from each other until the results were available for comparison. The second stage of the analysis was to assign each of the probable causes and contributory factors to a number of common categories. We decided not to use any pre-defined taxonomy but to allow each of the investigators to independently assign their own terms to each of the 'causes'.

The results of this process were then collated. There were some obvious differences in the terms used but there were also some 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 cause or contributory factor 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.

Results

As mentioned, our sample reports included separate sections on "Findings As to Causes and Contributing Factors". Our analysis was complicated, however, because the TSB does not distinguish probable causes from contributory factors in these sections. For instance, report A02F0069 contained the following list:

1. The pilot not flying (PNF) inadvertently entered an erroneous V_1 speed into the MCDU. The error was not detected by either flight crew, despite numerous opportunities.

2. The PNF called "rotate" about 25 knots below the calculated and posted rotation speed.

3. The pilot flying (PF) initiated rotation 24 knots below the calculated and posted rotation speed and the tail of the aircraft struck the runway surface.

4. A glide path signal was most probably distorted by a taxiing aircraft and provided erroneous information to the autopilot, resulting in a pitch-up event. The pitch-up could have been minimized if the autopilot had been disconnected earlier by the PF.

As can be seen, there is no indication as to which of these items is a cause and which is a contributory factor. Each analyst, therefore, had to use his own judgment. Both analysts independently identified three causes relating to human error and one contributing factor relating to equipment failure. Analyst M also identified three causes involving human error. However, they argued that the sole contributory factor should be classified as a problem with equipment design.

This reliance on individual judgment created disagreement over causes and contributory factors. Analyst J found 53 causes and only 35 contributory factors. Analyst M found correspondingly fewer causes, 44, and more contributory factors, 71. A more formal method for distinguishing causes from contributory factors could have reduced this variance (Johnson, 2003). At the start of the study, we decided not to use a more formal approach because the development of appropriate root cause analysis techniques remains an active area for research. We were also keen to employ the subjective criteria that might be employed by the readers of these documents.

As mentioned, the 27 incidents yielded a total of 53 probable causes for the first analyst. The mean number of probable causes was 1.9 with a standard deviation of 1.2. The second analyst identified 44 probable causes with a mean of 1.6 and a standard deviation of 1. There were 35 contributory causes identified by the first analyst with a mean of 1.3 and a standard deviation of 2.5. The second analyst identified 71 contributory causes with a mean of 2.5 and a standard deviation of 3.9. The mode over all probable causes was 1 while the mode for all contributory causes was 0.

The standard deviation associated with the mean results for both causes and contributory factors is relatively high. This can be explained in terms of a small number of reports, which were very different from the mode of one cause and zero contributory factors. In particular, both analysts identified two causes in report A97H0011. However, analyst J identified 13 contributory factors while M found 20 in this single incident. This report describes a loss of control on go-around under adverse weather conditions. Analyst J identified human error and problems in air traffic management as the main causes. Analyst M identified two instances of 'human error'. The thirteen contributory factors identified by Analyst J included five instances of managerial failure, two human errors, two regulatory problems, two aircraft design issues, a maintenance failure and a problem relating to the operational environment in which the accident occurred. In contrast, analyst M identified three human errors, seven management issues, six regulatory failures, three environmental factors and one instance of equipment failure. A number of other atypical reports also helped to pull the standard deviation away from the mode. For example, both analysts identified five instances of human error causing the incident described in TSB report A99Q0151:

> "The pilot flying did not establish a maximum performance climb profile, although required by the company's standard operating procedures (SOPs), when the ground proximity warning system (GPWS) "Terrain, Terrain" warning sounded during the descent, in cloud, to the non-directional beacon (NDB). The pilot flying did not fly a stabilized approach, although required by the company's SOPs. The crew did not carry out a go-around when it was clear that the approach was not stabilized. The crew descended the aircraft well below safe minimum altitude while in instrument meteorological conditions. Throughout the approach, even at 100 feet above ground level (agl), the captain asked the pilot flying to continue the descent without having established any visual contact with the runway environment. After the GPWS "Minimums, Minimums" voice activation at 100 feet agl, the aircraft's rate of descent continued at 850 feet per minute until impact. The crew planned and conducted, in cloud and low visibility, a user-defined global positioning system approach to Runway 31, contrary to regulations and safe practices."

Tables 1 and 2 summarise the data from our study. Although there is some disagreement over individual incidents, there is considerable consensus across the sample. Both investigators identified human error as the most common causal factor across the TSB sample at 56% for analyst J and 75% for analyst M. The relative difference between the proportions of incidents identified by the two analysts can be partly explained in terms of the broader range of categories that were considered by analyst J compared to analyst M. For example, analyst J also included 'loadmaster error' (2%) and 'ATM error' (6%) that were not included within the classification used by analyst M. With this caveat, the remaining results show considerable agreement; both analysts fall within one or two percent of their colleagues classification for environmental causes with 9%(J) and 7% (M), aircraft design 4% (J) and 5% (M), equipment failure 9% (J) and 9% (M), regulation 4% (J) and 2%(M), maintenance 2% (J) and 2% (M).

Table 2 shows that human error plays a lesser role in the contributory factors that were identified by both analysts in the TSB sample; 22% by analyst J and 28% by analyst M. Again, there is considerable agreement in terms of the overall percentages for each category of contributory factor. Analyst J identified 28% of all contributory factors as being related to company management. Analyst M found this in 27% of the factors in the accident reports. The agreement continued in regulation with 9%(J) and 11%(M), equipment failure 9%(J) and 7% (M), environmental factors 9% (J) and 8% (M). There is a more noticeable disagreement over the role of aircraft design. Analyst J identified it in only 9% of these contributory factors. Analyst M identified design flaws in 15% of the factors in the TSB sample. This can be explained in terms of a cluster of incidents in 1998. Analyst M identified three aircraft design flaws in the contributory factors for A98H0003, two in A98H0002 and A98H0011 and one in A98C0173. In contrast, Analyst J identified management failure as a contributory factor behind these design flaws.

These statistics reemphasize the importance of human error as a causal factor. We did not, however, identify any trend away from blaming the operator as might be predicted given the popularity of 'systemic theories' of failure in recent years. The frequency of human error identified by analyst J is: 3 probable and 1 contributory (1996), 2 probable and 3 contributory (1997), 6 probable and 1 contributory (1998), 9 probable and 0 contributory (1999), 4 probable and 1 contributory (2000), 1 probable and 1 contributory (2001), 6 probable and 1 contributory (2002). The frequency of distribution for analyst M is: 3 probable and 2 contributory (1996), 4 probable and 5 contributory (1997), 6 probable and 6 contributory (1998), 10 probable and 0 contributory (1999), 4 probable and 3 contributory (2000), 1 probable and 1 contributory (2001), 5 probable and 2 contributory (2002). The peak in 1999 is due largely to A99Q0151, mentioned earlier. There are also relatively high levels of human error identified during 1998 and 2002. 2002 was similar to 1999, with a single incident documented as A02F0069 producing several different forms of human error. In contrast, several different explain the rise in 1998 reports each with a small number of operator 'errors': A98Q0192, A98P0303, A98H0011, A98H0003, A98H0002, A98C0173, A98A0191, A98A0067. It is difficult to identify any trends that might characterize any change in the 'systemic view' over the 'person' approach to causal analysis, at least in terms of the distribution of human error between 1996 and 2002.

	1996		1997		1998		1999		2000		2001		2002		Total	
	J	M	J	M	J	M	J	M	J	M	J	M	J	M	J	M
Human Error	3(3)	3(3)	2(2)	4(3)	6(4)	6(6)	9(3)	10(4)	4(2)	4(2)	1	1	6(3)	5(3)	31(18)	33(22)
ATM Failure	0	0	2(2)	0	1	0	0	0	0	0	0	0	0	0	3(3)	0
Maintenance Problem	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1
Loading Error	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
Company Management	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
Regulation	0	0	0	0	2(2)	1	0	0	0	0	0	0	0	0	2(2)	1
Equipment Failure	1	1	1	2(2)	1	1	2(1)	0	0	0	0	0	0	0	5(4)	4(3)
Aircraft Design	0	0	0	0	2(1)	2(1)	0	0	0	0	0	0	0	0	2(1)	2(1)
Manufacturing	0	0	1	0	0	0	0	0	0	0	2(1)	0	0	0	3(2)	0
Environment	0	0	1	0	2(2)	2(2)	0	0	0	0	0	0	2(2)	1	5(5)	3(3)
Total	4(4)	4(4)	7(7)	6(5)	16(13)	12(9)	11(4)	10(4)	4(2)	4(2)	4(3)	2(2)	8(5)	6(4)	53	44

Table 1: Frequency of Probable Causes over Time, Analysts J & M. Parentheses represent number of different incidents, Canadian TSB.

	1996		1997		1998		1999		2000		2001		2002		Total	
	J	M	J	M	J	M	J	M	J	M	J	M	J	M	J	M
Human Error	1	2(2)	3(2)	5(2)	1	6(4)	0	0	1	3(1)	1	1	1	2(1)	8(7)	19(11)
ATM Failure	0	0	2(2)	0	1	0	0	0	0	0	0	0	0	0	3(3)	0
Maintenance Problem	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1(1)	0
Company Management	2(2)	2(2)	5(1)	12(3)	3(3)	5(4)	0	0	0	0	0	0	0	0	10(6)	19(9)
Regulation	0	0	3(2)	6(1)	0	2(2)	0	0	0	0	0	0	0	0	3(2)	8(3))
Equipment Failure	1	0	0	1	0	1	0	1	0	0	0	0	2(2)	2(2)	3(3)	5(5)
Aircraft Loading	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1(1)	0
Aircraft Design	0	1	2(1)	3(2)	1	6(3)	0	1	0	0	0	0	0	0	3(2)	11(6)
Manufacturing	0	2(1)	0	1	0	0	0	0	0	0	0	0	0	0	0	3(2)
Environment	0	0	1	4(2)	0	0	0	0	1	1	0	0	1	1	3(3)	6(4)
Total	4(4)	7(6)	17(10)	30(12)	7(7)	20(14)	0	2(2)	2(2)	4(2)	1(1)	1(1)	4(4)	5(4)	35	71

Table 2: Frequency of Contributory Causes over Time. Analysts J & M. Parentheses represent number of different incidents, Canadian TSB.

Although human error is still the most prominent causal and contributory factor in our study, it is important not to underestimate the frequency of managerial and regulatory failures. These issues play a greater role in the contributory factors than they do in probable causes. Managerial issues account for around 1% of all causes and 27% of contributory factors across both analysts. Regulatory issues account for 3% of all causes and 10% of all contributory factors. This not only provides insights into the practices and perspective of the TSB but for it also casts light on the two analysts who were involved in this exercise. Recall that the TSB reports do not distinguish between contributory factors and causes. Hence we were making qualitative judgements about those failures that should be assigned to each general classification. This analysis suggests that we were predisposed to view human error as a more salient probable cause than either managerial factors or regulatory failure.

Our results do also provide insights into the distribution of systemic issues within the causal and contributory factors between 1996 and 2002. All of the documents that were classified as describing these potential sources of failure come before 1999. From that year to 2002, neither analyst was able to identify any causes or contributory factors in managerial and regulatory failures. They did continue to find human causes, for instance analyst J found 6 instances of aircrew 'error' in 2002 while their colleague found 5. To summarise, it is difficult to discern any pattern that might indicate a rise in the 'systemic view' of failure. In contrast, the decline of managerial and regulatory issues in the TSB reports might indicate a decline in the prominence of this view.

Conclusions

When we began this analysis, we were keen to determine whether or not the 'systems' view of failure was having an impact on the output of accident investigations. Prominent investigators in both of the Canadian TSB [4] and the US NTSB [5] have argued that these factors must be considered when identifying the causes of adverse events. Our results have shown that the TSB do consider a wide range of causal and contributory factors in their reports. In particular, it seems clear that they have a long tradition of considering the regulatory and managerial precursors to adverse events. However, they do focus on the role of human error as a potential cause in most of the adverse events that they investigate. It also seems that the role of managerial and regulatory issues has declined in prominence in recent years. We would argue that it is *inaccurate* to assert, as some have, that: (1) the operator is always blamed, (2) most investigations stop as soon as they find someone to blame, or (3) organizational causes are usually ignored.

This paper has described an independent analysis of the primary and contributory causes of aviation accidents in Canada between 1996 and 2002. The purpose of the study was to assess the comparative frequency of a range of causal factors in the reporting of these adverse events. Our results suggest that the majority of these high consequence accidents were attributed to human error. A large number of reports also mentioned wider systemic issues, including the managerial and regulatory context of aviation operations. These issues are more likely to appear as contributory rather than primary causes in both sets of accident reports.

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