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Bayesian Inference and Aviation Accident Probability: Quantifying the Impact of Local Organisational Factors

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Organisational failure is at the root of many aircraft accidents. It can involve something as innocuous as a communication breakdown, or as innate as a toxic culture. It is a failure to recognise and repair deficiencies. In a safety critical industry, it is a failure to recognise vulnerabilities, and to maintain the safety management system. Based on data retrieved from the Australian Transport Safety Bureau (ATSB) and concentrating on a specific geographic area of low-capacity commercial air transport operations in the Far North Queensland (FNQ) region of Australia, this paper examines how local organisational factors can dramatically increase accident probability under certain conditions. Broad statistical data can be misleading, and this study proposes that a more localised perspective provides a more accurate summation of an operation's susceptibility to accidents and serious incidents. The study looked at all five fatal accidents that occurred in the region over a period of eleven years and compared the results with other serious incidents in the region, and also with the regional and national statistical data. The study found that it is possible to identify risk factors which are not apparent from broad statistical data. Bayes' theorem is used to quantify the findings, with the aim of providing a more accurate picture of organisational risk, and to consequently help to improve the safety of Part 135 commercial operations, particularly in remote areas.

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Introduction

It is a broadly held belief that human error (often interpreted as pilot error) is responsible for around eighty percent of aircraft accidents (Shappell et al., 2006), although the evidence for this figure is hard to find (Wróbel, 2021). Some would take the view that human error is involved in, and could be attributed to, all accidents in one way or another. However, neither of these perspectives contributes to improvements in safety. Safety management systems are structured on the principle of organisational safety, with several redundant layers of defences, or safety nets (Reason, 1990). So, when investigation reports highlight pilot error as a contributing or causal factor, they are simply targeting the final defensive layer, which is one of many that have already failed. It is true that organisational factors are sometimes exposed, but usually only in major investigations. So, when viewing the statistics, one comes away with the impression that pilot error is the main contributor, when it is merely one of several contributors. The prevalence of uncontrolled flight into terrain (UFIT), now called loss of control-inflight (LOC-I), and controlled flight into terrain (CFIT) accidents enhances the human error paradigm. Unfortunately, this approach has resulted in the plateauing of the accident rate (ATSB, 2020), and human factors initiatives have ceased to have any further effect. If a commercial flight has reached a situation in which simple human error can precipitate a disaster, then that is, by definition, an organisational failure (Reason, 1997). This study looked at statistical data from the ATSB, and five individual investigation reports of fatal accidents which occurred in the Far North Queensland (FNQ) region of Australia over an eleven-year period. This article asks the following research questions.

1. Have current accident causation models ceased to have an effect on the accident rate in Part 135 operations?
2. Would a more localised organisational perspective better identify true accident probability, and consequently lead to a further reduction in the accident rate?

The importance of reducing the accident rate is self-evident. However, in the geographic region with which this article is concerned (the Torres Strait and Cape York of FNQ), it is particularly relevant because, due to the remoteness, air transport is the primary available mode, and part of everyday life. For every fatal accident, there are several non-fatal ones, even more serious incidents, and a multitude of minor incidents, many of which can be stressful or even terrifying to passengers. Ultimately, technology will no doubt prove to be the most effective lever to lower the accident rate, as has been shown in Part 121 operations in Australia, and commercial jet transport operations worldwide. However, in the interim, identification and recognition of contributing factors at a local level will provide more relevant and effective information than can be gained from broad statistical data.

Theories and models of accident causation

Many models have been developed in an effort to categorise and describe the factors involved in accident causation. These include the Human Factors Analysis and Classification System (HFACS) (Shappell & Wiegmann, 2000), Systems Theoretic Accident Model and Process (STAMP) (Leveson et al., 2003), Causal Analysis Based on System Theory (CAST) (Stoop & Benner Jr, 2015), 24Model (Fu et al., 2020), and hybrid versions of the same (Lower et al., 2018). None of these models can reliably predict accidents. They provide a taxonomy for analytical and statistical purposes, but due to the inherent complexity and rarity of aviation accidents, the models are not capable of converting complex categorisations into useful predictive tools. The difficulty is compounded by the fact that organisational factors exist when accidents are circumvented, prevented, or do not develop at all. The factors that do promote normal conditions into dangerous situations and eventually into accidents are not readily apparent from statistical data or models, because they are local, not global, factors. Bayesian inference is ideally suited to such situations. Theories of causation have evolved from the concept of accident prone workers (Smiley, 1955) to the sequential domino theory (Heinrich, 1950), to the Swiss cheese organisational model (Reason, 1997), to non-linear complex systems. They all provide in-depth analysis, but there is yet no evidence of accident prevention (Grant et al., 2018). The ATSB, often considered a world-class exemplar of accident investigation, employs its own modified version of the Swiss cheese model, after having evaluated the highly regarded HFACS model (Bills et al., 2023), and finding it had limited scope as a predictive framework (ATSB, 2008).

History of accident prevention in aviation

By far, the biggest impetus to the reduction in the accident rate has come from technology, including such innovations as air traffic control systems, air navigation systems, GPS, terrain awareness warning systems (TAWS), flight management systems, flight control systems, information technology systems, metal fatigue management, power plant and airframe improvements (Geels, 2006; Hansman, 2005; Oster et al., 2013). The most important innovations designed to curb the human error rate are human factors training and crew resource management (CRM) training. If the statistics are correct, then there has been no significant decrease in that rate. As the overall accident rate has decreased significantly, and the relative influence of human error has remained relatively static, then it follows that human error accidents are being circumvented at the same rate as all other accidents, which implies that it is by something other than CRM or human factors training. That something can only be technology, which further implies that human error, although ubiquitous, does not carry the weight the statistics would have us believe. Consequently, the targeting of human error in the pursuit of accident prevention is misdirected.

The zero-accident asymptote

Whether or not one believes in the zero-accident paradigm, certain facts are inescapable. Most fatal and non-fatal accident rates in aviation have been decreasing for decades and many are generally plateaued close to the zero asymptote. This effect can be seen in other industries but does not necessarily occur in all industries (Bureau of Labor Statistics, 2023; NOPSEMA, 2019) . This implies that there are local factors involved (meaning specific to the region, industry, or sector). The fatal accident rate for Part 121 commercial air transport in the US has been zero or close to zero for many years (Source: NTSB). Australia has never had a fatal commercial jet transport accident in its history. There are many theories as to why we can virtually eliminate some accidents, but not all, including drift (Dekker, 2011), normalisation of deviance (Cullen & Wilcox, 2010), tipping points (O'Brien, 2020), and critical mass (Marwell & Oliver, 1993).

Post-accident patency of organisational factors

The most salient theme of investigations and inquests into organisational accidents is the juxtaposition of the patency of organisational failure prior to, and posterior to, the accident. That is, there is a collective incredulousness as to how the failures were not obvious in advance to all participants. How did they not see it coming? In fact, many people do (using human intuitive Bayesian inference), (Cosmides & Tooby, 1996; Stengård et al., 2022; Zhu et al., 2020), but the failures, for whatever reason, are not acted upon. An excellent example of this scenario can be seen in Accident 4 Appendix I of this document (ATSB Transport Safety Report No. 200501977) (Source: ATSB). This was the most serious accident to occur in the FNQ region, and the largest in Australia for decades. Consequently, there is a wealth of information which can be extracted from the ATSB report and the coroner's report (Office of the QLD State Coroner, 2007). The coroner accepted that it was a CFIT accident but questioned the paradox of why 'experienced competent pilots would engage in objectively dangerous flying' and surmised that the answer was massive organisational failure from the regulator all the way down to the crew. In hindsight, the failure was so bad, the accident was almost inevitable. Yet the company had operated under the same conditions for years without an accident. Frequentist probability would not have foreseen a problem, accident causation models did not see the problem, but even a cursory Bayesian inference would have detected a more accurate probability, based on regulatory, management, administrative, supervisory, maintenance, and training failures.

Containing organisational factors

It is apparent from the above example and many others that organisational failure can exist in an accident-free environment, at least temporarily, therefore failure is sometimes contained and sometimes not (Choo, 2008; Dekker, 2011). This has also been described as the common cause hypothesis (Heinrich et al., 1980; Thoroman et al., 2020). The factors that precipitate disasters, and convert normal operations into emergencies, are numerous, but they are local and specific to a particular operation at a particular time, and therefore cannot be predicted by global analysis methods. For Accident 4, statistically it is a CFIT occurrence in which the crew made a critical human error, however, that perspective will not prevent future accidents, and in fact, fifteen years later, on approach to the same aerodrome (albeit from the opposite direction), another fatal CFIT accident occurred (ATSB AO-2020-017), which on the surface displayed remarkable similarity to Accident 4, but upon investigation, had virtually nothing else in common (Source: ATSB). Yet, statistically, they are both CFIT due to crew error. The critical factor in both cases was the weather, which translated totally unrelated existing issues into fatal accidents. The prevailing view of the ATSB, the CASA, and the coroner (although there is some industry disagreement (FAA, 2023)) is that technology, specifically the mandatory installation of TAWS, would have prevented both accidents and saved twenty lives (ICAO, 2006). Bayesian inference would have seen this in advance.

Bayesian Networks in Accident Causation Analysis

Bayesian networks have been used to examine risk and probability in several aviation scenarios, such as mid-air collisions, runway overruns, pilot risk factors, crew performance and even flight delays (Arnaldo Valdés et al., 2018a; Arnaldo Valdés et al., 2018b; Chen & Huang, 2018; Wang & Gao, 2013; Wang et al., 2021; Zhang et al., 2023). However, all these studies are based on high-capacity commercial air transport sectors, where incident data is more available and more reliable than in the Part 135 sector, and in fact in at least one case the study relied on the Delphi technique to obtain a consensus of opinion from experts, with a subsequent admission of the possible subjectivity of data, which is quite acceptable for Bayesian inference. Therefore, this paper's suggestion that Bayesian inference can be used as an accident prevention tool is certainly not novel, however, the hypothesis that Part 135 organisations in remote areas can use the principle to determine accident probability more simply and more accurately than can be obtained with other methods, is a new and practical concept which could be implemented easily and cost-effectively based on statistical data, local knowledge and experience, and a consensus of expert opinion.

Methodology

This is a position paper that proposes a novel alternative approach to reducing the accident rate in Part 135 operations in regional and remote areas in Australia. These operations are characterized by low-technology single-pilot ageing aircraft, a lack of first-class aerodrome and navigation facilities, and small organisations with limited resources. All relevant statistical publications from the ATSB were manually searched in order to establish historical and current accident rates across all sectors and regions in Australia, specifically with relevance to the FNQ region which is highly representative of these types of operations. An eleven-year time period was chosen and the ATSB occurrence database was manually searched for all fatal commercial air transport accidents which occurred in the region over that period. Those investigation report summaries (verbatim) are contained, with links to the complete reports, in Appendix I. Summaries of two non-fatal accidents and one near miss are included for comparison purposes with links to the complete reports in Appendix II. The paper makes the point that incident reporting in Part 135 operations is largely unreliable as statistical data, and that causation and analysis models are also not effective for this sector. Simple Bayesian inference, combined with broad accident rate data and local expert knowledge based on experience, is then suggested as a method for predicting changes in true accident probability at a local organisational level. Specifically, for this region and time period, there were five fatal commercial air transport accidents. For one, the cause is uncertain, and for the other four, the investigation reports are sufficiently detailed such that two things are certain. They were all organisational accidents, and they would not have occurred in clear skies. Therefore, the simple Bayes example uses the likelihood of weather being involved in a fatal accident in that region over that period as the prior with a value of 0.8 (4 out of five).

Firstly, it is instructive to point out that the ATSB has changed its taxonomy over the years. For example, earlier reports will separate regular public transport (RPT) and general aviation (which included charter). Up to 2021, commercial air transport was divided into high-capacity air transport (both RPT and charter), low-capacity air transport (RPT), and charter. From 2021, it is Part 121 for large aeroplanes, and Part 135 for small aeroplanes. Also, in 2014 the Australian Bureau of Infrastructure, Transport, and Regional Economics (BITRE) adopted an ICAO standard of statistical classification, resulting in the ATSB reclassifying 320,000 occurrences from operation types to activity types (ATSB, 2020). In any case, despite the confusion and the difficulty of comparison, this has no effect on the validity of the following data, except that more than one taxonomy may be used. The data was retrieved manually from official ATSB statistical reports and summaries, and the accident reports were retrieved by a manual search of the ATSB database.

In 2004, the ATSB released a report covering VH registered civil aircraft general aviation fatal accidents in Australia for the period 1991 to 2000 (ATSB, 2004). The most telling statement in the report was that the small number of accidents and the tendency for annual fluctuations made it difficult to ascertain trends. Also, differences in methodological factors can cause variations in totals and rates. The report did find that about half of the accidents were attributed to UFIT, and about one third to CFIT. A discussion paper released in 2005 by the ATSB covering all civil aircraft in Australian airspace between 1990 and 2005 confirmed that the total number of fatal accidents had decreased over that period (ATSB, 2005a). However, the general aviation accident rate decrease was not found to be statistically significant. In 2006, the ATSB published a report on the prevalence of CFIT accidents in Australia covering the period from 1996 to 2005 (ATSB, 2006b). The conclusions were that CFIT accidents are rare yet extremely dangerous. They almost always occur in hilly or mountainous terrain. They can however occur in flat terrain and in conditions of clear visibility, under the visual flight rules (VFR) and instrument flight rules (IFR), fixed wing and rotary wing, by day and by night, but mostly on approach to land. They are most common in general aviation, which for this report, included charter. The one conclusion that can be drawn is that under the combined conditions of difficult terrain, on approach to land, and at night or in instrument meteorological conditions (IMC), and in low technology aircraft, the likelihood of a CFIT accident increases. In 2006, the ATSB published a report which was designed to identify the relative safety levels of the geographic area of FNQ compared to other areas in the state and the nation (ATSB, 2006a). The report covered the period from 1990 to 2005, and concluded that there was no identifiable statistical difference, and in part this was due to the low fatal accident rate in Australia, but also that the trends were quite comparable across the regions and the country. This report did not look at accident types, but rather at categories of operation, and included only aircraft with a maximum take-off weight (MTOW) below 11,000 kg, which covered some low-capacity RPT, charter, aerial work, flying training, and ferry. What the report did show was that the fatal accident rates reflected the types of operations which were most commonly conducted in each particular geographic area. For example, in the densely populated areas of the south of Queensland, where light aircraft charter is relatively rare, most accidents occur in the private and business category. In FNQ, where charter is an important and sizeable sector, most fatal accidents occur in that category. In FNQ, 47.1 % of accidents were in the charter category, and in South Queensland 72.3% were in the private/business category. These trends are seen throughout the country. So, despite the differing types of operations, the fatal accident rates per 100,000 landings are relatively similar. The authors also stated that even the geographical location of the accident could be statistically misleading because some flights crossed boundaries, and some events (such as pilot incapacitation) had no relevance to location. So, despite the large geographic area of Australia, the varying topography, and the diversity of its population, the only statistical inference that emerged was that the accident rate has decreased and is now basically static, and safety levels are the same across the country, with one caveat. You are more likely to see private pilots involved in accidents in populated areas, and more likely to see professional charter pilots involved in accidents in remote areas, simply because there are more of them. This report is a thorough statistical analysis, covering a fifteen-year period, yet the authors were unable to make any significant inferences relating to the research question.

Summary of ATSB data

All of these reports more or less support the industry belief that the overall accident rate has been decreasing and has now plateaued. But the statistical significance is low. And the high capacity air transport sector has seen the biggest improvement, whereas the general aviation sector has not shared in that improvement. The data shows that certain types of accidents are more likely to be fatal, particularly CFIT and UFIT. There is also support for the hypothesis that input data is variable and dependent on several factors which may distort the results. For example, there is no satisfactory way of accurately gauging the relative significance of contributing factors. Many of the actual investigation reports are no more enlightening. What can be said with some certainty is that accident probability is contextual and dependent on localised factors. Based on the continued prevalence and fatality rates of UFIT and CFIT accidents, we can also say that serviceable aircraft operating in flat terrain and clear skies are extremely safe in comparison to aircraft operating with lower maintenance standards, in difficult terrain, and in poor weather conditions, which includes reduced visibility, low cloud, rain, and night operations. And that is exactly what we should expect. The greater the difficulty, the greater the risk, and the higher the accident rate.

Accident probability - the influence of weather, technology, and terrain
(See Appendix II for links to ATSB complete reports)

In 2007, near Warraber Island in the Torres Strait (FNQ), a Cherokee Six ditched in the sea following an engine failure, the cause of which is unknown, as the aircraft was not recovered. The pilot and three passengers survived with minor injuries, due in large part to the millpond conditions at the time, and the availability of a rescue helicopter service on nearby Horn Island (Source: ATSB). In 2010, in the Torres Strait, near Horn Island, a Cessna Caravan operating RPT and a Britten-Norman Islander operating charter, passed within fifty metres of each other in cloud. All up, there were twenty-one people on board the two aircraft (Source: ATSB). It could have been one of the biggest accidents in Australia's history. There were no findings or recommendations. Statistically it is an airprox serious incident and has had no impact on the safety paradigm. Near misses continue but most go unreported. Often the pilots are not even aware, due to poor weather conditions (characteristic of this geographic area), and lack of new technology (characteristic of these sectors of the industry). In 2022, a Britten-Norman Islander conducted a forced landing onto a road on Moa Island in the Torres Strait due to fuel starvation. There were six school children on board. The aircraft crashed and the tail separated from the fuselage. Incredibly, there were no serious injuries (Source: ATSB). Fortunately for the occupants, the weather was benign. Each of these occurrences could easily have translated to fatal accidents, but for simple good fortune. However, the statistics do nothing to highlight the real problem, or prevent future repetition. In each case, the finger is pointed at human (including pilot and engineering) error, implying that proper behaviour would have prevented each occurrence. However, this fails to account for the fact that these errors are happening quite regularly, but usually they are captured by other defences. They are all essentially organisational or systemic occurrences, and in the interests of safety, should be viewed that way. At least one operator did. In 2022, near Mount Disappointment in Victoria, a VFR helicopter encountered IMC, attempted to conduct a U-turn, and collided with terrain, with all five occupants fatally injured. The primary cause was identified as pilot error and categorised as VFR into IMC, despite the fact that the standby artificial horizon was not working, and the operator had identified poor weather conditions as a risk. However, the operator subsequently drafted a dedicated risk assessment policy to guard against such accidents, upgraded the fleet with synthetic vision and terrain alerting functionality, and helicopter flight control systems. The operator realised that technology would be the best defence against future similar accidents (Source: ATSB).

According to the ATSB, despite decades of research by aviation professionals and human factors researchers, general aviation weather-related accidents remain a significant cause for concern (ATSB, 2005b). Even as late as 2022, a US study has reported that 'interpreting and categorising narrative data sources into standard categories with minimal bias is difficult because of subjectivity' (Long, 2022). The author further concludes that there is a disconnect between NTSB accident reports and NASA's aviation safety reporting system (ASRS) incident reports. The use of on-board weather equipment is rarely mentioned by either, however accidents involving such equipment resulted in very few injuries, and when fatalities did occur, there was no mention of the same equipment.

Summary of all five fatal commercial transport accidents between 2000 and 2011 in FNQ
(See Appendix I for ATSB investigation report synopses (verbatim) and links to complete reports)

The ATSB report discussed earlier, which sought to compare FNQ with other geographical areas, lists a total of seventeen fatal accidents in FNQ over the fifteen year period from 1990 to 2005 (ATSB, 2006a). However, the reports in general are not comprehensive, for many the cause is undetermined, the investigator did not attend all of the accidents, and there are some misleading categorisations. For example, a charter aircraft that crashed on takeoff is listed as private/business because it was a prelude to a training flight, and another charter aircraft is listed as ferry/positioning because it was enroute for fifteen minutes to pick up some passengers. These statistical nuances unfortunately skew the data and belie its usefulness. According to a report published in 2009, over the period 1998 to 2007, there were 24 fatal passenger transport category accidents in the whole of Australia (ATSB, 2009). This study examines five fatal commercial transport category accidents which occurred within the FNQ region over the period 2000 to 2011, which in relative terms, is representative, and as far as the author is aware, it is exhaustive. For comparison purposes, over the period 1990 to 2005, FNQ in all sectors recorded seventeen fatal accidents out of an Australia-wide total of 318 (ATSB, 2006a). The five events over this period are chosen because the reports are comprehensive, they span the entire region, and they are complex and reasonably transparent occurrences which exhibit a variety of contributing factors. They are representative of the issues involved in commercial aviation in remote areas in general, and FNQ in particular.

As this list is exhaustive for commercial transport operations over an eleven year time period in a particular geographic region, we can immediately draw some conclusions. (Source: ATSB). Firstly, the probability of a fatal commercial accident in good weather in this region is almost zero. Four of the five accidents almost certainly would not have happened in clear skies. The cause of the fifth is uncertain. Three of the accidents involved collision with water, and two involved collision with mountainous terrain. All of the aircraft were old technology. None had TAWS or synthetic vision. Four were single pilot. One had two crew, but the first officer (FO) was not properly qualified. Two were operating VFR and entered IMC. Three were operating IFR. Four were on approach to land, and one was in cruise. Four were operating in extremely difficult conditions. An interesting fact is that four of the aircraft were transiting the area, while the other was piloted by a very inexperienced novice. Therefore, the probability of an experienced pilot domiciled in the area being involved in a fatal accident is statistically zero, at least for this period. So, it is clear by now that in combination, such things as weather, inexperience, outdated technology, terrain, and reduced familiarity or recency, can be fatal. Organisational failure is what allows these situations to develop. The insidious nature of how this happens can be gleaned from some of the investigation reports. None of these insights will be uncovered by national statistics, however they are local factors that are well known to local operators. An experienced pilot knows when a flight is starting to be compromised. Bayes' theorem provides a mathematical system, (albeit sometimes based on subjective inputs because statistics, as stated previously, are not completely reliable), that is capable of providing a graphical representation of accident probability.

Organisational factors and organisational failure

Organisational factors are those inputs which influence the safety of a flight prior to the hangar floor and the flight line. They are also described as latent conditions (Reason, 1997). They can be both positive and negative, and can stem from legislative, regulatory, management, commercial, operational, and supervisory influences. Some are general to the industry, and some are specific to an operator. Some are cultural, whilst others may be fleeting, dependent on current organisational climate. Organisational failure is that situation in which latent conditions have breached defensive layers and subsequently compromised the safety system to the point where flights are operating without the protection of redundant layers of safety (Reason, 1997). Quite often, such a situation is not obvious to all participants, and organisations would be much better equipped to deal with reductions in safety levels if they were able to have a visual representation of how risk is affected by changing conditions, both internal and external. Bayes theorem is able to demonstrate how accident probability changes, and that allows organisations to adapt their safety management systems to flag such risk, and to make the necessary changes that will maintain the safety nets in place.

Using Bayesian Inference

The common criticism that Bayesian probability receives is that it is based on subjective data. However, statistical data can be broad-based, subjective, irrelevant, contradictory, and less than reliable. Outcomes-based frequentist probabilistic evidence, when considering localised rather than generalised events, is of less value than local knowledge, experience, and anecdotal evidence. There is also evidence that in some cases, accident rates are deterministic, rather than probabilistic, because some operators have much better safety records than others operating similar aircraft (ATSB, 2018) . Different engine types can exhibit similar disparities in occurrence rates. Between the years 2012 to 2016, there were 417 reported occurrences of turboprop powered aircraft power plant events (ATSB, 2018). Only three were categorised high risk, and they were all Cessna 208 aircraft which conducted forced or precautionary landings. There were only five Cessna 208 occurrences in total out of the 417 that were reported. Most incident reports come from high capacity aircraft operations, yet most accidents occur in the smaller aircraft categories. None of the events occurred in FNQ where two relatively large operators are located. In fact, despite the fact that the C208 is a single engine aircraft operating in a difficult environment in FNQ (RPT island hopping saltwater operations into very short runways with a five month rainy season), over a fifteen year period to 2023, aside from an airprox, there had not been one serious incident recorded (Source: ATSB). The variations in occurrence rates which can be geographical, temporal, or organisational, support the notion of localised data, and Bayesian inference is ideally suited to this methodology of determining risk and probability (Xu, 2023).

This is a simple example of how an organisation can use Bayesian principles to examine risk. As stated previously, over an eleven year period in FNQ, there were five fatal commercial air transport accidents, at least four of which would not have occurred in clear skies. Therefore, the probability of weather being involved in a fatal accident is 0.8. Using Bureau of Meteorology data (which can also be combined with local knowledge), over a twenty-seven year period, the weather station on Horn Island (the hub of remote operations in the Torres Strait in FNQ) recorded an annual mean of 24 days in which rainfall exceeded 25mm (Bureau of Meteorology, 2024). This is considered representative of a day of low cloud and poor visibility due to rain. Therefore 24 out of 365 days equates to 0.07 (the chance of a poor weather day). If the overall statistical probability of a transport category accident is one in 100,000 (this figure is arbitrary because what the equation shows is how probability is multiplied), which is 0.00001, then this is the result.

$$P(A|B) = (P(B|A) * P(A))/P(B)$$

Probability of an accident given poor weather is equal to 0.8 * 0.00001 / 0.07 which equals 0.0001. So, probability has increased ten times. Multiple risk factors can be entered in the equation if they occur simultaneously. An organisation with a good safety management system should be able to identify their own risks and develop their own probability rates.

Quantifying organisational factors

When the STAMP model was introduced, the author recalled studies that found that management commitment to safety, and safety culture in general, were the most important factors in accident causation, and that the collection and analysis of massive amounts of data does in no way guarantee success in determining system safety (Leveson, 2004). Leveson's boundaries of safe behaviour are dependent on correctly identifying risk and probability, but although the principle is transferrable across sectors and organisations, the risk factors are not, as they are not generic, but rather specific to those sectors and organisations. Quantifying the impact of organisational failure on accident probability is a difficult task. There is no doubt that a toxic culture has a negative effect on safety, but the effect is not measurable. Tracing human error back to a toxic culture post-accident may help explain what happened but does nothing to prevent future accidents. However, the Bayesian principle of updating beliefs based on new information is still applicable, as is illustrated in the following diagram and tables. The information can be used to forecast increased accident probability of individual flights, based on past events, statistical data, and expert local knowledge. Figure 1 is a representation of the relationship between organisational failures and measurable factors.

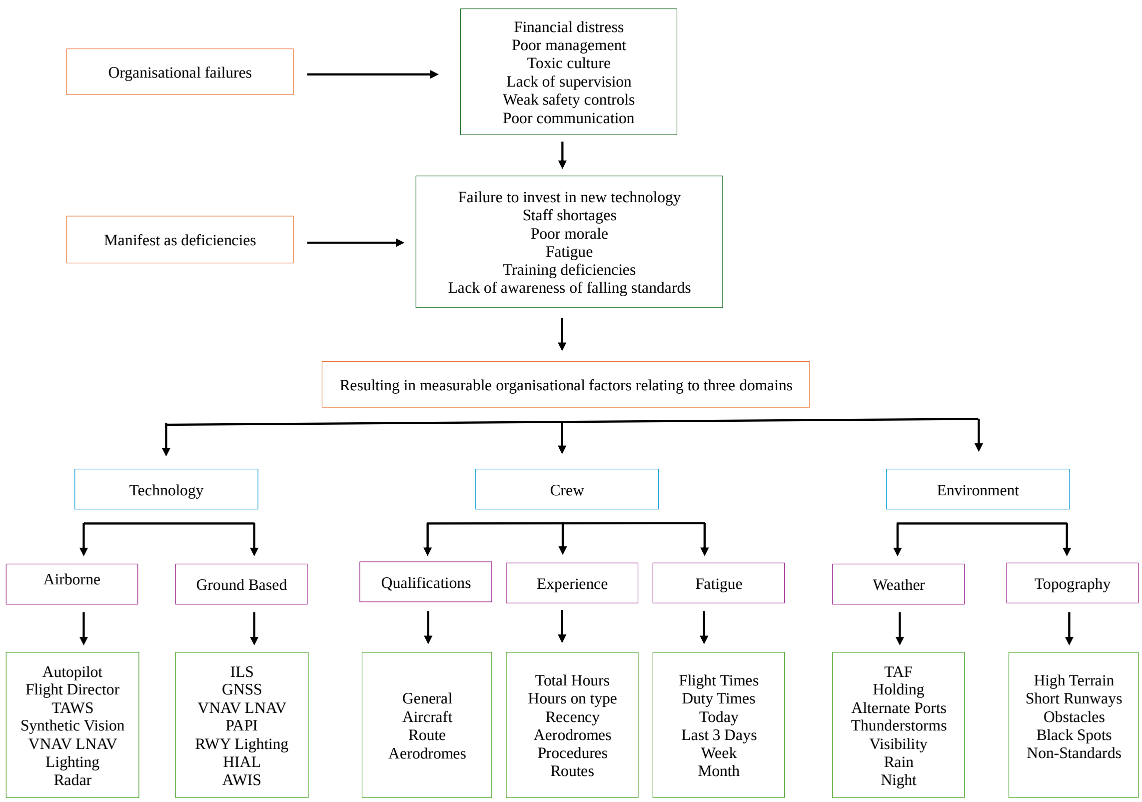

Figure 1: Measuring Organisational Failure

Table 1 shows that for four of the accidents, at least six of the seven categories of potential contributing factors (which resulted from organisational failures), were in fact easily identifiable before the flights departed, noting that the cause of Accident 2 is uncertain. Of course, some factors, such as topography, weather, and ground based technology are outside the control of the operator, however it is the failure to recognise, prepare and adjust for these factors, rather than the factors themselves, that is the cause of increased accident probability.

	Airborne Technology	Ground Based Technology	Crew Qualifications	Crew Experience	Crew Fatigue	Weather	Topography
A1	X	N/A	X	X	X	X	X
A2	X	N/A	OK	OK	OK	OK	OK
A3	X	X	X	X	OK	X	X
A4	X	X	X	X	OK	X	X
A5	X	X	X	X	X	X	X

Table 1: Category Failures for the Five Accidents

These factors can be quantified using numerical data similar to that represented in tables 2, 3 and 4, but which is relevant to the particular operation. In this case, the lower the score, the higher is the accident probability. These tables relate directly to the categories in Table 1. It is then apparent how the cumulative effect of low technology aircraft, difficult environmental conditions, and crew deficiencies is the driving force behind increased accident probability.

	Terrain	Obstacles	Runway	Lighting	Circuit	Approach	WX Aids	Total Score
	High (1) Medium (2) Low (3)	High (1) Medium (2) Low (3)	Short (1) Medium (2) Long (3)	RWY (1) Centre (2) PAPI (3)	Black Hole (1) Right Turn (2) Standard (3)	Visual (1) GNSS (2) AVG (3)	Nil (1) AWIS (2) TAF (3)	
A1	1	1	3	3	3	1	3	15
A2	1	1	3	3	3	2	1	14
A3	2	2	3	1	2	1	1	12
A4	1	1	3	1	3	2	1	12
A5	2	2	3	1	3	1	1	13

Table 2: Aerodrome Criteria for the Five Accidents

	Autopilot	TAWS	Synthetic Vision	Flight Director	Approach	TCAS	Radar	Total Score
	Nil (1) 3-Axis (2) Approach (3)	Nil (1) GPWS (2) EGPWS (3)	Nil (1) SVS (2) EVS (3)	Nil (1) Analog (2) Digital (3)	LNAV (1) AVG (2) AVG x2 (3)	Nil (1) TAS (2) TCAS (3)	ADSB (1) ALT (2) WX (3)	
A1	1	1	1	1	1	1	1	7
A2	2	1	1	1	1	1	1	8
A3	1	1	1	1	1	1	1	7
A4	1	1	1	1	1	1	1	7
A5	2	1	1	1	1	1	1	8

Table 3: Aircraft Equipment for the Five Accidents

	Approvals	Total Time	Fatigue	Type Recency	Aerodrome Recency	Approach Recency	Night Recency	Total Score
	Minimum (1) Complete (2) Trainer (3)	1000 (1) 1500 (2) 2000 (3)	Red (1) Yellow (2) Green (3)	6 Months (1) 3 Months (2) 30 Days (3)	6 Months (1) 3 Months (2) 30 Days (3)	6 Months (1) 3 Months (2) 30 Days (3)	6 Months (1) 3 Months (2) 30 Days (3)	
A1	3	3	1	1	1	3	1	13
A2	3	3	3	3	1	3	2	18
A3	1	1	3	2	3	1	1	12
A4	1	2	2	1	2	1	1	10
A5	3	3	1	3	2	1	1	14

Table 4: Pilot Factors for the Five Accidents

Discussion

The problem with discerning accurate information from aviation statistics is borne out by these findings from the ATSB. In 2012, the Bureau estimated that at least forty percent of aviation wire strikes are unreported (ATSB, 2012). They later found that over a ten year period up to 2019, ninety percent of all accidents and fatal accidents, and eighty percent of serious incidents occurred in the general aviation and recreational sectors, yet seventy-five percent of reported incidents were from the commercial air transport sector. This tends to indicate that the integrity of incident reporting is somewhat suspect (ATSB, 2020). Unfortunately, none of the ATSB research and analysis reports provide strong statistical information that would warrant an intervention that could confidently be expected to make a significant difference to safety. The accident rates are too low, the trends are too variable, and the data upon which they are based is lacking in accuracy. Both UFIT and CFIT accidents, which represent the largest accident types, are too general and lack specificity when looking to narrow the target area of causation. Hence the industry is reduced to warning operators of these dangers rather than eliminating them. Yet the combined direct causes of UFIT and CFIT accidents could roughly be categorised as mechanical failure, operator error, and environmental influence (ATSB, 2004). The one thing which has historically provided the greatest bulwark against all three is technology (despite the inherent risks of automation). That is why small aircraft are most susceptible to these accidents. They operate in the most difficult environment, and they lack the technology. The statistics do not accurately describe what is happening in all sectors other than high capacity commercial air transport, and in fact they paint a picture that is misleading and misdirecting of resources.

Limitations and Future Research

The use of Bayesian networks to establish causal relationships, risk, and probability is not new. However, there does not seem to be any evidence that models such as HFACS, STAMP, CAST, and others actually contribute to reducing the accident rate, particularly in Part 135 operations. A qualitative analysis of a single accident investigation report combined with a coroner’s report (as in Accident 4), yields far more relevant information than a Bayesian network diagram or a quantitative analysis by any of the available models. In fact, the authors of the STAMP/HFACS taxonomy conclude as much (Lower et al., 2018). They are complex descriptive tools but there is little evidence of their predictive or preventive capacity (Grant et al., 2018). The Bayesian inference method proposed is deliberately simplistic in order to be a useful practical tool which can be updated on a regular basis. This paper focused on Part 135 small aircraft operations in a remote geographic area with a single contributing factor, that being weather, in order to illustrate the basic concept, but there is no reason that the same principle cannot be applied just as easily to other organisational factors, such as staff shortages, training deficiencies, maintenance difficulties, and commercial imperatives, all of which have been proven to affect safety.

Conclusion

The statistics show that overall, aviation in Australia is very safe, but they also show that as aircraft size decreases, and aircraft age increases, accident probability increases. High capacity operations in Australia bear no resemblance to charter operations in remote areas. The statistics, if read carefully, do provide evidence that commercial operations in remote areas are susceptible to certain factors which can dramatically increase true probability. These factors are weather, lack of technology, and difficulty of operations. At present, the emphasis is constantly on human error and human factors, but future safety initiatives should target organisational factors. Aviation infrastructure in remote areas needs to be updated. Longer runways, better navigation aids, runway approach lighting, newer aircraft with better performance and on-board technology, and better maintenance facilities are the things that will make an appreciable difference to safety. In the interim, the best we can do is at least to recognise what are the true causal or contributory factors, rather than just the most direct or salient ones. This will allow operators to build a graphical representation of true accident probability by identifying those factors to which they are most susceptible. Bayes' theorem allows us to do precisely that by updating beliefs based on objective data from the statistics and subjective information based on knowledge and experience which is inherent in every organisation. Viewing probability purely as a function of statistical data is not a realistic approach. Subjective, even anecdotal, local knowledge is more directly relevant. Supervisors, pilots, and engineers have a greater awareness of the challenges facing an organisation than can be derived from statistics. They are intuitively cognisant of situations in which a flight is becoming compromised through the compound effect of multiple factors. Deriving solutions from statistics is a top-down approach that is no longer providing gains. Many substantial safety improvements in aviation have stemmed directly from single accidents, or series of accidents. This is a bottom-up approach that has worked. Viewing accident probability from a local level should be a part of organisational risk management for small operators. A simple approach using Bayes' theorem is a suitable method. Although this paper has focused on the impact of the most salient factor identified in the study, that being weather, it is important to state that weather is of course a normal part of aviation. Although not normally defined as such, weather is an organisational factor if it affects the safety of a particular organisation's operation. Four of these accidents involved serious organisational failures which exacerbated the influence of weather. In combination with organisational failures, such as deficiencies in training, maintenance, and communication, weather, particularly in remote operations, can become critical. Future research could look at defining how traditional organisational factors can be quantified for the purpose of identifying and preempting changes in accident probability.

Appendix I

Fatal commercial air transport accidents FNQ region 2000 - 2011 (Source: ATSB)

Accident 1 03 August 2000 ATSB Transport Safety Report No. 200003233
https://www.atsb.gov.au/publications/investigation_reports/2000/aair/aair200003233

The pilot departed Margaret Bay later than planned without the certainty that the flight could be completed in the required daylight conditions. The pilot continued flight in weather conditions for which he was not currently qualified. The pilot continued flight in weather conditions for which the aircraft was not adequately equipped. The pilot, after receiving radar navigation assistance, was unable to see the runway lights. The pilot possibly experienced spatial disorientation and loss of control while maneuvering the aircraft in darkness and poor weather without adequate visual cues.

Accident 2 10 April 2001 ATSB Transport Safety Report No. 200101537
https://www.atsb.gov.au/publications/investigation_reports/2001/aair/aair200101537

Radar data recorded by Air Traffic Services and witness reports indicated that the aircraft was flying straight and level and maintaining a constant airspeed. Therefore, it is unlikely that the aircraft was experiencing any instrumentation or engine problems. Why the pilot continued flight into marginal weather conditions at an altitude that was insufficient to ensure terrain clearance, could not be established.

Accident 3 11 January 2002 ATSB Transport Safety Report No. 200200035
https://www.atsb.gov.au/publications/investigation_reports/2002/aair/aair200200035

Weather conditions at Horn Island aerodrome were less than visual meteorological conditions at the time of the occurrence. The pilot was not current for flight in IMC. The pilot lost control of the aircraft at an altitude from which recovery was not considered possible.

Accident 4 07 May 2005 ATSB Transport Safety Report No. 200501977
https://www.atsb.gov.au/publications/investigation_reports/2005/aair/aair200501977

On 7 May 2005, a Fairchild Aircraft Inc. SA227-DC Metro 23 aircraft, registered VH-TFU, with two pilots and 13 passengers, was being operated by Transair on an instrument flight rules regular public transport service from Bamaga to Cairns, with an intermediate stop at Lockhart River, Queensland. At 1143:39 Eastern Standard Time, the aircraft impacted terrain in the Iron Range National Park on the north-western slope of South Pap, a heavily timbered ridge, approximately 11 km north-west of the Lockhart River aerodrome. At the time of the accident, the crew was conducting an area navigation global navigation satellite system (RNAV (GNSS)) non-precision approach to runway 12. The aircraft was destroyed by the impact forces and an intense, fuel-fed, post-impact fire. There were no survivors. The accident was almost certainly the result of controlled flight into terrain, that is, an airworthy aircraft under the control of the flight crew was flown unintentionally into terrain, probably with no prior awareness by the crew of the aircraft's proximity to terrain. The investigation report identifies a range of contributing and other safety factors relating to the crew of the aircraft, Transair's processes, regulatory oversight of Transair by the Civil Aviation Safety Authority, and RNAV (GNSS) approach design and chart presentation.

Accident 5 24 February 2011 ATSB Transport Safety Report No. AO-2011-033
https://www.atsb.gov.au/publications/investigation_reports/2011/aair/ao-2011-033

At 0445 Eastern Standard Time on 24 February 2011, the pilot of an Aero Commander 500S, registered VH-WZU, commenced a freight charter flight from Cairns to Horn Island, Queensland under the instrument flight rules. The aircraft arrived in the Horn Island area at about 0720 and the pilot advised air traffic control that he intended holding east of the island due to low cloud and rain. At about 0750 he advised pilots in the area that he was north of Horn Island and was intending to commence a visual approach. When the aircraft did not arrive, a search was commenced but the pilot and aircraft were not found. On about 10 October 2011, the wreckage was located on the seabed about 26 km north-north-west of Horn Island.

Appendix II

Other accidents and serious incidents detailed in the study

Cherokee ditching near Warraber Island
https://www.atsb.gov.au/publications/investigation_reports/2007/aair/ao-2007-007

Near mid-air collision C208 and BN2 near Horn Island
https://www.atsb.gov.au/publications/investigation_reports/2010/aair/ao-2010-022

Forced landing BN2 Moa Island
https://www.atsb.gov.au/publications/investigation_reports/2022/aair/ao-2022-046

Helicopter CFIT Mount Disappointment
https://www.atsb.gov.au/publications/investigation_reports/2022/aair/ao-2022-016

References

Arnaldo Valdés, R. M., Gómez Comendador, V. F., Perez Sanz, L., & Rodriguez Sanz, A. (2018a). Prediction of aircraft safety incidents using Bayesian inference and hierarchical structures. *Safety Science*, *104*, 216-230. https://doi.org/10.1016/j.ssci.2018.01.008

Arnaldo Valdés, R. M., Liang Cheng, S. Z. Y., Gómez Comendador, V. F., & Sáez Nieto, F. J. (2018b). Application of Bayesian Networks and Information Theory to Estimate the Occurrence of Mid-Air Collisions Based on Accident Precursors. *Entropy (Basel)*, *20*(12). https://doi.org/10.3390/e20120969

ATSB. (2004). *Aviation Research Paper B2004/0010. General Aviation Fatal Accidents: How Do They Happen? A Review of General Aviation Fatal Accidents 1991 to 2000*. https://www.atsb.gov.au/sites/default/files/media/36723/Fatal_accidents_how_happen.pdf

ATSB. (2005a). *Analysis of Fatality Trends Involving Civil Aviation Aircraft in Australian Airspace Between 1990 and 2005 B2005/0388*. https://www.atsb.gov.au/sites/default/files/media/36453/Research_Fatality_Tr.pdf

ATSB. (2005b). *General Aviation Pilot Behaviours in the Face of Adverse Weather*. https://www.atsb.gov.au/sites/default/files/media/36438/Pilot_behaviours_adv.pdf

ATSB. (2006a). *Fatal Aircraft Accidents: Far North Queensland in Context* (ATSB Transport Safety Research Report B2006/0034, Issue. https://www.atsb.gov.au/publications/2006/b20060034

ATSB. (2006b). *Aviation Research and Analysis Report - B2006/0352 Final. CFIT: Australia in Context 1996 to 2005*. https://www.atsb.gov.au/sites/default/files/media/29968/b20060352.pdf

ATSB. (2008). *Evaluation of the Human Factors Analysis and Classification System as a Predictive Model AR-2008-036*. https://www.atsb.gov.au/sites/default/files/media/3536263/ar2008036.pdf

ATSB. (2009). *Australian Aviation Safety in Review: 1998 to 2007*. https://www.atsb.gov.au/publications/2009/ar2008079

ATSB. (2012). *Under Reporting of Aviation Wirestrikes*. https://www.atsb.gov.au/sites/default/files/media/3920552/ar-2011-004_final.pdf

ATSB. (2018). *Power plant failures in turboprop-powered aircraft*. https://www.atsb.gov.au/sites/default/files/media/5774415/ar-2017-017-final.pdf

ATSB. (2020). *Aviation Occurrence Statistics (Rates Update) 2010 to 2019*. https://www.atsb.gov.au/sites/default/files/media/5778822/ar-2020-047_final.pdf

Bills, K., Costello, L., & Cattani, M. (2023). Major aviation accident investigation methodologies used by ITSA members. *Safety Science*, *168*, 106315. https://doi.org/10.1016/j.ssci.2023.106315

Bureau of Labor Statistics. (2023). *National Census of Fatal Occupation Injuries 2022*. https://www.bls.gov/news.release/pdf/cfoi.pdf

Bureau of Meteorology. (2024). *Climate Statistics - Horn Island*. http://www.bom.gov.au/climate/averages/tables/cw_027058_All.shtml

Chen, W., & Huang, S. (2018). Evaluating Flight Crew Performance by a Bayesian Network Model. *Entropy*, *20*. https://doi.org/10.3390/e20030178

Choo, C. (2008). Organizational disasters: Why they happen and how they may be prevented. *Management Decision*, *46*, 32-45. https://doi.org/10.1108/00251740810846725

Cosmides, L., & Tooby, J. (1996). Are humans good intuitive statisticians after all? Rethinking some conclusions from the literature on judgment under uncertainty. *Cognition*, *58*(1), 1-73. https://doi.org/10.1016/0010-0277(95)00664-8

Cullen, F., & Wilcox, P. (2010). Encyclopedia of Criminological Theory. In. SAGE Publications, Inc. https://doi.org/10.4135/9781412959193

Dekker, S. (2011). *Drift into Failure: From Hunting Broken Components to Understanding Complex Systems* (1 ed.). CRC Press. https://doi.org/10.1201/9781315257396

FAA. (2023). *Terrain Awareness and Warning (TAWS) Nuisance Alerts*. https://www.faa.gov/other_visit/aviation_industry/airline_operators/airline_safety/info/all_infos/info23003

Fu, G., Xie, X., Jia, Q., Li, Z., Chen, P., & Ge, Y. (2020). The development history of accident causation models in the past 100 years: 24Model, a more modern accident causation model. *Process Safety and Environmental Protection*, *134*, 47-82. https://doi.org/10.1016/j.psep.2019.11.027

Geels, F. W. (2006). Co-evolutionary and multi-level dynamics in transitions: The transformation of aviation systems and the shift from propeller to turbojet (1930–1970). *Technovation*, *26*(9), 999-1016. https://doi.org/10.1016/j.technovation.2005.08.010

Grant, E., Salmon, P. M., Stevens, N. J., Goode, N., & Read, G. J. (2018). Back to the future: What do accident causation models tell us about accident prediction? *Safety Science*, *104*, 99-109. https://doi.org/10.1016/j.ssci.2017.12.018

Hansman, R. (2005). The Impact of Information Technologies on Air Transportation. In *43rd AIAA Aerospace Sciences Meeting and Exhibit*. American Institute of Aeronautics and Astronautics. https://doi.org/10.2514/6.2005-1

Heinrich, H. W. (1950). *Industrial accident prevention : a scientific approach* (1st ed.). McGraw-Hill.

Heinrich, H. W., Petersen, D., Roos, N. R., Brown, J., & Hazlett, S. (1980). *Industrial accident prevention : a safety management approach* (5th ed.). McGraw-Hill.

ICAO. (2006). *Celebrating TAWS Saves: But Lessons Still to be Learnt*. https://www.icao.int/safety/fsix/Library/TAWS%20Saves%20plus%20add.pdf

Leveson, N. (2004). A new accident model for engineering safer systems. *Safety Science*, *42*(4), 237-270. https://doi.org/10.1016/S0925-7535(03)00047-X

Leveson, N., Daouk, M., Dulac, N., & Marais, K. (2003). Applying STAMP in accident analysis. *Workshop Investigation Reporting Incidents Accidents (IRIA)*.

Long, T. (2022). Analysis of Weather-Related Accident and Incident Data Associated with Section 14 CFR Part 91 Operations. *Collegiate aviation review*, *40*(1). https://doi.org/10.22488/okstate.22.100203

Lower, M., Magott, J., & Skorupski, J. (2018). A System-Theoretic Accident Model and Process with Human Factors Analysis and Classification System taxonomy. *Safety Science*, *110*, 393-410. https://doi.org/10.1016/j.ssci.2018.04.015

Marwell, G., & Oliver, P. (1993). *The Critical Mass in Collective Action*. Cambridge University Press. https://doi.org/DOI: 10.1017/CBO9780511663765

NOPSEMA. (2019). *Annual Offshore Performance Report: Safety and Environmental Performance of Australia's Offshore Petroleum Industry*. https://www.nopsema.gov.au/sites/default/files/documents/2021-03/A674653.pdf

O'Brien, E. (2020). When Small Signs of Change Add Up: The Psychology of Tipping Points. *Current Directions in Psychological Science*, *29*, 55-62. https://doi.org/10.1177/0963721419884313

Office of the QLD State Coroner. (2007). *Inquest into the Aircraft Crash at Lockhart River*. https://www.courts.qld.gov.au/__data/assets/pdf_file/0003/86682/cif-lockhart-river-aircrash-20070817.pdf

Oster, C. V., Strong, J. S., & Zorn, C. K. (2013). Analyzing aviation safety: Problems, challenges, opportunities. *Research in Transportation Economics*, *43*(1), 148-164. https://doi.org/10.1016/j.retrec.2012.12.001

Reason, J. (1990). *Human error*. Cambridge university press.

Reason, J. (1997). *Managing the Risks of Organizational Accidents* (1 ed.). Taylor & Francis. https://doi.org/10.4324/9781315543543

Shappell, S., Detwiler, C., Holcomb, K., Hackworth, C., Boquet, A., & Wiegmann, D. (2006). *Human Error and Commercial Aviation Accidents: A Comprehensive, Fine Grained Analysis Using HFACS*. https://commons.erau.edu/cgi/viewcontent.cgi?article=2315&context=publication

Shappell, S., & Wiegmann, D. (2000). The Human Factors Analysis and Classification System-HFACS. https://skybrary.aero/sites/default/files/bookshelf/1481.pdf

Smiley, J. A. (1955). A clinical study of a group of accident-prone workers. *Br J Ind Med*, *12*(4), 263-278. https://doi.org/10.1136/oem.12.4.263

Stengård, E., Juslin, P., & van den Berg, R. (2022). How Deep Is Your Bayesianism?—Peeling the Layers of the Intuitive Bayesian. *Decision*, *9*. https://doi.org/10.1037/dec0000186

Stoop, J., & Benner Jr, L. (2015). What do STAMP-based Analysts Expect from Safety Investigations? *Procedia Engineering*, *128*, 93-102. https://doi.org/10.1016/j.proeng.2015.11.508

Thoroman, B., Salmon, P., & Goode, N. (2020). Applying AcciMap to test the common cause hypothesis using aviation near misses. *Applied Ergonomics*, *87*, 103110. https://doi.org/10.1016/j.apergo.2020.103110

Wang, H., & Gao, J. (2013). Bayesian Network Assessment Method for Civil Aviation Safety Based on Flight Delays. *Mathematical Problems in Engineering*, *2013*, 1-12. https://doi.org/10.1155/2013/594187

Wang, Y., Pang, Y., Chen, O., Iyer, H., Dutta, P., Menon, P. K., & Liu, Y. (2021). Uncertainty quantification and reduction in aircraft trajectory prediction using Bayesian-Entropy information fusion. *Reliability Engineering & System Safety*, *212*, 107650. https://doi.org/10.1016/j.ress.2021.107650

Wróbel, K. (2021). Searching for the origins of the myth: 80% human error impact on maritime safety. *Reliability Engineering & System Safety*, *216*, 107942. https://doi.org/10.1016/j.ress.2021.107942

Xu, C. (2023). Application of Bayes Theorem to Accident Analysis and Classification. *Highlights in Science, Engineering and Technology*, *47*, 46-57. https://doi.org/10.54097/hset.v47i.8163

Zhang, C., Liu, C., Liu, H., Jiang, C., Fu, L., Wen, C., & Cao, W. (2023). Incorporation of Pilot Factors into Risk Analysis of Civil Aviation Accidents from 2008 to 2020: A Data-Driven Bayesian Network Approach. *Aerospace*, *10*(1), 9. https://doi.org/10.3390/aerospace10010009

Zhu, J.-Q., Sanborn, A. N., & Chater, N. (2020). The Bayesian sampler: Generic Bayesian inference causes incoherence in human probability judgments. *Psychological review*, *127*(5), 719.