MASTER’S DEGREE IN ORGANISATIONAL PSYCHOLOGY

An Exploration of General Aviation Occurrences in South Africa (2015-2017): Application of the Human Factors Analysis and Classification System using Bayes’ Theorem

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Declaration

I declare that this research project is my own, unaided work. It has not been submitted before for any other degree or examination at this or any other university.

S. Tshuma

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Signature of Researcher:

Date: 15 February 2025

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List of Abbreviations and Acronyms

AcciMap	Accident Analysis Mapping
AMO	Aircraft Maintenance Organisation
ATC	Air Traffic Controllers
ATHEANA	Technique for Human Error Analysis
CFIT	Controlled Flight into Terrain
CPL	Commercial Pilot Licence
CPT	Conditional Probability Table
CREAM	Cognitive Reliability and Error Analysis Method
CRM	Crew Resource Management
DOD	Department of Defence
FAA	Federal Aviation Administration
FRAM	Functional Resonance Analysis Method
GA	General Aviation
GEMS	Generic Error Modelling Systems
HEIST	Human Error Identification in Systems Tool
HFACS	Human Factors Analysis and Classification System
ICAO	International Civil Aviation Organisation
IMC	Instrument Meteorological Conditions
NPL	National Pilot Licence
OGI	Oil and Gas Industry
PPL	Private Pilot Licence
SACAA	South African Civil Aviation Authority
SCM	Swiss Cheese Model
SHELL	Software Hardware Environment Liveware
SOP	Standard Operating Procedure
SPL	Student Pilot Licence
STAMP	Systems Theoretic Accident Model and Processes
TCA	Thematic Content Analysis
TRACEr	Technique for Retrospective and Predictive Analysis of Cognitive Error
USA	United States of America
VFR	Visual Flight Rules

Chapter 1: Introduction

1.1 Overview

The South African Civil Aviation Authority (SACAA) is the civil aviation governing body responsible for activities ranging from pilot licensing, compliance monitoring, accident and incident investigations, aviation development, and innovation (SACAA, 2021). The history of civil aviation in the Republic of South Africa dates back to 1929, with some of its commercial airlines operating under Part 121 still operating to date, namely South African Airways, FlySafair, and SA Airlink. However, some well-known commercial airlines such as Comair, SA Express, Kulula.com, Mango, and Fly Blue Crane have either been liquidated or grounded for various reasons in what seemed to be a promising future in the development of South Africa's airline industry (Steyn & Mhlanga, 2016). The civil aviation industry also includes the general aviation (GA) sector, which in many respects has grown substantially over the past decades in South Africa. There are many internationally accredited GA flight schools in South Africa, such as the Johannesburg Flying Academy, Aeronav Academy, and the 43 Air School in Port Alfred.

General aviation is defined by the International Civil Aviation Organisation (ICAO) as any civil aviation activity that does not involve paid passenger transport. Therefore, civil aviation is divided into two primary segments: commercial and GA operations. Commercial airline operations include scheduled passenger and cargo services that involve remunerated operations. In contrast, the GA sector covers a wide range of non-scheduled civil aviation operations that include agricultural services, aerial work, emergency rescue services, flight training, weather monitoring, and recreational flying operations like corporate business jets, gliders, aerobatic flights, and powered parachutes (Liu et al., 2013; SACAA, 2021). These operations are classified as non-scheduled as they do not operate on fixed schedules or flight timetables. Consequently, GA operations can be sporadic, unpredictable, and more prone to adverse occurrences than commercial airlines (Liu et al., 2013).

Research and statistical data indicate that GA is subject to less stringent regulations and do not benefit from the same level of comprehensive and coordinated flight safety provisions observed in the commercial airline sector (SACAA, 2025). This is primarily because aviation authorities such as the ICAO enforce stringent regulations for commercial airline operations through rigorous pilot training, certification, aircraft inspection, maintenance, the use of sophisticated high-tech aircraft, and efficient up-to-date air traffic controller (ATC) protocols (ICAO, 2010, Annexure 13). Moreover, Dambier and Hinkelbein (2006) observed in their analysis of GA aircraft accidents in Germany that while systematic accident investigations were standard for scheduled air services, detailed analysis of accident causes in non-scheduled air services was conducted only when fatalities occurred. Similarly, research in Southern Africa reveals a significant dichotomy between GA and commercial airline operations, with commercial airlines having better safety performance records (Schlumberger, 2010; Steyn & Mhlanga, 2016). For instance, the SACAA (2025) reported 199 GA accidents and incidents in South Africa in 2021, resulting in 29 fatalities. By contrast, commercial airline operations in the same year recorded two accidents and zero fatalities.

Furthermore, the importance of safety in South Africa's GA sector is more apparent because of the diversity in pilot licences. Different pilot licences reflect varying levels of expertise or training experience and range from recreational flying to professional aviation careers. The most common licences include commercial, private, national and student pilot licences. Commercial pilot licence (CPL) holders are usually involved in remunerated operations such as charter flights, agricultural aviation, or cargo transportation. The training and competencies essential for flight proficiency for a commercial licence include 100 hours as pilot-in-command, 10 hours of instrument time, five hours of night flight time, five take-offs and landings as pilot-in-command (Idowu, 2022; Thatcher & Michaelides-Mateou, 2017). A private pilot licence (PPL), in contrast, allows pilots to operate non-revenue light aircraft for recreational and personal purposes (Boyd et al., 2021). Additionally, PPL holders are required to show competency in threat and error management, pre-flight operations, take-off, climb, cruise, descent, approach, landing, and post-flight operations.

A national pilot licence (NPL) is similar to the PPL but is less demanding in terms of training. NPLs are typically issued within specific jurisdictions to meet the needs of the pilot operating domestically. In South Africa, this licence restricts pilots to smaller aircraft such as a light sport or a conventional controlled microlight aircraft and the pilot can only be accompanied by one passenger during the day (Doskow, 2012). Additionally, the minimum requirement to qualify for an NPL is 35 hours of flight time (SACAA, 2025), whereas the student pilot licence (SPL) is an entry-level credential for individuals beginning their journey in aviation. These pilots undergo flight training under the supervision of certified instructors and might be restricted from carrying passengers or flying solo under certain conditions. Instructors are required by the ICAO to ensure that SPL holders can control the aircraft by external visual reference, have operational experience in recognising threats, recover from spiral dives, recover from full stalls, recover from unusual altitudes using basic flight instruments, comply with air traffic services, and standard communication procedures to mention a few (Thatcher & Michaelides-Mateou 2017). Decades of research have indicated that pilot training is a significant preventative measure to serious accidents as the lack of these skills has been found to be a contributing factor to training flight accidents and incidents around the world (Shao et al., 2014).

This variability makes this sector highly safety-sensitive and necessitates a comprehensive analysis of the human and organisational factors contributing to adverse GA occurrences in South Africa to develop effective safety measures that will prevent fatalities and reduce economic losses (Matshediso, 2014). Furthermore, in Southern Africa air transportation is considered a major component of the travel and tourism industry. Statistics South Africa estimates that the travel and tourism industry is estimated to have contributed more than R74 billion to South Africa's annual gross domestic product and sustains around 230,000 jobs within the entire value chain in the country (Lubbe & Vermooten, 2021). It has been argued that accidents and incidents in the GA sector will cause irreparable harm to the reputation and rating of South Africa as a flight training and tourism destination if left unabated (SACAA, 2025).

The present research investigated 48 adverse GA occurrence reports between 2015 and 2017 and systematically categorized factors contributing to adverse GA occurrences. For accident analysis in this report, adverse GA occurrences were divided into three categories, namely accidents, serious incidents, and incidents. Definitions of accidents, serious incidents, and incidents were retrieved from the International Civil Aviation Organisation (ICAO), Annexure 13. An aircraft accident is "an event during aircraft operations where someone is seriously injured or killed, the aircraft sustains significant damage, or the aircraft is inaccessible" (ICAO, 2010, p.1). A serious incident is described as "an event during aircraft operations (happening from the time of boarding until disembark) which involves circumstances indicating that there was a high probability of an accident but no accident occurred" (ICAO, 2010, p.1). An incident is described as "an event during flight operation, not classified as an accident, but which affects or has the potential to affect the safety of the passengers or aircraft" (ICAO, 2010, p.1).

Each category of adverse GA occurrences was applied to the Human Factors Analysis and Classification System (HFACS) framework and Bayes' theorem. The HFACS framework was used to systematically identify hidden (latent) and direct (active) failures that lead to an adverse occurrence. However, while the HFACS is an effective tool in analysing human factors in safety-critical industries such as GA, it has notable limitations such as its reliance on qualitative data and inability to predict future occurrences. Integrating Bayes' theorem into this study addressed these limitations by helping researchers to assess the likelihood of an event occurring in the future by calculating the prior probability of an occurrence given the presence of latent factors. The goal of an accident and incident investigation is to learn from previous failures (Dekker, 2019). The direct contribution of this study to the body of knowledge in human error and aviation safety came from the findings obtained from applying the HFACS framework and the Bayes' theorem to GA accidents, serious incidents, and incidents.

Existing GA research conducted in other countries indicates that aviation accident investigation research offers simple descriptive results (Baker et al., 1993; Li & Baker, 1999). Researchers propose that studies should use quantitative and qualitative methods because this approach provides a comprehensive analysis of accident causality (Akhtar & Utne, 2014; Yildirim et al., 2019). A study by Zhou et al. (2018) proposes the use of mixed methodologies especially in developing countries to assess their effectiveness. Furthermore, aviation studies in developing countries are usually concerned with tourism and sustainable aviation business models (Heinz & O'Connell, 2013; Njoroge & Samunderu, 2021; Njoya, 2016; Steyn & Mhlanga, 2016). This study therefore attempted to contribute to knowledge by filling in the gaps that currently exist regarding the GA sector in South Africa.

Chapter 2: Literature Review

The following chapter aims to provide a theoretical background to the present research. It begins with a literature review that explores human error and accident analysis. Then, it explores one of the earliest models for understanding the complex nature of how accidents occur, the Swiss Cheese Model (SCM). Following this, the chapter outlines the development of the HFACS framework. A visual analysis is then presented in the final section of the literature review to offer a detailed description and understanding of the framework. Subsequently, the application of Bayesian methodology is explained, thus demonstrating how it was used to analyse contextual data to determine the probability of adverse occurrences in the context of South African general aviation accidents, serious incidents, and incidents.

2.1 Human Error and Accident/Incident Analysis

Reason (1990, p. 3) defines error as "a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fail to achieve the intended outcome". Poor task performance and high error rates can be explained by a variety of human factors. In cognitive studies, researchers found that the loss of situational awareness, attention lapses, memory deficits, and flawed processing strategies increase the probability of human error (Endsley & Garland, 2000). Ergonomic studies identify and analyse human error in terms of human-machine interface compatibility (Leveson, 2020). In motivational studies, an error is considered psychosocial and a reflection of the operators' level of self-efficacy, work engagement, an indication of adequate incentives or lack thereof (Locke & Latham, 2006).

Another approach describes human errors on three levels, namely skill-based, rule-based, and knowledge-based (Gupta et al., 2021). Skill-based errors include improper procedures and missed checklist items caused by a lapse in attention, inadequate knowledge, lack of training, or stress (Wiegmann & Shappell, 2003). Rule-based errors are usually associated with moderate levels of experience and errors occur when an operator takes a course of action in a situation that requires a different approach (Dekker, 2019). Lastly, knowledge-based errors occur when the operator is unfamiliar with a situation and might not know the appropriate procedures to follow. According to Reason et al. (2006), errors at this level originate from factors such as cognitive bias, selectivity, problems with complexity, workspace limitations, or overconfidence.

Furthermore, human fallibility to error is well documented in human error identification methods such as the Technique for Human Error Analysis (ATHEANA) which was developed for error identification, task analysis, and calculating the likelihood of adverse events in the nuclear power industry. The Cognitive Reliability and Error Analysis Method (CREAM) and the Technique for Retrospective and Predictive Analysis of Cognitive Error (TRACEr) techniques are used to evaluate the operator's cognitive processes and their response reactions and behaviour in different situations (Hirose, et., al., 2020). In addition, The Human Error Identification in Systems Tool (HEIST) developed by Kirwan1(994), was designed to proactively identify potential human errors in complex systems before they occur. Similarly, Reason et al. (2006) developed the Generic Error Modelling system (GEMS) to understand operator behaviour before an accident and after the event happens, which is also known as problem-solving errors.

The Systems Theoretic Accident Model and Processes (STAMP) established by Leveson (2004) proposed that human error is an outcome of complex organisational, technical, and environmental interactions within the system. According to Leveson (2016), technology is reaching a tipping point and advancing at a rate seemingly faster than the operator's capabilities. This is mainly because the management of the system relies on human expertise and performance; however, they remain fallible and inherently prone to committing errors (Hollnagel, 2018; Parasuraman & Wickens, 2008). Leveson's (2004) observation is supported by Dekker (2019) who propose that the frequency of human error increases as systems become more complex. Furthermore, the authors found that technological advancements leave the human component exposed. Figures differ; however, the consensus is that approximately 80% of aviation accidents are attributed to human error (Shappell et al., 2017). Kharoufah et al. (2018) found that pilot error caused 79% of fatal accidents in the United States of America's (USA) general aviation sector.

Shappell and Wiegmann (2001) further argue that human error is a warning sign or symptom of a bigger problem, therefore attributing accidents solely to human error is simplistic, if not too naive, because human error is a normal human function. Studies spanning decades suggest that accidents caused by human error are in no sense homogeneous. Shappell et al. (2017) believe that the emphasis on human error as a cause of accidents has resulted in a blame culture. It can be argued that traditional accident investigation is rooted in a culture of blame and may be appropriate for insurance claims and criminal investigations. Safety investigators would argue that their goal is to determine why the accident occurred, what happened, and what can harbe done to prevent it from happening again. The term 'old view' versus 'new view' is used to explain how the understanding of error has progressed in literature (Larouzee & Le Coze, 2020).

The old view is a conventional assumption that mishaps were solely the product of the operator's fault. An example is declaring the cause of an accident as the pilot's loss of situational awareness during instrument meteorological conditions or to broader cultural factors such as the normalised bad habits within a flight crew. The new view of human error allows researchers to evaluate the operator's mistakes but also the latent system defects. Instead of being personal and asking who, the new approach systematically asks why. Why the loss of situational awareness or engagement in risk-taking behaviour happened? This is critical because in aviation, for example, interactions of the flight crew in the cockpit involve complex interactions that are characterised by the presence of different hierarchies among flight crew members, varied training standards, complex ergonomic designs, as well as cross-cultural differences in risk perception, attitudes, and behaviour.

Literature indicates that as transportation methods increase their use of advanced technology, the complexity surrounding accidents requires innovative techniques that investigate the causes of the accidents beyond simple cause-and-effect approaches (Underwood & Waterson, 2013). Earlier scholars found that even when enormous effort has gone into perfecting systems through technology, it seems they remain fallible and it is largely for this reason that the systematic analysis of accident causation is prioritized (Hollnagel, 2018; Leveson, 2004). Hollnagel and Goteman (2004) found that accident analysis methods can be divided into sequential, epidemiological, and systematic techniques. Sequential techniques were originally proposed in the Domino effect model which describes the factors leading to an accident as the progression of discrete events that occur in a particular order.

Epidemiological techniques are concerned with the latent and active contributions to accidents. Epidemiological techniques have compared the distribution of diseases in the body as being similar to latent failures that lie dormant within the system before contributing to an adverse event (Underwood & Waterson, 2013). This analogy helps us to understand how risks accumulate in complex systems before resulting in an accident or incident. Examples of well-known epidemiological techniques include the SCM and the HFACS framework. The SCM provides a visualization of how latent conditions within a system can interact with active errors to create pathways for accidents. Building on similar principles, the HFACS offers a detailed analysis and classification of human and organisational factors. Systematic techniques assess how and why a system can operate effectively but still fail (Underwood & Waterson, 2013). These techniques are designed to explore the complexity of accidents resulting from non-linear interactions in socio-technical systems (Hollnagel, 2018; Leveson, 2004). Examples include GEMS, Accident Analysis Mapping (AcciMap), STAMP, and the Functional Resonance Analysis Method (FRAM).

2.2 Reason's Swiss Cheese Model (SCM)

The SCM requires little introduction as one of the earliest conceptual frameworks that attempted to provide a comprehensive framework analysing system failures and understanding why and how accidents occur (Wiegmann & Shappell, 2003). A Google search on SCM yields approximately 11,900,000 hits ranging from aviation, maritime, railroad, and mining, among other industries (Bonsu et al., 2016; Suryoputro et al., 2015). The model was developed by Reason (1997) to explain the cause of accidents. The SCM metaphorically uses 'Swiss cheese' as an analogy to represent failures as 'holes' in slices of cheese. These holes can change in shape and size as they line up to create a window for an accident to occur. The holes in the slices can sometimes be detected and corrected before an accident event takes place. Therefore, each slice is a protective barrier that either causes or prevents an accident (Wiegmann et al., 2022). The protective barriers consist of four levels, namely organisational influences, unsafe supervision, preconditions for unsafe acts, and unsafe acts. Overall, the SCM highlights the importance of understanding the complex interplay between various causal factors that contribute to system safety or error.

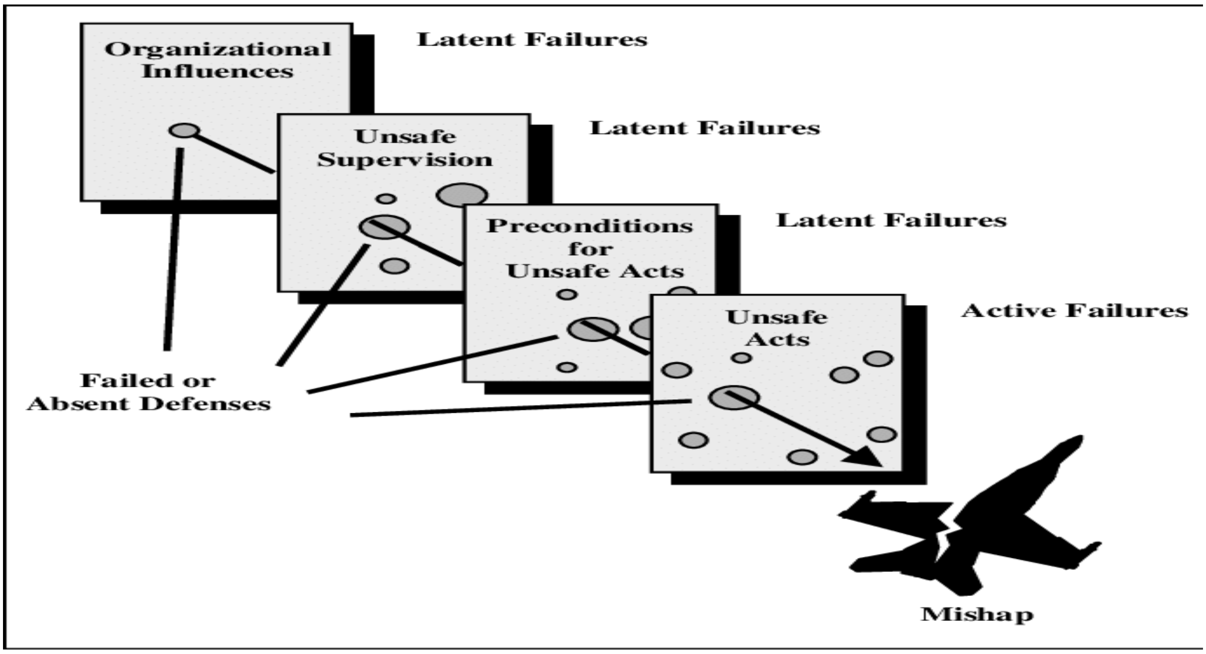
Researchers have attributed human error either directly or indirectly as the primary cause of the accidents. Research findings indicate that human error is the decisive factor in 70 to 80% of all accidents (Kharoufah et al., 2018). Reason (2006) further describes human error as having a sharp end. The pointy end represents the operator of the system, whether it is an oil rig operator, ATC, surgeon, train driver, pilot, or the ship's captain. Active failures are called active because they occur when the operator is actively performing a duty (Wiegmann et al., 2022). Furthermore, causal factors associated with the SCM's unsafe acts level are related to active failures that led to the accident (Cohen, 2017).

Reason (1990) argued that "instead of viewing the operator as the main cause of the accident, operators tend to be inheritors of system defects and their part is usually that of adding the final garnish to a lethal brew whose ingredients have already been long in the cooking" (p. 173). Similarly, Zohorsky (2020) found that while active failures may serve as the final initiating event for accidents due to some error in judgment or decision-making on the part of the operator and may be listed as the cause of the accident, latent failures are generally more to blame (p. 30). Latent failures are described as a blunt end. These failures are located higher up in the system such as outdated maintenance procedures, inadequate pilot training, or organisational culture that were present for a considerable amount of time before the accident (Shabani et al., 2024). These latent conditions are a key concept in the SCM and represent underlying weaknesses within the system.

The difference between active and latent failures is that active failures have immediate consequences such as a fatal accident while latent failures can lie undetected for days or even years before contributing directly or indirectly to an accident. Thus, relying on the absence of accidents as an indication of safety within a system can be dangerous since the risk of harm is not always apparent (Shabani et al., 2024). The Piper Alpha is an example of an accident that was caused by long-standing systemic latent conditions that remained hidden in the system without being dictated (Reason et al., 2006). The Piper Alpha fire was caused by the removal of a safety valve without proper checks, subsequently leading to a gas leak and deadly explosion. This accident exposed a weakness in safety systems such as communication, training, and effective decision-making under pressure (Reid, 2020). The accident highlighted the impact of human error as a result of failed defences. An adaptation of Reason's (1990) SCM is presented in Figure 1 where it highlights latent and active failures, protective barriers, and holes.

Figure 1:

The Swiss Cheese Model of Human Error Causation



Note. Adapted from Human Error: Models and management, by J. Reason, 1990, *British Medical Journal, 300*(6732), 1137-1140. Figure 1 - uploaded by Douglas A. Wiegmann, https://commons.erau.edu/publication/737

In his 1997 book, Reason raised concerns about the model, stating that "the pendulum may have swung too far in our present attempts to track down possible errors and accident contributions that are widely separated in both time and place from the events themselves (p. 234). Reason cautioned against the excessive focus on identifying minor errors and applying the model too broadly and dogmatically. Reason et al. (2006) argue that the model was designed as a general tool to highlight the alignment of multiple weaknesses that contribute to accidents. Ironically, despite the author acknowledging the models' limitations, he was by no means the only one. Prominent authors in the field of human error and system safety have criticized the simplicity, practical applicability, and usefulness of the SCM in today's technologically advanced systems (Bonsu et al., 2016; Dekker, 2002; Leveson & Le Coze, 2020; Suryoputro et al., 2015).

Dekker (2002) criticizes SCM for portraying safety barriers as isolated entities. The defence barriers are dynamic and interact with each other in ways that can either strengthen or weaken the overall system. Dekker (2002) further criticizes the SCM for not providing enough detail about the holes in the "cheese." The model fails to address the root cause of the weaknesses, how they develop and change over time, or how they ultimately align to create accidents. Suryoputro et al. (2015) further emphasise these shortcomings through their findings which indicated that the SCM may not be fully suited for in-depth analysis of complex accidents like train derailments. Integrating the SCM into newer models like the HFACS, STAMP, and AcciMap provides an enhanced level of system comprehension when analysing accident causation (Hulme et al., 2019).

Building on these critiques, other authors echo Dekker's concerns about the SCM's practical application compared to other models such as the HFACS framework (Bonsu et al., 2016; Luxhoj & Kauffeld, 2003). The model does not clearly define the nature of the holes within the safety system, making it difficult to use in real-world operational settings. Luxhoj and Kauffeld (2003) further highlight the model's inability to capture the complex relationships between accident factors, arguing that this limitation has led to unclear and impractical findings. The authors also criticize Reason (1997) for not providing clear guidelines for using the SCM and placing the burden on accident investigators and researchers to identify weaknesses that cause accidents without adequate guidance. Additionally, Perneger (2005) conducted a study that aimed to determine if the components of the SCM are understood in the same way by quality improvement professionals and the findings revealed that the SCM is far from univocal as the understanding of the model's specific features varied considerably among the professionals.

Other critics of Reason's seminal work are Young et al. (2023) who provide a broader critique of the SCM. The authors argue that the model is overly focused on identifying latent conditions only after accidents occur. Additionally, the SCM's emphasis on the management of these shortcomings might overshadow essential human factors such as the role of emotions, attention, decision-making, stress, situational awareness, and fatigue. Dekker (2002) concurs, by stating that the model creates sub-systems and fails to consider the system as a whole. In other words, the model tends to treat human error as a generic factor rather than exploring specific cognitive mechanisms. Hollnagel (2018) acknowledges these limitations and finds that complex linear models shift the analysis from the front-line operator to the organisation and its management.

Another criticism is whether or not a model developed in the 20th century can be used to understand accidents in highly automated systems (Leveson & Le Coze, 2020). In a compelling paper conducted by Larouzee and Guarnieri (2015), the authors reviewed the effectiveness of the SCM in the modern world and provided a balanced argument. They argued that the model is less relevant today because technology has changed and it cannot explain why highly automated systems fail. While the effectiveness of the model has diminished in some contexts, it remains relevant in industries where human error continues to be a significant factor. As long as humans are in the cockpit or performing surgeries in hospitals, the Swiss Cheese Model will remain relevant to understanding accident causation in high-risk industries (Larouzee & Guarnieri, 2015).

Despite the SCM's several shortcomings, it is not obsolete and, in many ways, remains the industry safety standard. By recognising the interplay between active failures at the hands of underlying latent conditions and front-line operators, the SCM revolutionized the understanding of accidents by shifting the focus from individual blame to systemic issues. In conclusion, the SCM provides the foundation for accident and incident analysis methodologies like the HFACS framework.

2.3 Building upon SCM: The development of Human Factors Analysis and Classification Systems (HFACS) framework

The HFACS is a post-hoc framework designed to systematically identify meaningful trends and causal factors of accidents that may not have been apparent in the original data (Cohen, 2017). The classification framework is considered post-hoc because it examines accident and incident investigation reports retrospectively to identify causal factors using the HFACS framework. Wiegmann and Shappell (2000) developed the HFACS to analyse human factors within the aviation sector. It was originally designed for the USA armed forces which include the Coast Guard, Navy, Air Force, Army, and maritime operations. The HFACS has since proven its versatility. Wiegmann and Shappell (2003) demonstrated its applicability in USA civil aviation, that is commercial (Wiegmann & Shappell, 2017) and the general aviation sector (Wiegmann & Shappell, 2003). Today, the influence of the HFACS exceeds beyond aviation and researchers have successfully applied the HFACS to diverse industrial sectors such as aerospace (Li & Harris, 2006), health care (Diller et al., 2014), mining (Patterson & Shappell, 2010), nuclear power (Yoon et al., 2016), construction (Hale et al., 2012), and maritime (Celik & Cebi, 2009).

Table 1 presents a selection of prominent accidents across various industries caused by human factors.

Table 1:

A Selection of Prominent Adverse Occurrences Globally in Various Industries since the late 1980s not caused by Natural Disasters, War, or Political Conflict

Industrial Accidents	Key Human Factors	Fatalities	Source
Maritime:			
MV Dona Paz collision and sinking (1987)	Inadequate training of the crew, operator failure to maintain the ship.	>4,000	Perez et al., 2011; Soliman et al., 2013
Al Salam Boccaccio 98 (2006)	Bad weather, technical failures, human error.	1,161	
MV Sewol sinking (2014)	Overload of the ship, inadequate crew training, and captain negligence.	304	
Oil:			
Deep-water Horizon Oil spill (2010)	Negligence on the part of the company (BP), insufficient staff training.	11	National Commission on the BP Deepwater Horizon, 2011
Construction:			
Grenfell Tower Fire (2017)	On-site fire extinguishers had expired and insufficient fire safety measures.	72	McKenna et al., 2019

Industrial Accidents	Key Human Factors	Fatalities	Source
Mining:			
Soma Mine (2014)	Company negligence (Soma Holdings), poor training of the workers.	301	Duzgun, & Leveson, 2018
Health care:			
Therac-25 (1985 - 1987)	Organisational factors, design flaws, human error.	6	Leveson & Turner, 1993
Aerospace:			
Space shuttle Challenger disaster (1986)	Organisational and political pressure to launch, poor environmental conditions.	7	Schwartz, 1987
Aviation:			
Tenerife runway collision (1977)	Miscommunication between the pilots and the air traffic controller, failure to follow standard operating procedures (SOPs).	583	Cookson, 2009
Charkhi Dadri mid-air collision (1996)	Heavy airspace traffic, miscommunication between pilot and air traffic controller, low flight altitude, and lack of collision avoidance systems.	349	Chatterjee et al., 2021
Nigeria Airways flight 2120 crash (1991)	Use of substandard fuel, pilot error, poor weather conditions.	261	Babu, 2025

Wiegmann and Shappell (2003) adapted Reason's SCM four levels, namely organisational influences, unsafe supervision, preconditions for unsafe acts, and unsafe acts as a foundation for the HFACS framework. According to Zhan et al. (2017), the HFACS framework sheds light on the definition of the "holes" in the SCM by including sub-categories within the four levels because this facilitates practical application to real-world scenarios. Additionally, each of the four HFACS levels has categories and sub-categories covering a range of human error psychological theories, namely organisational, psychosocial, ergonomic, cognitive, aeromedical, and behavioural (Zohorsky, 2020).

Organisational theories propose that errors begin at the higher levels of an organisation. That is, inadequate resource management and flawed operational processes are likely to create an environment where errors are more likely to occur (Rad, 2013). The psychosocial perspective addresses how interpersonal and social dynamics stemming from poor support and leadership often cause mental health challenges and poor performance. Psychosocial factors include a lack of trust between supervisors and subordinates or inadequate supervision of subordinates (Holloway, 2016). The ergonomic theories explore the interaction between humans and how design factors influence performance (Leveson, 2016). Human errors explained by cognitive theories usually involve misjudgements, or lapses that occur due to flawed reasoning, limited attention, or information overload (Endsley & Garland, 2000). Aeromedical theories pertain to the physiological aspects of human performance and examine how factors like fatigue or physical health can impair operator performance (Wiegmann & Shappell, 2017). Behavioural theories analyse how learned behaviour and personal tendencies shape individual responses in different situations (Vargas, 2017).

The adapted HFACS table used for this research has three categories under the *organisational influences* (Level 4), namely resource management, organisational climate, and organisational process. *Resource management* has sub-categories that include human resources, budget restrictions, and equipment issues. *Organisational climate* sub-categories include the structure of command, company policy and company culture towards safety. *Organisational process* sub-categories include deadline pressures, oversight, and SOPs. The HFACS framework's Level 4 aligns with organisational theories of accident causation. Rad (2013) argued that accidents are caused by an unexpected collapse of the first domino, which initiates a sequence of events that result in the collapse of all the subsequent dominos.

Failures within the organisation are a systematic chain of events that starts with the lack of control at the management level (i.e. budget restraints) and is followed by basic causes (i.e. stress), intermediate causes (i.e. unsafe acts), an accident (i.e. the actual event), and finally damage (i.e. harm or loss). For instance, in aviation when management fails to allocate sufficient funds for aircraft maintenance, this might lead to a decline in the overall reliability of the fleet. These budget restrictions could increase the likelihood of technical malfunctions during flight operations, force pilots to make critical decisions under pressure, and subsequently lead to an accident or serious incident. According to Ma et al. (2023), reducing the prevalence of general aviation accidents requires interventions directed to crucial causal categories at the HFACS organisational level, such as resource management.

Unsafe supervision consists of the following four categories, that is inadequate supervision, planned inappropriate operations, failure to correct a known problem, and supervisor violations. Level 3 can be explained using organisational theories like the Domino Effect theory and from a psychosocial perspective. This level demonstrates how decisions made by supervisors can either promote good safety practices or increase the risk of accidents. For example, if an aviation flight training school was facing financial challenges, decision- makers might decide not to hire newly qualified flight instructors. Poor oversight from staff shortage might result in unprepared or unqualified SPL holders being granted permission to engage in unsupervised solo flights. The subsequent chain reaction is the increased number of student pilot accidents and near misses as a result of *inadequate supervision* and *supervisory violations*.

Additionally, this level addresses the psychosocial perspective which looks at how social relations between supervisors and trainees can negatively impact employee mental health (Holloway, 2016). Psychosocial hazards are addressed in the HFACS Level 3 because the tier focuses on issues such as *failure to correct a known problem* and *the planning of inappropriate operations* by supervisors. These factors stem from poor management and the lack of leadership that supervisors provide to their subordinates. For instance, if an unqualified SPL holder is allowed to go on a solo flight, this is an indication that the supervisor failed to correct a known problem. Furthermore, allowing a student pilot to perform tasks when they are under-qualified is considered planning an inappropriate operation. Research indicates that entry-level trainees require support, encouragement, and structure in supervision to avoid increased stress levels and error rates (Holloway, 2016).

The *precondition for unsafe acts* (Level 2) addresses broader organisational and aeromedical influences. This tier consists of three categories, namely environmental factors, personnel factors, and the condition of the operators (Wiegmann & Shappell, 2000). The SHELL model (software, hardware, environment, and live-ware) is a human factors framework used can be used to explain key human interactions between people and other systems components, whether those events are physical, technical, or organisational in nature. The SHELL model identifies the mismatches between the operators and their systems (software, hardware, environment, and live-ware). According to the SHELL model, software refers to SOPs and guidelines set by the organisation. Hardware covers the technical environment of the system, which includes the equipment and ergonomic design of aircrafts (Storm et al., 2022). The environment covers three elements, namely the economic climate, social and physical factors. The live-ware refers to the system operator directly involved with the accident; in aviation, this may include the pilot, ATC, or technicians. Atmospheric and physical conditions, such as weather, terrain or visibility, can create a mismatch between the live-ware (operator) and the environment. Similarly, the technological environment, which includes the design and functionality of equipment, if poorly designed and ergonomically incompetent, could lead to a mismatch between the live-ware and hardware and increase the risk of errors.

The Crew Resource Management (CRM) is another model that can help to explain the *personnel factors* sub-category. Personnel factors refer to how individual and team attitudes, behaviours, and competencies influence the likelihood of unsafe acts. CRM pertains to the importance of ATCs and aircrew training in an attempt to change and manage behaviours that could lead to adverse occurrences. Research findings indicate that because pilots and ATCs are the main front-line operators, they are exposed to direct work and emotional stressors (Tshabalala & De Beer, 2014). Therefore, CRM training encourages front-line operators to recognise these personal vulnerabilities and develop strategies to counteract them.

Lastly, the aeromedical perspective pertains to how adverse mental and physical health conditions as well as physiological changes can impair the operators' abilities and make them more prone to errors (Dekker, 2019). This perspective can explain the *condition of the operator;* by way of explanation; this sub-category under the HFACS draws on various physiological and mental factors that directly impact human performance (Wiegmann & Shappell, 2017). For example, a lack of rest, or prolonged working hours can lead to fatigue. A fatigued pilot may experience a decline in cognitive functions such as judgement, attention, and memory.

The *unsafe acts* or HFACS Level 1 is concerned with the errors committed by front-line operators (i.e. pilot, ATC, or aircrew) that lead to unintended adverse outcomes. This tier is divided into *errors* (i.e. decision, skill-based, and perceptual) and *violations* (routine and exceptional). Cognitive theories of human error can explain the decision, skill-based, and perceptual errors in high-risk industries (Hobbs, 2008). They examine how operators perceive information, process it, and make decisions. According to Wiegmann and Shappell (2003), errors such as *decision errors* can occur due to a lack of knowledge or adequate information. Cognitive studies further indicate that decision errors can be influenced by attention lapses, slips, and memory deficits (Hobbs, 2008; Reason, 1990).

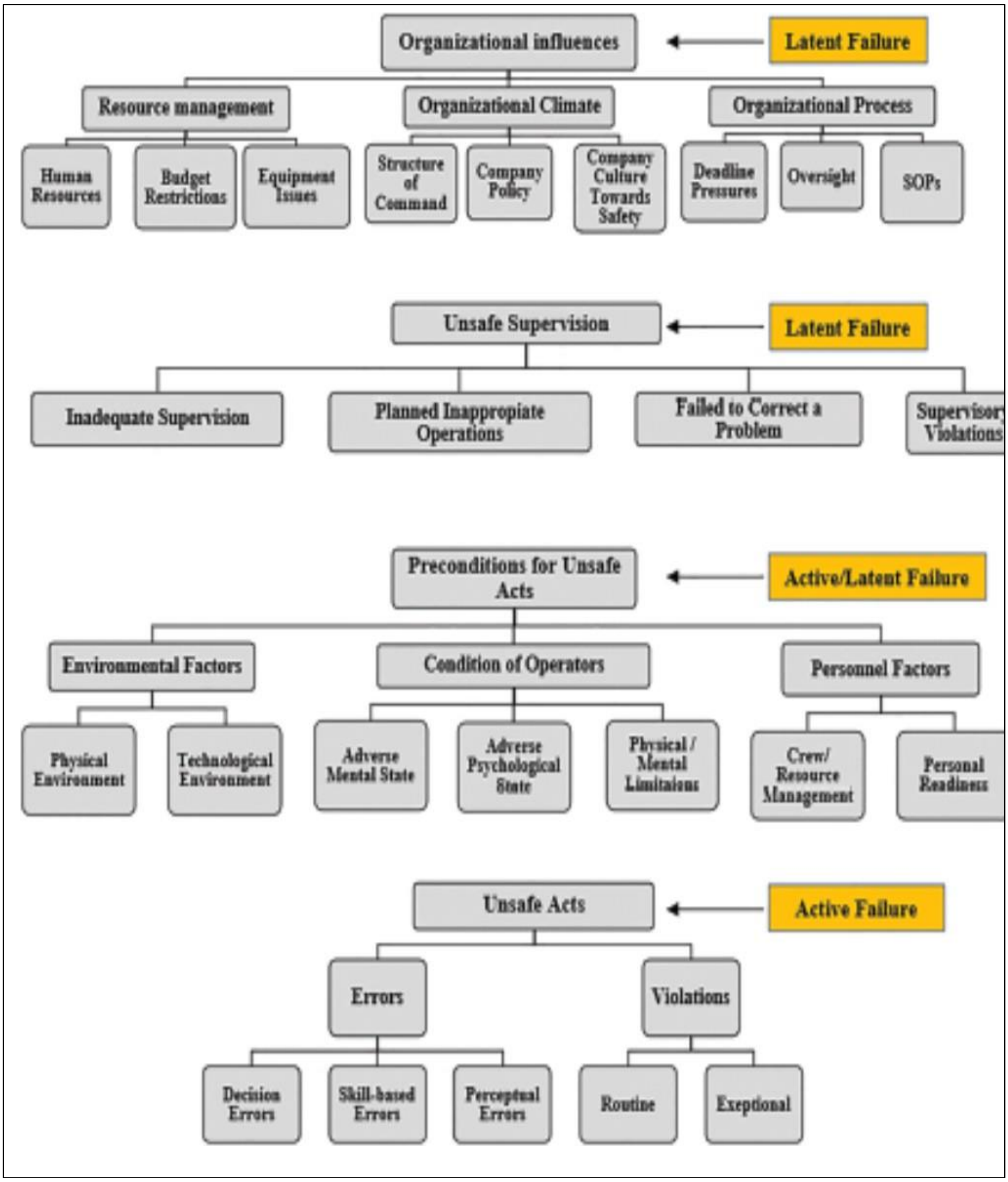
Skill-based errors are usually committed by individuals with high-level expertise as a result of psychosocial factors such as stress, fatigue, and task repetition (Dekker, 2019). Finally, *perceptual errors* can be understood from Endsley and Garland's (2000) model of situational awareness, which explains the complex interaction between humans and their environment. According to Endsley and Garland (2000), perception is understood as the operator's ability to perceive the elements in the environment through visual and auditory sensory inputs. An aviation example is a pilot ready for take-off and their awareness of the instruments and controls in the cockpit. In addition, the connection between the operator's cognitive functioning and ergonomic design is important as visual illusion and spatial disorientation have been reported as contributing factors in aviation accidents (Meeks et al., 2018).

The behavioural perspective can explain routine and exceptional *violations*. This perspective recognises the influence of positive (i.e. rewards or promotions) and negative (i.e. avoiding punishment) reinforcement in encouraging safe behaviour. For example, individuals who commit *routine violations* typically work within SOPs; however, in certain situations they can decide to "bend the rules." A pilot working under pressure from management might commit a routine violation by consciously skipping a pre-flight checklist such as checking fuel quantity. The pilot might be under the impression that this will save time and impress management. An *exceptional violation*, unlike a routine violation, is considered outside the operator's typical behaviour but a deliberate decision to disregard safety regulations (Wiegmann & Shappell, 2003). This could include rushing to get to the destination despite challenging weather conditions. The pilot might engage in unacceptable and dangerous "macho" (l can do it!) behaviour, believing that it would impress colleagues or passengers.

At its most basic level, the HFACS explicitly distinguishes latent and active failures. Latent failures are underlying factors within the organisational structure, like inadequate supervision, training, and poorly defined policies that remain hidden in the system for days or years without being detected. Latent failures within the system can be attributed to the direct or indirect cause of an accident (Reason, 1990). Active failures are the immediate cause of the accident in the hands of an individual (i.e. pilot, maintenance personnel, ATC) or team (i.e. cabin crew). Additionally, research indicates that latent failure and active failures are extremely difficult to control and predict (Zhou, 2018). Figure 2 illustrates the HFACS framework as adapted from Wiegmann and Shappell (2017). Researchers propose that studies should use quantitative and qualitative methods because this approach provides a comprehensive analysis of accident causality (Akhtar & Utne, 2014; Yildirim et al., 2019). This is particularly relevant in developing countries, where aviation safety oversight systems may be under-resourced and accident data may be inconsistently reported.

Figure 2:

The Human Factors Analysis and Classification System (HFACS) Framework



Note. A Human Error Approach to Aviation Accident Analysis: the Human Factors Analysis and Classification System (1st ed) Routledge. Adapted from Wiegmann, D. A., & Shappell, S.A. 2017. https://doi.org/10.4324/9781315263878

According to Li and Harris (2006), the HFACS empowers safety professionals and investigators to systematically identify specific human factors and develop accident and incident prevention strategies. Ergai et al. (2016) examined the inter-rater reliability of the HFACS and the results revealed the HFACS taxonomy to be reliable in terms of the inter- rater reliability. Munene (2016) applied the HFACS to aviation accidents in Kenya, Nigeria, and South Africa, and found that 70% of the accidents are caused by human error and adverse weather conditions. In military aviation research, Miranda (2017) applied the Department of Defence Human Factors Analysis and Classification System (DoD HFACS) and was able to identify latent failures (organisational policy, technological environment, and supervisor ability) conducive to certain types of unsafe acts (performance-based and decision-making errors).

Kelly and Efthymiou (2019) employed HFACS to identify the human factors involved in aviation accidents that resulted in controlled flight into terrain (CFIT). The findings identified individual and human factors as contributors to accidents. Zhou et al. (2018) investigated the role of human errors in railway incidents and the results indicated that the framework was useful in presenting how a railway accident/incident occurs. The study further revealed a significant interdependence between human factors. Sunaryo et al. (2019) found the HFACS to be relevant in analysing and classifying medication errors caused by human factors.

In addition to Figure 2, to delve deeper into the specific four levels of the HFACS framework, Table 2 provides a breakdown of each category, sub-category, and descriptions.

Table 2:

The Human Factors Analysis and Classification System's (HFACS) Four Levels of Categories and Sub-categories Descriptions

HFACS Categories/Sub-categories	Descriptions	Source
Level 4: Organisational Influences		
Resource Management	Human resources: This refers to recruitment, training, and retention of personnel. Poor management of human resources can result in unqualified employees, low morale, and inadequate staffing.	Appley & Trumbull, 2012; Siegrists & Li, 2016; Maslach & Leiter, 2017
	Budget restrictions: financial constraints can force an organisation to reduce training, cut corners, or delay maintenance.	Hobfoll, 2011; Reason et al., 2006
	Equipment issues: this involves the allocation, upgrading, and maintenance of equipment necessary for safe operations.	Hollnagel, 2018
Organisational Climate	Structure of command: this involves the hierarchy within the organisation. A poorly defined command structure can lead to communication breakdown, unclear responsibilities, and confusion.	Underwood & Waterson, 2013
	Company policy: these are the policies set by the organisation to guide behaviour and decision-making at all levels.	Stokes & Kite, 2017
	Company culture towards safety: this is the overall attitude of the organisation toward safety. If safety practices are prioritized, this can reduce the risk of accidents. Conversely, if safety is seen as secondary, this can increase the likelihood of accidents.	Dekker 2019

HFACS Categories/Sub-categories	Descriptions	Source
Organisational process	Deadline pressures: organisational emphasis on meeting deadlines, particularly at the expense of safety procedures, can lead to rushed decisions when employees feel pressured to bypass safety protocols to meet organisational demands.	Bakker & Demerouti, 2014; Hollnagel, 2018
	Oversight: the quality and degree of oversight is important as inadequate oversight may allow unsafe conditions to persist.	Underwood & Waterson, 2013
	Standard operating procedures (SOPs): these are well written instructions designed to ensure consistency in operations. SOPs that are poorly designed or communicated can lead to unsafe practises.	Wiegmann & Shappell, 2003; Reason et al., 2006
Level 3: Unsafe Supervision		
Inadequate Supervision	Inadequate supervision can manifest in a lack of guidance, failure to train subordinates, and failure to properly monitor equipment and personnel which leads to operational inefficiencies.	Ayiei et al., 2020
Planned Inappropriate Operations	Supervisors may plan or approve operations without adequately assessing the associated risks.	Wiegmann & Shappell, 2003
Failed to correct the problem	Supervisors may be aware of safety issues but fail to take corrective action. Supervisors may also grant operational approval despite unresolved safety issues – increasing the likelihood of accidents or near misses.	Hollnagel & Goteman, 2004
Supervisory Violations	Supervisors may deliberately act in ways that contravene established safety procedures by prioritizing operational efficiency or cost-saving	Guo et al., 2021

HFACS Categories/Sub-categories	Descriptions	Source
	measures over safety - teams engage in unsafe practices either through direct orders or through poorly set examples by superiors.	
Level 2: Preconditions for Unsafe Acts		
Environmental Factors	Physical environment: this refers to atmospheric and physical conditions (weather, terrain, temperature, visibility) that can affect the operator's performance.	Storm et al., 2022
	Technological environment: this includes the functionality of equipment and how well it interacts with the operator. Outdated technology, poor ergonomic designs, or complex systems that are difficult to operate can lead to operator errors.	Hollnagel, 2018; Leveson, 2004
Condition of operators	Adverse mental state: this refers to cognitive impairments such as fatigue, emotional distress, and stress that can negatively impact an operator's decision-making and performance.	Maslach & Leiter, 2017
	Adverse physiological state: factors such as illness, fatigue, and intoxication are some of the physical conditions that can impair the operator's ability to perform duties effectively.	Dekker, 2019
	Physical/mental limitations: this pertains to inherent ergonomic, physical, or cognitive restrictions that may limit an operator's performance.	Siegrists & Li, 2016
Personnel Factors	Crew resource management: lack of coordination, poor communication, or interpersonal conflict amongst crew members can lead to misunderstandings and ultimately unsafe conditions during operations.	Appley & Trumbull, 2012; Shappell et al., 2017
	Personal readiness: this involves the operator's preparedness to	Bakker & Demerouti, 2014; Maslach & Leiter, 2017

HFACS Categories/Sub-categories	Descriptions	Source
	undertake their duties because factors such as substance abuse, insufficient rest, and failure to adhere to fitness-for-duty requirements can impair an operator's ability to perform safely.	
Level 1: Unsafe Acts		
Errors	Decision errors: these are conscious but incorrect decisions made by an operator - decision errors occur when the operator chooses a course of action that is inappropriate for the given circumstance because of flawed reasoning or inadequate knowledge of the situation.	Wiegmann & Shappell, 2003
	Skill-based errors: these errors can include an operator pressing the wrong button, or omitting a step in a standard procedure - these errors are not the result of poor decision-making but rather a result of lapses in attention, simple slips, or memory failures.	Luo & Gao, 2022
	Perceptual errors: these errors can happen when environmental conditions impair the operator's perceptions, leading to misjudgement of distance or speed based on incorrect or degraded sensory input.	Endsley, 2000
Violations	Routine: routine violations occur when operators take shortcuts and these deviations from SOPs become common practice over time because they are seen as minor.	Flin & O'Connor, 2017; Kelly & Efthymiou, 2019; Reason et al., 2006
	Exceptional: these violations are more serious as they involve a deliberate disregard for SOPs and bypass protocols, often with a high level of risk.	Dekker, 2019

Despite its strengths, the HFACS framework has been criticised for issues related to consistency. Similar to the SCM, some critics have expressed a viewpoint that there is no clear evidence that the HFACS framework is understood in the same way by all users (Dekker, 2019). Beaubien and Baker (2002) highlight inconsistent reporting on inter-rater agreements. In other words, researchers, investigators and specialists analysing the same accident or incident may not always apply the HFACS categories consistently. Several studies have found evidence to support the inter-rater and intra- rater reliability of the HFACS framework; the findings also reveal opportunities for improving the HFACS implementation in the coding process because of low consensus between raters (Ergai et al., 2016; Olsen, 2011). It has further been argued in the literature that because the HFACS framework is used by graduate students, aviation psychologists, and human factors specialists, there is potential for bias and inconsistency in the coding process since these individuals are not the target audience for the framework (Li & Harris, 2005; Olsen, 2011).

Dekker (2019) criticizes the framework for its insufficient emphasis on the causal sequence of events leading to an accident. The HFACS struggles to differentiate between the causes and simple effects of the accident. In addition, Beaubien & Baker (2002) argue that there are inconsistencies in the analysis and that "simply identifying a problem as resulting from organisational influences provides few clues for remedial action" (p. 18). It has become common practice for scholars to extend the HFACS framework into industry-specific analysis for targeted interventions. Furthermore, although the HFACS categories and sub-categories may be adapted to fit the context of different industries, the four levels (organisational influences, unsafe supervision, preconditions for unsafe acts, and unsafe acts) in most cases remain consistent.

There are several well-known HFACS derivatives used across industries, including air traffic controller accidents (HFACS-ATC), oil and gas industries (HFACS-OGI), the Department of Defence (DoD HFACS), mining industry (HFACS-MI), maritime machinery space fire and explosion (HFACS-MSS), surgery-related incidents (HFACS-Healthcare), ship grounding (HFACS-Ground), railroad accidents (HFACS-RR and/or HFACS-RAs), the helicopter maintenance error (HFACS-ME), and the Australian defence force (HFACS-ADF) (Mazaheri, et al., 2015; Patterson & Shappell, 2010; Reinach & Viale, 2006; Scarborough & Pounds, 2001; Schroder-Hinrichs et al., 2011; Theophilus et al., 2017; Xia et al., 2018; Zhan et al., 2017). These HFACS modifications offer alterations to Wiegmann and Shappell's model. Research findings indicate that the modified applications of the HFACS ensure that all levels of the system are considered in a systematic and thorough manner (Diller et al., 2014).

Another criticism is the classification system's inability to address quantitative relationships beyond weather conditions, the pilot's experience, or the pilot's demographics (Liu et al., 2013). A few studies have incorporated quantitative statistical tools such as Bayesian methodology and the modelling of the HFACS framework to quantify the probability of an accident occurring in the future (Miranda, 2018; Xia et al., 2018). Recent studies are calling for researchers to incorporate quantitative methods into the HFACS framework, especially in developing countries (Zhou et al., 2018).

2.4 Bayes' Theorem Method

According to Gelman & Shalizi (2013), Bayes' theorem is a foundational principle in probability theory and a statistical method that enables safety professionals to estimate the probability of an event by calculating the prior probability of its occurrence, given the presence of latent factors. Pawlak (2003) defines the outcome of Bayesian analysis as the posterior distribution, which reflects an updated understanding of a situation after incorporating new data and evidence. Furthermore, Bayesian methods are widely regarded as a robust approach for reasoning and prediction under uncertainty, particularly in complex systems with multiple interdependent variables (Ozbay & Noyan, 2006, as cited by Rostamabadi et al., 2019, p. 60). As previously noted, while the HFACS is an effective framework for analysing human factors in safety-critical industries, it has notable limitations, including its reliance on qualitative data and its inability to predict future events. Zhou et al. (2018) emphasise the importance of combining both quantitative and qualitative risk assessments in studies focused on aviation safety in developing countries.

Further to this, Bayes' theorem can be utilised to analyse data within a framework. From a Bayesian perspective, evidence must increase the probability of a given hypothesis while reducing the probability of alternatives. This approach is particularly valuable because the HFACS framework is structured across four hierarchical levels and simply examining these relationships qualitatively often proves insufficient for capturing the interdependencies at play (Rostamabadi et al., 2019). It is possible to explore how specific factors at each level influence one another. Hence, applying Bayesian methods within this framework allows researchers to assess conditional dependencies among these factors within each category of the HFACS framework. Previous research by Li et al. (2019) highlighted the significance and utility of employing Bayesian methods in relation to the HFACS framework, as it provides a probabilistic approach to understanding relationships. This method offers a more profound understanding of the causal factors underlying adverse events. Using Bayes' theorem for the final analysis of the GA HFACS data, the results were presented in a table format to provide a deeper understanding of the reasons for failures in the system. This approach emphasises the importance of understanding accidents, serious incidents, and incidents rather than relying on the unhelpful notion of human error.

In the present research, connections between variables were analysed to illustrate their interrelationships. Furthermore, these connections were examined quantitatively to identify the most likely factors contributing to adverse GA occurrences. The analysis was conducted in two key steps to guide the overall investigation. First, the relationships between random variables were determined based on the HFACS framework. This crucial step established how the factors influence one another. Second, a Conditional Probability Table (CPT) was constructed using Microsoft Excel Version 2024. This step was essential for defining the probabilities associated with each variable.

Within the context of this research, the Bayes' theorem allowed for a more profound understanding of the categories within GA HFACS, moving beyond the simplification of human error. The statistical operation considered the relationships between variables within HFACS categories to answer critical conditional probability questions. For example, the formula can be adapted to determine: "Given the presence of a latent failure, what is the probability of an accident, serious incident, or incident?" By incorporating prior data and refining the probabilities through Bayes' theorem, the analysis delivered a deeper insight into the factors contributing to GA occurrences, providing a more meaningful understanding of systemic failures.

By considering the human factor as the "event" (E) and adverse occurrences in GA (accidents, serious incidents, incidents) as the hypothesis (H), the relationship can be described mathematically using Bayes' theorem.

Where:

$$P(H/E)= \frac{P(E\backslash H)P(H)}{P(E)}$$

•P (H|E) is the probability of the hypothesis (an adverse GA occurrence), given that the event E (HFACS category) has occurred.

•P (E|H) is the probability of the event (HFACS category), given that an adverse occurrence, the hypothesis, has occurred.

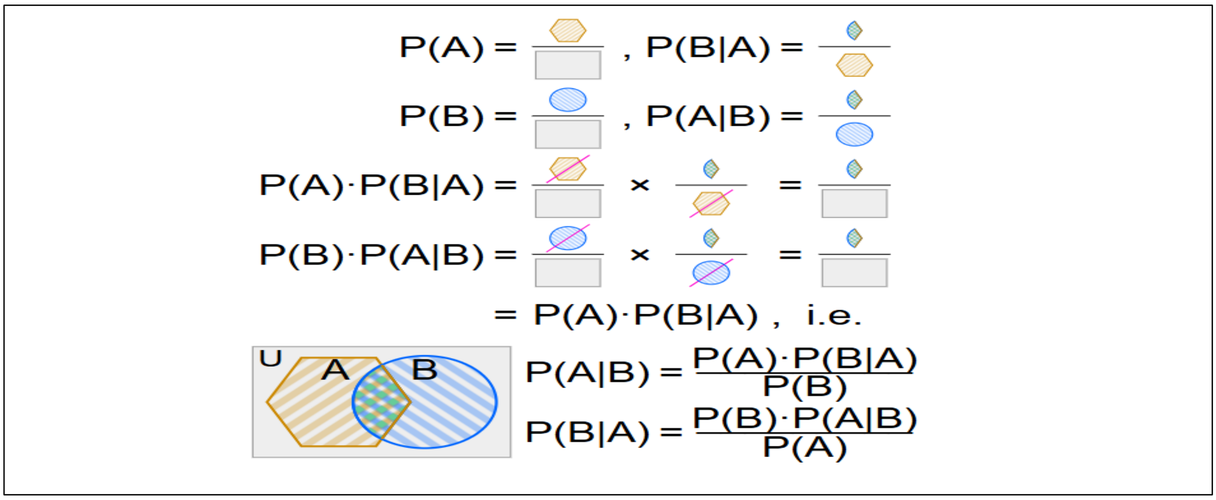
•P (H) is the prior probability of event A occurring.

•P (E) is the prior probability of event B occurring. Thus,

P(E|H) is the posterior probability of an HFACS category occurring when an adverse occurrence in GA, such as an accident, serious incident, or incident has occurred. These calculations were plotted using Bayes' theorem as a first example and thereafter all posterior probabilities were tabled.

Figure 3:

Pictorial Visualisation of the Bayes' Method using Venn Diagrams



2.5 Research Questions

This project was concerned with the discernible patterns of the human factors categories from the GA occurrence data reports in South Africa between the years 2015 and 2017. This timeframe includes a selection of closed and finalised general aviation investigation reports. Given that aviation investigations can extend over months or years before closure, this justified the choice of data timeframe. The timeframe also provided a pre-COVID-19 analysis when incident and accident rates were considered high in the South African GA sector, prior to the decline in flight activity caused by the pandemic. The investigation into the contribution of human factors in adverse GA accidents, serious incidents, and incidents used the HFACS framework to identify the most prevalent latent and active failures. Furthermore, the study incorporated Bayes' theorem to enrich the analysis and understanding of human factor contributions within the HFACS framework. This integration enhanced HFACS by introducing a quantitative dimension to the analysis of qualitative data. Additionally, applying Bayes' theorem to past adverse GA occurrences established a novel approach to quantifying the likelihood of future occurrences arising from similar human factor influences. The following research questions guided the study:

RQ1: What are the most prevalent latent and active human failures contributing to adverse general aviation occurrences in South Africa between the years 2015 and 2017?
RQ2: What latent failures and active failures impact GA accidents, serious incidents, and incidents individually?
RQ3: What latent and active failures impact GA accidents and serious incidents combined?

RQ1 attempted to ascertain the distribution of organisational and human factors across the various HFACS levels of organisational influences, supervisory, preconditions, and unsafe actions. Coding and categorization were used to pinpoint recurring themes such as inadequate supervision, regulatory issues, human errors, pilot actions, and decision-making failures observed in the adverse occurrences. Although conventional HFACS frameworks can effectively identify both latent and active factors that influence adverse institutional occurrences, links cannot be effectively quantified. This shortcoming is addressed in RQ2 and RQ3. To answer RQ2 and RQ3, the Bayes' theorem was used to quantify the probabilistic influence of specific variables by analysing the presence of other related factors.

Chapter 3: Methodology

This chapter presents the methodological foundation used in this study and details the chosen research design, justifying its suitability for addressing the research questions. Descriptions regarding the process of obtaining the study sample are outlined together with the specific sampling method used and its rationale. Details regarding sample size and demographic characteristics are provided. In addition, adhering to ethical principles is paramount and this section addresses the ethical considerations involved in the research report. Finally, the chapter concludes by detailing the methods used to analyse the qualitative and quantitative data.

3.1 Research Design

Research design is “a set of decisions that make up the master plan for specifying the methods and procedures for collecting and analysing the needed information” (Radhakrishnan, 2013, p. 25). Based on the nature of the research study, a non-experimental and mixed-methods design was utilised to comprehensively explore the factors contributing to adverse occurrences in South Africa’s GA sector between the years 2015 and 2017. For the current research study, the analysis focused exclusively on accidents, serious incidents, and incident reports that had been designated as final and closed cases at the time of conducting this research. The cohort consisted of 48 such reports that were analysed. The SACAA conducts investigations at two distinct levels, namely factual and final. Demographic data pertaining to the accident or incident, including details on the location and severity of injuries, are presented in the factual report, which serves as an initial investigation without determining causal factors. The study specifically concentrated on final reports which identified the causal factors linked to the adverse occurrences. The research was thus classified as non-experimental as it did not involve the manipulation of variables or imposing controlled conditions.

A mixed methodology was appropriate for the nature of the study because of the complexity of the research problem. Understanding the underlying factors contributing to adverse GA occurrences is multifaceted. Thus, utilising both qualitative and quantitative methods gave more rigour and insights to the research study. The study consisted of a qualitative component because it utilised thematic content analysis in the coding and identification of themes and latent causes of incidents of adverse GA occurrences. Thematic Content Analysis (TCA) involves analysing the text systematically to identify key themes and patterns across a data set

(Clarke & Braun, 2017). This resulted in a thorough description of the data and allowed the researcher to have a better understanding of the research problem. However, qualitative designs are known to be time-consuming, costly, and difficult for other researchers to duplicate the study. Furthermore, since qualitative research approaches rely on linguistic rather than numerical data, they are usually more subjective and personal. Due to the qualitative aspect of the study and reliance on subjective analysis, it might be a challenge for other researchers to replicate the exact methodology or obtain identical results if the study were to be replicated.

The study also consisted of a quantitative component because Bayesian analysis introduced a statistical element by assessing the likelihood of future occurrences based on identified factors. The quantitative approach was used to minimize subjectivity and researcher bias. In addition, according to scholars, quantitative methods are less subjective because they are based on empirical reasoning and allow for objectivity compared to qualitative methods (Rahman, 2020). By using quantitative methods the researcher increased the chances for others to duplicate the study and conduct further research. It is, however, necessary to be aware of some of the limitations associated with a quantitative methodology. At the most basic level, there is concern about oversimplifying the multifaceted nature of the research problem.

The investigation utilised secondary data derived from South Africa's GA accidents, serious incidents, and incidents reports spanning the years 2015 to 2017. Notably, the research relied exclusively on this single data source. Interestingly, the utilisation of a singular data source rather than employing multiple sources, a practice known as triangulation, may hinder the cross-verification and validation of the study (Azungah, 2018). Nevertheless, scholarly literature suggests that employing established frameworks such as the HFACS framework and Bayes’ theorem enhances the theoretical validity of the research by leveraging recognised models (Beaubien & Baker, 2002; Dekker, 2019; Shappell & Wiegmann, 2001). Additionally, the integration of both methodologies contributes to a holistic comprehension of the study, thereby fortifying its overall validity (Kothari, 2004).

3.2 Coding Process of HFACS Categories

The coding of adverse GA occurrence reports was conducted independently by two raters who included the lead research investigator and the project supervisor, who is an expert in human factors and aviation safety. The primary investigator underwent training that commenced with definitions and tables sourced from Shappell and Wiegmann (2017), supplemented by insights from ICAO (2010) Annexure 13 on Aircraft Accident Investigations. Research suggests that raters who receive training are better at producing consistent results, and more robust and reliable conclusions (Cohen et al., 2018). Subsequently, the lead research investigator applied this training to categorise the contributing elements using the HFACS framework. The raters, including the lead investigator, engaged in self-study to acquaint themselves with the HFACS framework and pertinent topics related to the phenomena under exploration, prior to beginning the coding work.

It was important to count each category within the HFACS framework more than once for a single accident was to be avoided. For instance, if a rater determined that a decision or judgement error caused the adverse occurrence, a routine violation could not be selected for that scenario more than once as both are classified under the unsafe acts category and thus one causation would be counted more than once. In assessing the consistency of evaluations between the two raters, the researchers computed a measure of inter-rater reliability. For cases involving two raters, the percentage difference served as a commonly utilised metric (Rau & Shih, 2021). This method involves determining the absolute difference between the scores assigned by each rater for every factor and then dividing this difference by the average of the scores, presenting the outcome as a percentage (Microsoft Excel 2024 was utilised for these calculations). It is important to acknowledge that the percentage difference method has limitations. For example, it may not be suitable when ratings exhibit high variability or when discrepancies between raters are systematic rather than random. Nonetheless, a notable advantage of this approach is its simplicity in calculation and interpretation (Goodwin, 2001). Ideally, complete agreement occurs when the inter-rater reliability percentage difference is 0. Table 4 offers a summary of an occurrence alongside the responses provided by the raters.

3.3 Sample

The sampling frame consisted of 48 archived investigation reports detailing adverse occurrences within South Africa's GA sector from 2015 to 2017. The use of secondary data was advantageous, leveraging the accessibility of the official SACAA’s (2023) web-based database which is available to the public. The inclusive criteria applied to the reports used in this study were based on the following: (*a*) data falling within the years 2015 to 2017, (*b*) final and closed investigation reports at the time of data retrieval, and (*c*) accidents, serious incidents, and incidents that occurred with the borders of the Republic of South Africa.

A non-probability convenience sampling method was employed to attain the desired sample. Unlike random selection, non-probability sampling involves the intentional selection of specific units by the researcher. Given the study's focus on adverse GA occurrences in South Africa within a defined timeframe, convenience sampling proved suitable for this research. This method facilitated the careful selection of investigation reports, and given the fact that the sampling method was both convenient and economical, it was appropriate for use in this research study. By using a non-probability convenience sampling approach, the researcher identified the relevant population efficiently for quality control. Thus, this method offers advantages in terms of convenience and cost-effectiveness.

Furthermore, given that aviation investigations can extend over months or years before closure, this justified the choice of data timeframe (2015-2017). However, limitations arose from the niche sample, creating a challenge in the generalization of findings to the broader population, affecting external validity. In addition, the researcher's reliance on aviation investigators' integrity introduced potential data quality issues, lowering control over data accuracy. This reliance on investigator-reported data may compromise reliability and validity through errors and inaccuracies. In addition, secondary data restricted scope, follow-ups, and in-depth exploration. Moreover, data bias stemming from original demographic or cultural contexts may hinder generalizability to diverse settings and populations.

From a total of 48 investigation accident and incident reports, 16.6% were from the year 2015, 41.7% were from 2016, and another 41.7% were from 2017 (refer to Table 6). The highest number of occurrences originated from the Gauteng Province at 37.5%, followed by the Limpopo Province at 16.5%, Western Cape Province at 12.5%, Eastern Cape Province at 8.3%, the Free State, Mpumalanga Province, North West Province, and KwaZulu-Natal provinces all at 6.3% (refer to Table 7 and Figure 4). Regarding pilot qualifications, 39.6% of pilots in command held commercial licences, 35.4% held private licences, 16.7% held national licences, and 8.3% had student licences (refer to Table 8).

3.4 Demographic Variables

The investigation reports included demographic information of the sample. The information provided included the location of occurrence, number of people on board, number of people injured, number of people killed, and licence type of the pilot in command.

3.5 Procedure

It was the researcher's responsibility to adhere to the ethical guidelines. After requesting ethical clearance from the University of the Witwatersrand Human Research Ethics Committee, the researcher was granted permission to conduct the research (Ethics clearance certificate number: MAORG/23/10W; Appendix D). Once permission was obtained, the researcher collected 48 adverse GA occurrence reports between the years 2015 and 2017 from the SACAA online database. The researcher was not required to submit an access request letter by the university for permission to access the investigation reports since the SACAA is an online database open to the public. The investigation reports were downloaded and stored on a laptop with password security. Only the researcher and research supervisor had access to the downloaded documents.

The data obtained from the SACAA website was coded into Microsoft Excel to transcribe important information retrieved from the report analysis, such as location of occurrence, synopsis, probable cause, number of people on board, number of people injured, number of people killed, and licence type of the pilot in command. To ensure the study's reliability and generalizability, a mixed-methods (triangulation) design, which consisted of both quantitative and qualitative research methods, was used. The sample consisted of 48 adverse GA occurrences reports from 2015 to 2017. The HFACS framework was used to assess potential human factors which were then assessed using Bayes' theorem analysis to determine the likelihood of future events.

3.6 Independent Variables

The independent variables considered the cause of adverse GA occurrences (accidents, serious incidents, or incidents). The latent systemic failures identified through thematic content analysis of the investigation reports were operationalized using the HFACS framework and Bayes' theorem. This was achieved through the following:

1. The HFACS framework was used to identify latent and unsafe acts that contribute to adverse GA occurrences in South Africa.
2. The Bayesian method was used to assess the severity of these underlying factors by determining the most common causal factors and calculating the probability of an event occurring, given that another event has occurred (Gelman & Shalizi, 2013).

3.7 Dependant Variable

The dependent variables were represented by the occurrence of adverse events in the South African GA sector, specifically focusing on accidents, serious incidents, or incidents within the database spanning 2015 to 2017.

3.8 Data Analysis

For the qualitative phase of the study, HFACS was used to identify latent and active failures in the data. The data collected from the SACAA online website were coded into Microsoft Excel and then imported into IBM Statistics v.29 for statistical analysis. Thereafter, Bayes' theorem was applied to determine the probability of an adverse GA occurrence occurring given the prior probability of a specific human factor in the occurrence. Thus, human factors with higher prior probabilities were more likely to be significant contributors to adverse GA occurrences. To achieve this objective, statistical software packages were employed to analyse and quantify the GA HFACS data. The algorithms within these platforms were utilised to construct a mathematical representation of the relationships and dependencies between different pieces of information extracted from the investigation reports. This analysis of accidents, serious incidents, and incidents was used to interpret the data and make predictions based on new information input into the system.

Chapter 4: Results

The following chapter presents an analysis of the qualitative and quantitative results obtained from the data that was collected for the study. The qualitative results indicated that a total of 414 human and organisational factors were found in 48 adverse GA occurrences in South Africa between 2015 and 2017. The key themes that emerged from the analysis across accidents, serious incidents, and incidents were human resources, organisational policy, organisational climate, inadequate supervision, failure to correct a known problem, physical environment, the condition of operators, decision errors, skill-based errors and routine violations. The quantitative results were divided into descriptive and inferential statistics. Tables and Bayesian methodologies were used to illustrate the main findings.

4.1 Qualitative Findings

The sampling frame consisted of 48 archived investigation reports detailing adverse occurrences within South Africa's GA sector from 2015 to 2017. The inclusive criteria applied to the investigation reports used in this study were based on the following: (*a*) data falling within the years 2015, 2016, and 2017, (*b*) closed investigation reports at the time of data retrieval, and (*c*) accidents, serious incidents, and incidents that occurred with the borders of the Republic of South Africa. The study utilised TCA in the coding and identification of themes. TCA involves systematically analysing the text to identify key themes and patterns across a data set (Clarke & Braun, 2017). This section will focus on the rater categorisation, agreement percentages, and the results from the coding process and application of the HFACS categories to the 48 investigation reports.

4.2 Rater Categorisation

The two raters classified contributing factors into distinct levels within the HFACS framework using a systematic bottom-up approach. The review process commenced with Level 1 (unsafe acts - active failures like errors or violations from the pilot's viewpoint) and progressed to Level 4 (organisational influences - latent failures such as operational or resource management issues). Each factor in the HFACS framework was rated independently on a scoring scheme with a ratings of 1 to 10 (Refer to appendix C). Following individual evaluations by each rater, an inter-rater reliability assessment was performed by calculating the percentage agreement for each factor (Appendix C). Subsequently, a second round of rating was undertaken to enhance agreement levels towards a desirable threshold (~0.80).

Table 3:

Inter-rater Reliability Analysis (Percentage Agreement)

HFACS Category	Interrater Agreement	Remarks
(Level 4) Organisational Influences	84%	Reliable
Resource management	89%	Reliable
Organisational climate	77%	conditionally reliable
Organisational process	83%	Reliable
(Level 3) Unsafe supervision	87%	Reliable
(Level 2) Preconditions for unsafe acts	84%	Reliable
Environmental factors	74%	conditionally reliable
Personnel factors	91%	Reliable
(Level 1) Unsafe acts	81%	Reliable
Errors	83%	Reliable
Violations	77%	conditionally reliable

Table 3 presents valuable insights into the consistency of HFACS classifications used by the different evaluators. The generally high inter-rater agreement (> 80% for most categories) suggests that the raters were applying the HFACS framework in a consistent manner. This strengthens the reliability of the overall HFACS analysis conducted on aviation adverse occurrences. At Level 1, where errors occur directly due to unsafe acts, the findings indicated a substantial frequency of occurrences with an overall agreement of 81% among raters. This indicates a reliable categorisation of errors attributed to individual actions as a result of poor judgment, decision-making, skill-based errors, and routine violations. Level 2, which addresses preconditions for unsafe acts, highlighted the significance of environmental and personnel factors.

Notably, while environmental factors demonstrated conditionally reliable agreement at 74%, personnel factors showed a remarkable reliability of 91%. Furthermore, the study revealed instances where inadequate supervision or supervisory violations on Level 3 contributed to operational failures. The substantial agreement rate of 87% among raters indicated a reliable assessment of supervisory shortcomings. Lastly, at the highest level, the analysis identified resource management, organisational climate, and organisational processes as significant contributors to adverse GA occurrences, with agreement rates ranging from 77% to 89%. From the inter-rater reliability computations in Table 3, it was determined that there was an average of 85% (SD=5%) agreement on decisions made by the raters and thus categorisation was considered reliable. However, only once inter-rater reliability was ensured, a final agreement was reached on the outcome of HFACS categorisation.

Table 4:

Frequency of Active and Latent Failures across 48 Accidents, Serious Incidents, and Incidents in South Africa (2015-2017)

Failure Type	**Accidents**	**Serious incidents**	**Incidents**	**Total**
Organisational Influences (Level 4)				
Resource management	2	3	1	6
Human resources	13	0	4	17
Budget restrictions	1	0	1	2
Equipment issues	4	5	0	9
Organisational climate	25	5	6	36
Structure of command	1	0	1	2
Company policy	26	5	5	36
Company culture	0	1	1	2
Organisational process	3	0	1	4
Deadline pressure	0	0	1	1
Oversight	1	1	1	3
SOPs	5	3	0	8
Total organisational influences	68	28	18	131
Unsafe Supervision (Level 3)				

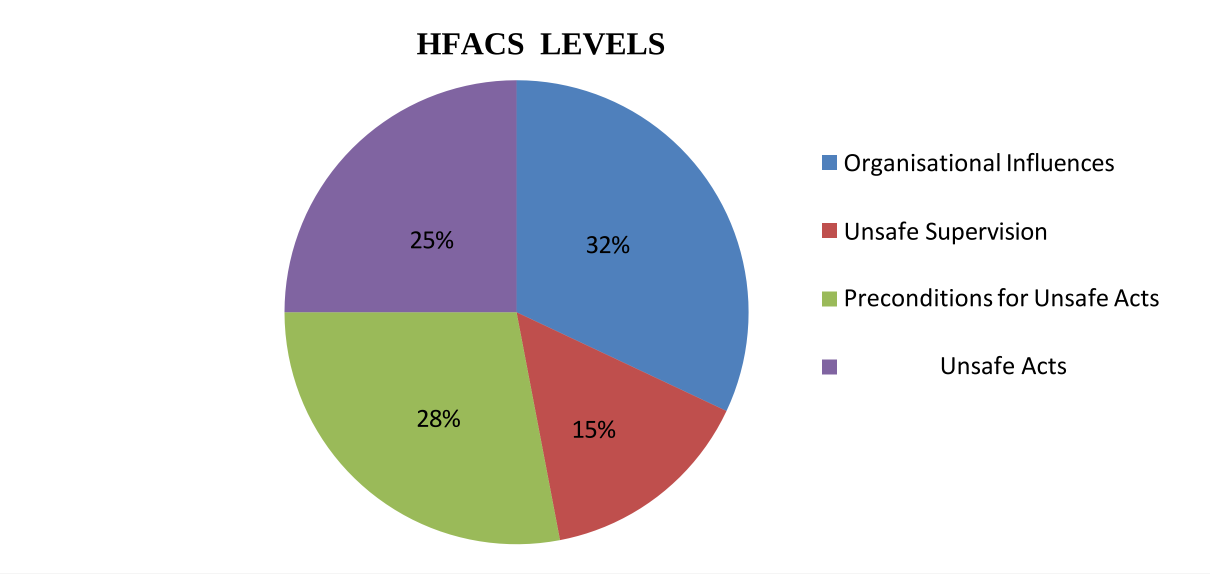
Failure Type	Accidents	Serious incidents	Incidents	Total
Inadequate supervision	28	7	7	42
Planned inappropriate operation	4	3	1	8
Failure to correct a known problem	12	1	6	19
Supervisory violation	0	1	0	1
Total unsafe supervision	38	12	14	64
Preconditions for Unsafe Acts (Level 2)				
Physical environment	36	4	10	48
Technological environment	2	3	1	6
Condition of operators	26	6	5	37
Adverse mental state	3	0	3	6
Adverse psychological state	0	0	1	1
Physical/mental limitations	0	0	2	2
Personnel factors	4	1	2	7
Crew/resource management	3	0	4	7
Personal readiness	0	0	0	0
Total Preconditions for Unsafe Acts	74	14	28	114
Unsafe Acts (Level 1)				
Decision errors	30	10	6	46
Skill-based errors	27	18	7	42
Perceptual errors	1	0	0	1
Routine violations	10	0	6	16
Exceptional violations	0	0	0	0
Total Unsafe Acts	68	18	17	105

The results in Table 4 indicate that 414 HFACS causal factors were determined from the 48 general aviation accidents, serious incidents, and incidents investigation reports. It is important to note that the total number of organisational level and front-line human factors exceeded 48 cases as most of the investigation reports contained multiple contributing factors across different categories of the HFACS framework. However, to avoid overrepresentation of a single case, it was important for the researcher to avoid counting each category within the HFACS framework more than once for any individual report. The obtained outcome showed that a total of 414 factors as per HFACS were found involved in the 48 reports analysed, of which 309 (74.64%) were at the organisational level and 105 (25.36%) were at the frontline or operational level.

For the purposes of this study, organisational influences (Level 4), unsafe supervision (Level 3), and preconditions were classified as organisational level because latent failures represent high-level factors that shape the environment and conditions in which frontline workers operate. These factors are typically beyond the direct control of frontline personnel (Shappell et al., 2017). The unsafe act (Level 1) was classified as the frontline or operational level. This level focuses on the immediate circumstances that operators face before an operator commits an unsafe act. The unsafe acts level represents the things people do (or fail to do) that often result in adverse outcomes. Table 4 provides a summary of the identified active and latent failures in adverse GA occurrences in South Africa using the HFACS framework.

Figure 4:

Percentage Distribution of the Human Factors Analysis and Classification System Four Levels (2015-2017)



The analysis of 48 investigation reports in Table 4 identified a total of 414 human factor elements classified into the HFACS categories. As shown in Figure 4, the majority of the factors (*n* = 131; 32%) fall under Organisational influences, followed by Preconditions for Unsafe Acts (*n* = 114; 28%), Unsafe Acts (*n* = 105; 25%), and Unsafe Supervision (*n* = 64; 15%).

Figure 5:

Distribution of Human Factors Analysis and Classification System Levels across Adverse General Aviation Occurrences (2015-2017)

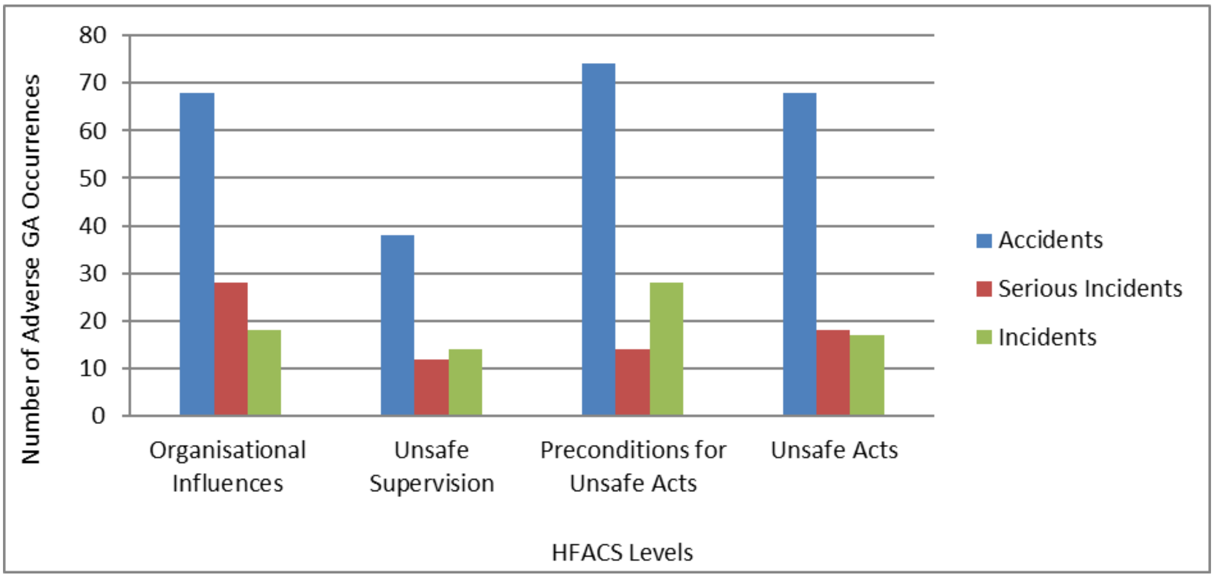


Figure 5 illustrates the distribution of HFACS levels across accidents, serious incidents, and incidents in GA between 2015 and 2017. The highest proportion of failures is observed at the Preconditions of unsafe acts (Level 2), particularly in accidents (74 occurrences), followed by Organisational influences (Level 4) and Unsafe acts (Level 1) (68 occurrences for each level. Serious incidents and incidents show a relatively lower distribution across all the HFACS levels, however; Organisational influences had the most frequent category for serious incidents (28 occurrences). Unsafe supervision (Level 3) had the lowest distribution across accidents, serious incidents, and incidents. The research subsequently addressed the following research question:

4.2.1 RQ1

What are the most prevalent latent and active human failures contributing to adverse general aviation occurrences in South Africa between the years 2015 and 2017?

The key themes that emerged from the analysis across accidents, serious incidents, and incidents were human resources (17 occurrences), organisational policy (36 occurrences), organisational climate (36 occurrences), inadequate supervision (42 occurrences), failure to correct a known problem (19 occurrences), physical environment (48 occurrences), conditions of the operator (37 occurrences), decision errors (46 occurrences), skill-based errors (42 occurrences) and routine violations (16 occurrences). It is important to note that the categories and corresponding sub-categories (i.e. the Themes) were sorted based on their placement on the HFACS framework's levels, thus organisational influences are listed first, followed by unsafe supervision, preconditions for unsafe acts, and unsafe acts. The order also represents how the four HFACS levels are separated between latent (organisational influences, unsafe supervision, and preconditions for unsafe acts) and active failures (unsafe acts).

4.2.2 Human Resources

This theme highlighted a potential shortage of highly skilled pilots and flight instructors who have the specific knowledge to maintain proficiency. The following extracts are an indication of training issues. It is evident from investigation report 6 that the serious incident involved a student pilot who displayed a lack of acceleration judgement and control during the taxiing phase after landing. Investigation report 40 revealed that the accident that killed the pilot and two passengers was caused by the private pilot's failure to adhere to weight and balance limitations. It emerged from this investigation report that the private pilot did not uphold the stringent safety regulations set by international and national aviation governing bodies such as the Federal Aviation Administration (FAA) and the SACAA. The following extracts illustrate insufficient training:

> *"A student pilot, from an aviation training organisation (ATO) was the sole occupant on board the aircraft. He was engaged in his second solo consolidation flight. After landing on Runway 22, upon vacating the runway at exit 2, air traffic controller (ATC) observed the pilot vacating at a substantial speed (too fast) and the aircraft veered off the taxiway and carried through a bush type of terrain. As the pilot attempted to steer the aircraft back onto the taxiway, the propeller struck a large rock, which was concealed by vegetation. The wheel spats were also damaged by smaller rocks. The ATC activated the crash alarm and the emergency vehicle (RV1) was dispatched to the aircraft to render assistance. The aircraft was towed back to the hangar as the propeller sustained substantial damage. The student pilot was not injured."* (**Investigation Report 6**)

"The pilot and the two passengers were fatally injured during the accident. The aircraft was destroyed during the impact sequence as well as by the post-impact fire that erupted thereafter. The investigation revealed that although the aircraft was within its weight limit, it was operated close to its maximum weight limit, outside of its centre of gravity (CG) limit, and at high-density altitude, leading to a poor take-off and climb performance which resulted in a crash." (**Investigation Report 40**)

4.2.3 Organisational Climate

This theme accounted for 36 contributory factors in adverse GA occurrences. The theme provides an overview of an environment shaped by the organisation's way of doing things, its values, behaviours, levels of trust, and support between employees and management. The fatal accident that killed the pilot and occupant displays an organisational climate that is complacent in enforcing safety measures, especially regarding adverse weather conditions. The private pilot was unable to handle instrument meteorological conditions (IMC), in other words, this means flying in conditions that require pilots to navigate solely by instruments. The pilot experienced difficulties operating the aircraft as a result of low visibility, cloud cover, and drizzle.

In another report, the Aircraft Maintenance Organisation's (AMO) preliminary findings while investigating the incident indicated two prior incidents that left some undercarriage components damaged due to hard landings. The two incidents were never reported. The following extracts illustrate training reporting as a reflection of organisational climate:

"On 13 October 2016 at approximately 0915Z, the private pilot (PPL) accompanied by a passenger who were both German Nationals, took off from Manzengwenya airfield in KwaZulu-Natal on a private flight to BrakpanBenoni aerodrome (FABB) in Gauteng (…) However, en-route to Brakpan-Benoni aerodrome, the aircraft was involved in an in-flight breakup in instrument meteorological conditions (IMC) in the vicinity of the Jozini dam in KwaZulu-Natal near the Mozambique border. There was slight cloud cover and it was drizzling. The pilot and the passenger were fatally injured during the accident sequence. The aircraft was destroyed by a post-impact fire that erupted following impact with the ground.

The investigation revealed that the pilot entered into IMC conditions and subsequently became disorientated and lost control of the aircraft." (**Investigation Report 37**)

"The nose section of the aircraft impacted the runway and skidded for a short distance until it came to a stop. The damage to the aircraft was limited to the nose section. There was no exposure of injury to any of the occupants. The aircraft was inspected by an appropriately authorised AMO prior to recovering it from the scene. The AMO inspected the aircraft with the aim of determining the cause of the nose gear collapse. The AMO's preliminary finding was that the aircraft suffered an unreported hard landing on a previous training flight which caused damage to some of the undercarriage components and/or parts. During this last incident flight, their observation was that another hard landing was experienced which probably contributed to the ultimate failure of the damaged undercarriage components and/or parts. After the damaged components and/or parts were replaced the aircraft was flown back to FAPA safely." (**Investigation Report 36**)

4.2.4 Organisational Policy

Organisational policy accounted for 36 contributory factors in general aviation occurrences that involved policies set by the organisation. The following extract illustrates a serious incident that reflects the absence of effective communication between pilots. There was no adherence to SOPs for aviation communication set by civil aviation governing authorities such as the SACAA and ICAO, which include establishing initial contact with air traffic controller (ATC), landing clearance requests, and receiving landing clearance from the ATC. The ATC failed to manage the flow of simultaneous landings and left the commercial pilots to self-coordinate. The following extract illustrates a gap in regulatory policies:

"Two aircraft, a Foxbat, ZU-KOL and a R44 helicopter, ZS-RXD were involved in a mid-air collision whilst on final approach for landing at Kitty Hawk aerodrome. The pilot of the Foxbat stated that he suddenly heard a loud bang which was followed by severe engine vibrations. According to the pilot of ZS-RXD, he suddenly saw aircraft ZU-KOL coming from the left, whereupon his helicopter's main rotor struck the aircraft on its right wing and the engine propeller blades (…) neither pilot sustained injuries during the accident sequence.

The investigation determined that the collision was due to neither pilot being able to see the other during the final approach. The aircraft's mid-air collision was due to *thorough communication failure by the helicopter pilot during landing approach following the decision by the helicopter pilot to shorten his right leg base by flying overhead and making a tight turn in his landing attempt."* (**Investigation Report 38**)

4.2.5 Inadequate Supervision

This theme was identified through various descriptions where supervisors and instructors demonstrated a lack of proactive involvement and a failure to intervene during emergencies. The serious incident from investigation report 2 revealed that rotor speed dropped below the minimum threshold which led to a hard landing and subsequent damage to the helicopter. The report highlights the instructor's failure to intervene earlier and ensure the required rotor speed. The accident from investigation report 31 provides a narrative where the instructor failed to provide the Commercial pilot with the necessary guidance during a landing sequence. Furthermore, the fatal accident from investigation report 42 indicates that the instructor was aware that the Student pilot was struggling to maintain control but failed to intervene before losing sight of the aircraft. The following extracts illustrate inadequate supervision:

> *"The pilot, accompanied by a student pilot, was involved in a training flight when the accident occurred. According to the pilot in command (instructor), who had approximately 2070 hours helicopter flying experience and 120,7 flying hours on the helicopter type, the main rotor was rotating at low revolutions per minute (rpm) during the latter phase of the autorotation, and a hard landing followed. The main rotor then flexed and severed the tail boom. The helicopter was stopped and all electrically controlled components were switched off. Neither the instructor nor the student was injured during the event. The investigation revealed that the helicopter landed hard during autorotation resulting in the main rotors severing the tail boom. The hard landing was caused by the RPM dropping below minimum rotor speed."* (**Investigation Report 2**)

> *"The aircraft took off from FASI on a training flight when 14 minutes into the flight, the aircraft returned to FASI. On approach, the aircraft was at a high speed and landed too deep on runway 32. On touch-down, the aircraft bounced and lost directional control before impacting and colliding with a wall. The instructor was aware that the aircraft had a high speed on approach and landing however, he took control when he realised that the aircraft was going to overshoot the end of the runway. Both occupants sustained minor injuries. The investigation revealed that the cause of the accident was*

due to high-speed landing leading to the aircraft landing deep in the runway, bouncing, and losing directional control. A contributing factor was the instructor not intervening timeously to prevent the accident from occurring." (**Investigation Report 31**)

"The student pilot took off from Runway 11 at Kroon Airfield on a solo training flight. After flying a circuit he executed a landing which was uneventful. During his second circuit, when turning on the cross-wind leg for Runway 11 the microlight was doing abnormal turns to the left and right. The instructor pilot who was in radio contact with the student instructed him not to do the turns and stay in the circuit. The student then turned downwind. It seems as if the microlight aircraft was oscillating from left to right with a continuous increase and decrease in height and a continuous change in power settings. According to the instructor pilot, it appeared to him the student pilot was not in control of the microlight aircraft and he instructed him to increase power and get control of the aircraft. He also instructed the student to turn towards the airfield as he was passing the normal point of turning base-leg.
*The pilot then started his turn to the left for the base-leg. The turn was at a high angle of bank and the turn was continuous until the aircraft was almost inverted. The instructor pilot then lost sight of the aircraft and moments later saw black smoke in the vicinity where he lost sight of the aircraft. He then rushed to the scene and found the wreckage engulfed in flames. The pilot was fatally injured and the microlight aircraft was destroyed by the post-impact fire." (**Investigation Report 42**)*

4.2.6 Failed to Correct a Known Problem

This theme demonstrates instances where supervisors or instructors were aware of safety issues but failed to take corrective action to mitigate them. The accident report from investigation 31 indicated that during flight training, the instructor was aware of the excessive speed during a landing approach but failed to take control of the aircraft until it became apparent that an overshoot and loss of control were imminent. This demonstrates the instructor's failure to actively monitor and guide the Student pilot during a critical phase of flight. The following extract illustrates the failure to correct a known problem:

"(…) on approach, the aircraft was at a high-speed and landed too deep on runway 32. On touch down, the aircraft bounced and lost directional control before impacting and

colliding with a wall. The instructor was aware that the aircraft had a high-speed on approach and landing however, he took control when he realised that the aircraft was going to overshoot the end of the runway. Both occupants sustained minor injuries. The investigation revealed that the cause of the accident was due to a high-speed landing resulting in a bounce and a loss of directional control. The lack of or poor intervention by the instructor contributed to the accident." (**Investigation Report 31**)

4.2.7 Physical Environment

This theme was mentioned explicitly as a contributory factor in numerous investigation reports. The theme was represented by physical environmental factors such as airfield conditions, weather, terrain, visibility, and obstructions. There was a fatal accident after the aircraft encountered rotor turbulence. This is a physical environment factor that affected the air environment and caused a sudden loss of altitude and subsequent crash. The following extract illustrates physical environmental factors:

> *"According to the pilot of ZU-ICI, the two aircraft were flying along the mountain valley using thermals to gain height and continued to climb over mountains which reached an elevation of approximately 5655 feet (…). ZU ICI observed ZU-CIU losing altitude rapidly and impacting the mountain edge. The pilot was fatally injured and the passenger was seriously injured. The aircraft was substantially damaged. The investigation revealed that the aircrafts were flying using thermals to gain height with the engine power reduced to idle. The aircraft flew towards the mountain along the valley in a northerly direction and turned west between the mountain valleys. It encountered rotor turbulence which led to loss of height, and the aircraft impacted the side of the mountain in a nose-down altitude."* (**Investigation Report 17**)

In another accident report, the rising sun impaired the pilot's vision. This led to the pilot's loss of situational awareness during take-off and impaired the operators' ability to avoid power lines. Similarly, another accident was caused by the pilot's loss of directional control during a strong gust of wind which caused the right wing to lift unexpectedly. The following extracts provide illustrations of natural environmental conditions:

“The pilot accompanied by a passenger, took-off for a private flight, at approximately 03:30Z from Blaauwboschpan farm with the intention to fly overhead the farm. He then decided to land on a nearby farm and took off again. During take-off transition, the pilot noticed the power lines in his path which he was not aware of. He took evasive actions to avoid the power lines however the main rotor blades made contact with the power lines resulting in the helicopter impacting the ground. The helicopter was substantial. At the time of reporting this accident, the helicopter had already recovered from the accident site without the consent of AIID. The investigation revealed that the helicopter accident was due to a collision with power lines following the pilot’s visual obstruction by the rising sun at the time. The time mentioned above is exactly the time at which the sun rises during this season.” (**Investigation Report 26**)

“The pilot, the sole occupant on board the aircraft, was engaged in a fire fighting operation. He indicated that the hopper tank was filled to capacity, and runway 17 was elected for take- off with the prevailing wind from the west at approximately 15 knots according to his assessment of the wind sock. The pilot stated that he commenced with the take-off run and as the tail of the tail dragger lifted, he encountered a strong gust from the right, which lifted the right wing and caused the aircraft to bounce. The pilot was unable to counter-act the situation and he lost directional control of the aircraft, which veered off runway 17 to the left.
The pilot was not injured in the accident. The aircraft sustained substantial damage when both the main landing gear struts broke off and the propeller bent after making contact with the ground.” (**Investigation Report 5**)

4.2.8 Condition of Operators

One of the themes that emerged was the condition of operators. A national pilot licence holder lost control of the aircraft following an inadvertent spin caused by excessive loss of airspeed. This suggests potential situational misjudgement or a lapse in decision-making. The investigation revealed that no prior mechanical or system failures had occurred. This indicates that cognitive impairment factors like mental fatigue or emotional distress impaired the pilot’s ability to react effectively before the fatal accident. The following extract illustrates condition of the operator’s adverse mental state:

"The pilot who was the sole occupant on-board the glider was conducting a private flight from Potchefstroom (FAPS) aerodrome to Orkney and back when the accident occurred.
Visual meteorological conditions (VMC) prevailed in the area. The launching began at about 11H30Z. ZS-GYY was successfully launched upon which it climbed and headed towards Orkney area as planned. In approximately three hour's flight time on returning to FAPS at about 1 000 feet above ground level (AGL), the pilot reported his position to FAPS ground advisor "downwind active runway 03" and his intension to land, which was acknowledged.
The aircraft did not show up as expected and an aerial search was launched upon which ZS- GYY wreckage was spotted opposite the South African army base, approximately 1.4 km south west of FAPS. The aircraft was destroyed by impact forces and the pilot was fatally injured. Post-accident examination of the wreckage established that no pre-impact failures had occurred in any of the primary flight control systems. The investigation concluded that the accident was due to loss of control after the aircraft went into an inadvertent spin that developed from excessive loss of airspeed after a turn." (**Investigation Report 47**)

4.2.9 Decision-making Error

This was a recurrent theme in numerous reports and was often evident in instances where the operator selected a course of action that failed to align with the demands of the situation. Report 23 found no apparent mechanical defects during the post-accident investigation. The narrative suggests that the national pilot failed to respond to the situational demands before the fatal crash. The phrase *"lack of a sense of immediate danger"* in the investigation report suggests that the pilot either underestimated the risks or delayed necessary critical decisions to mitigate the problem. Similarly, the accident from investigation report 24 indicates that the flight was conducted under visual flight rules (VFR) and preceded without issues until the aircraft arrived at Driefontein Airfield. The pilot's late decision-making to initiate a go- around resulted in the aircraft failing to gain sufficient lift before reaching the end of the runway. The following extracts provide illustrations of pilot error:

"The pilot was fatally injured and the passenger sustained serious injuries. The aircraft was destroyed by post-impact. Accidents and incident investigation division (AIID) was notified and the investigators were promptly dispatched to the scene. In-depth examination of the

*wreckage and the engine did not identify defects. The investigation determined that the accident was as a result of poor decision making and lack of a sense of immediate danger." (**Investigation Report 23**)*

"The pilot, accompanied by three passengers, took off on a private flight from Vredendal aerodrome in the Western Cape for Driefontein airfield, an unmanned aerodrome near Fochville in North West. The flight was conducted under VFR conditions. On arrival at Driefontein – his first visit here – the pilot conducted a low-level inspection of the runway, and then commenced his approach for runway 21. According to the pilot, he configured the aircraft appropriately and was expecting a normal landing. It appears, however, that he was caught off guard by the upslope of the runway. During the landing roll, he realised that he was running out of runway and decided to initiate a go-around. This decision came too late and the aircraft failed to get airborne by the time it reached the end of the runway. It continued straight ahead, crashed through the perimeter fence, skidded over a provincial road and came to a halt against a tree." (**Investigation Report 24**)

4.2.10 Skill-based Errors

This was represented by lapses in attention, slips, memory failures, lack of experience, or inadequate practice. A student pilot completed pre-flight checks, and initiated take-off, and touch-and-go-landing without incident. A skill-based error occurred shortly after the student returned for another touch-and-go landing. The manoeuvre was executed improperly with the flaps retracted to zero degrees. This led to a stall and subsequent crash. An accident involving a commercial pilot and a passenger resulted in fatal injuries after the pilot failed to maintain control of the aircraft. The pilot did not take corrective action to recover the aircraft before the crash. The report indicated no evidence of environmental or mechanical anomalies in the post-accident examination. The following extracts illustrate the error:

"The student boarded the aircraft and completed the pre-start checks before starting the engine. Take-off from FAVV was uneventful, followed by a good-touch-and-go landing on runway 21 at FAPS. Within a few minutes the student returned for an additional touch-and- go. After touchdown the aircraft bounced severely, and the student took power with the intent to effect an instant go-around maneuverer with the

flaps retracted to zero degrees. The aircraft stalled and impacted the ground heavily approximately 177m, to the right of the runway 21 threshold. The aircraft was substantially damaged. The pilot sustained serious injuries to his head. A post-accident examination of the aircraft did not reveal any pre-impact anomalies that would have precluded normal operation." (**Investigation Report 1**)

"On Sunday 3 September 2017, at 0908Z, ZS-JDN, a Cessna 172M, departed from Wonderboom Aerodrome (FAWB) for a private flight with the intention of returning to FAWB. The intention of the flight was to route to the Hartbeespoort Dam and surrounds as a private flight operating under Part 91. At 0940Z, a local farmer noticed smoke rising from the mountainside on his property. On further investigation, the farmer found the wreckage of the aircraft. This was immediately reported to the local police and fire departments. The aircraft was destroyed in the post-impact fire and both occupants on board had sustained fatal injuries. The investigation determined that the most probable cause was that the aircraft experienced a loss of airspeed while attempting to climb out of the valley. This led to a stall condition, which caused the aircraft to impact terrain due to insufficient altitude for recovery." (**Investigation Report 7**)

In another investigation report, a national pilot engaged in flight operations although the pilot had insufficient operational experience on the aircraft type. The following extract illustrates this error:

"The pilot accompanied by a passenger took off from Bapsfontein for a private flight. The pilot stated that he stalled the microlight during take-off. The microlight landed on some vegetation around the airfield. The aircraft sustained substantial damages during the accident sequence whereby the pilot and his passenger experienced minor injuries. The investigation revealed that the cause of the accident was lack of control of the aircraft configuration due to insufficient operational experience on the aircraft type." (**Investigation Report 44**)

4.2.11 Routine Violation

This theme was represented by instances where the operator engaged in actions that deviated from SOPs. These deviations are often considered normal practice, minor, and frequently overlooked. A student pilot was observed by the air traffic controller vacating at an excessive speed (too fast). This serious incident indicates that the student pilot was not following SOPs for taxiing at a controlled speed. The following extract illustrates this violation:

> *"A student pilot, from an aviation training organisation (ATO) at FAOH was the sole occupant on board the aircraft. He was engaged in his second solo consolidation flight. After landing on Runway 22, upon vacating the runway at exit 2, air traffic controller (ATC) observed the pilot vacating at a substantial speed (too fast) and the aircraft veered off the taxiway and carried through a bush type of terrain. As the pilot attempted to steer the aircraft back onto the taxiway, the propeller struck a large rock, which was concealed by vegetation. The wheel spats were also damaged by smaller rocks. The ATC activated the crash alarm and the emergency vehicle (RV1) was dispatched to the aircraft to render assistance. The aircraft was towed back to the hangar as the propeller sustained substantial damage. The student pilot was not injured in the incident. The student pilot lost control of the aircraft after landing and the aircraft veered off the taxiway into the bush where the propeller struck a large rock concealed by vegetation."* (**Investigation Report 6**)

4.3 Quantitative Findings

The quantitative results were produced by the IBM Statistical Package for Social Sciences (SPSS) version 29 program and divided into descriptive and inferential statistics. Furthermore, the Bayes' theorem was used to further analyse the data. Tables and Bayesian results were used to illustrate the main findings of the inferential analyses.

4.3.1 Descriptive Statistics

Table 5:

Frequency and Percentage Distribution of Adverse General Aviation Occurrences in South Africa across Three Years

Year	Frequency	Percentage
2017	20	41.67
2016	20	41.67
2015	8	16.66
Total	48	100

It is evident from Table 5 that the majority of adverse general aviation occurrences took place in the years 2016 and 2017 (41.67%), while the least number of adverse occurrences took place in the year 2015 (16.66%).

Figure 6:

Trends of Adverse General Aviation Occurrences (Accidents, Serious Incidents, and Incidents) between 2015 and 2017

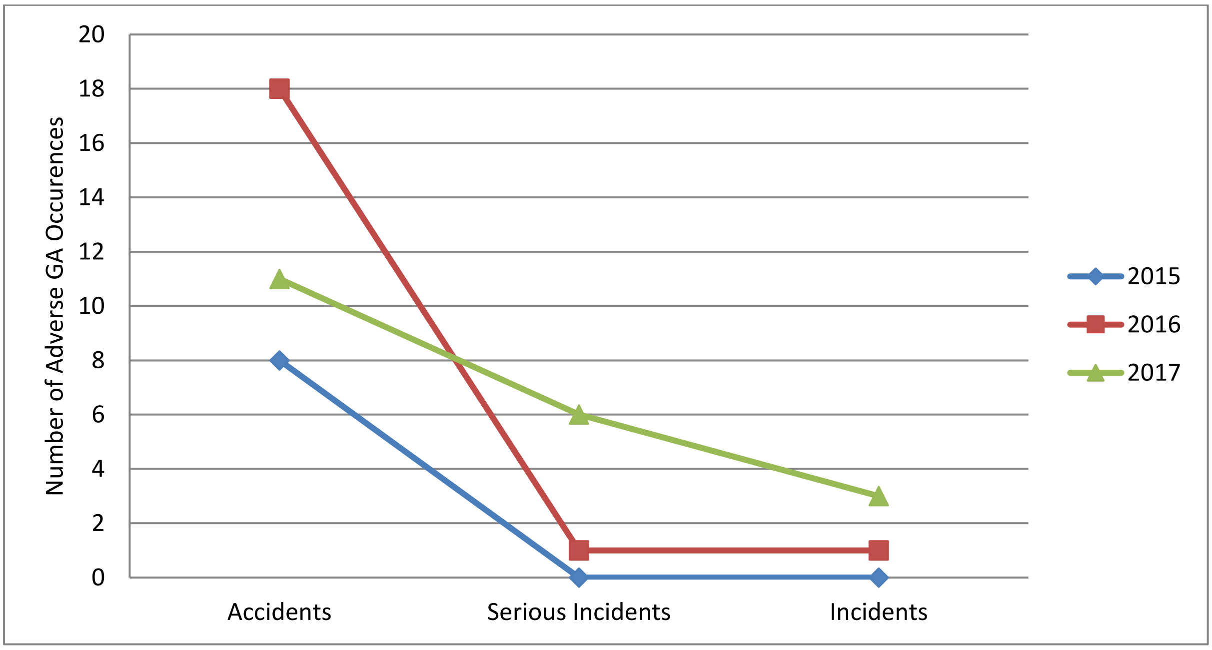


Figure 6 shows the number of adverse general aviation accidents, serious incidents, and incidents between 2015 and 2017. The number of accidents increased significantly increased from 2015 (*n* = 8) to 2016 (*n* = 18), then decreased in 2017 (*n* = 11). There were zero serious incidents in 2015 (*n* = 0), with a minimum number in 2016 (*n* = 1) followed by a slight increase in 2017 (*n* = 3). The number of incidents remained low in 2015 (*n* = 0) and 2016 (*n* = 1), followed by a noticeable increase in 2017 (*n* = 6).

Table 6:

Number of Operators and Passengers who were injured in an Adverse General Aviation Occurrence in South Africa (2015-2017)

Year	Number of people Injured	Percentage of people injured
2017	2	11.76%
2016	11	64.71%
2015	4	23.53%
Total	**17**	**100**

Table 6 presents the number of people who were injured during aircraft operations. In total, 17 people were injured in the period 2015-2017. The most injuries, 64.71%, took place in 2016, while the least, 11.76%, took place in 2017.

Table 7:

Number of Operators and Passengers who were killed in an Adverse General Aviation Occurrence in South Africa (2015-2017)

Year	Number of people killed	Percentage of people killed
2017	4	26.67%
2016	9	60%
2015	2	13.33%
Total	**15**	**100**

As shown in Table 7, a total of 15 people were killed in the period 2015-2017. The highest number of people killed was 60% in 2016, followed by 28.67% in 2017, and 13.33% in 2015.

Figure 7:

Geographical Variations of Adverse General Aviation Occurrences within Provinces in South Africa (2015-2017)

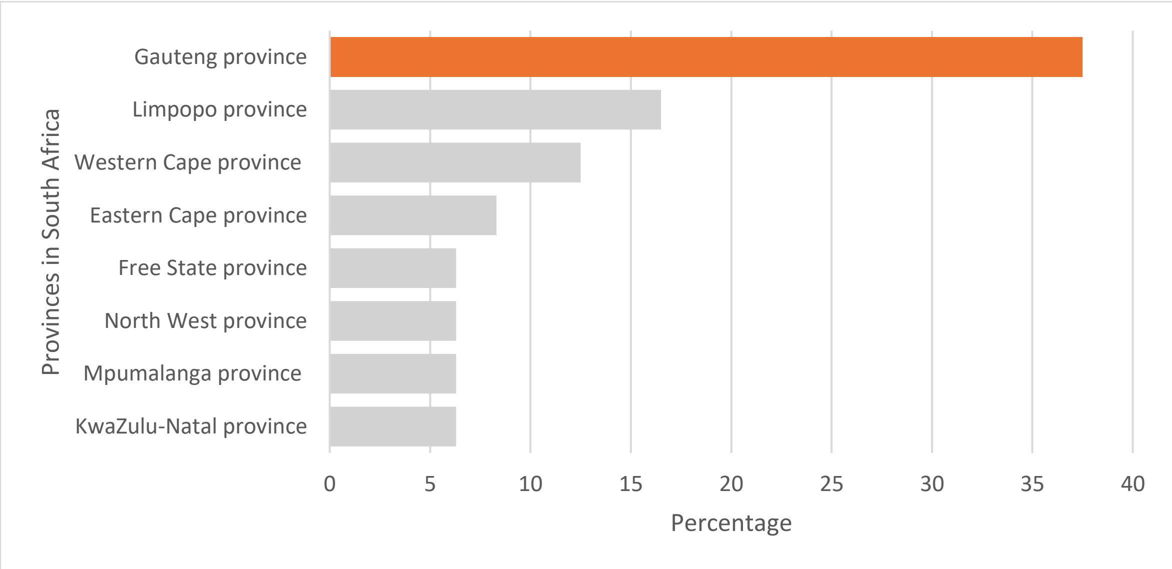


Figure 7 presents a breakdown of general aviation accidents, serious incidents, and incidents in the period 2015-2017 that took place in South Africa by provinces. The majority of adverse occurrences (*n* =18; 37.5%) were reported from Gauteng. Limpopo Province (*n* = 8; 16.5%) also reported a noticeably high number of adverse occurrences, followed by the Western Cape (*n* = 6; 12.5%), and Eastern Cape Province (*n* = 4; 8.3%). Of the 48 investigation reports, three (6.3%) each of the adverse occurrences were reported in the Free State, KwaZulu-Natal, Mpumalanga, and North West respectively.

Table 8:

Summary of the Most Prevalent Latent and Active Failures that took place across Eight South African Provinces (2015-2017)

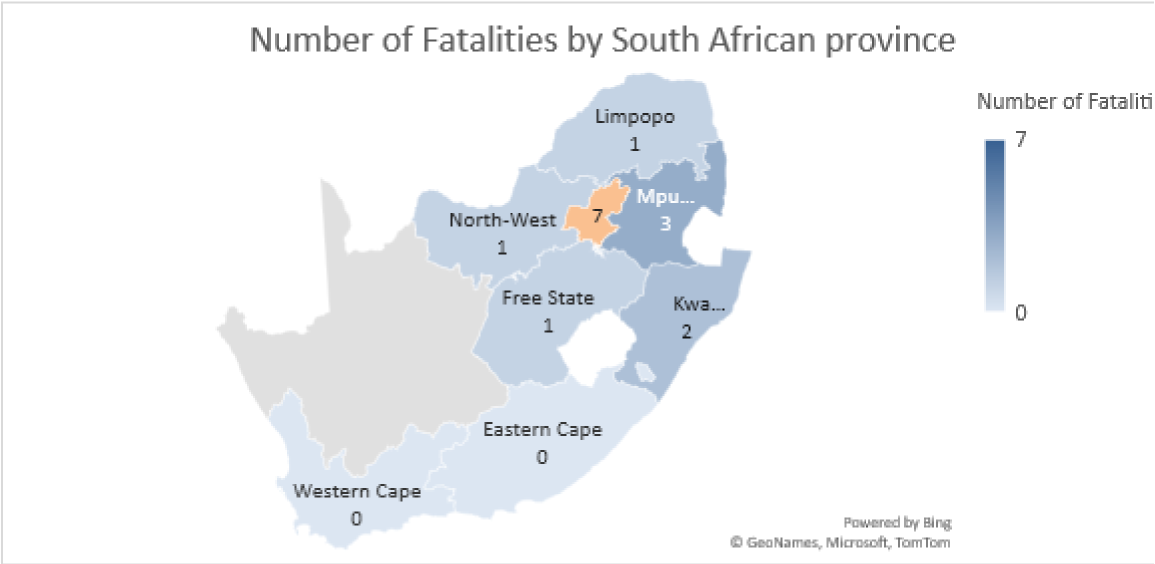
Province	Counts	Percentage	Most prevalent latent (organisational) and active failures (human factors)
Eastern Cape province	25	7.38%	Organisational climate, organisational policy, inadequate supervision, condition of the operators, failed to correct a known problem, decision-making error, skill-based error, physical factors.
Free State province	28	8.26%	Organisational climate, organisational policy, human resources, inadequate supervision, condition of the operators, failed to correct a known problem, physical environment, decision-making error, skill-based error, routine violation.
Gauteng province	118	34.81%	Organisational climate, organisational policy, human resources, inadequate supervision, condition of the operators, failed to correct a known problem, physical environment, decision-making error, skill-based error, routine violation.
KwaZulu-Natal province	23	6.78%	Organisational climate, organisational policy, inadequate supervision, failed to correct a known problem, condition of the operators, physical environment, decision-making error, skill-based error.
Limpopo province	50	14.75%	Organisational climate, organisational policy, inadequate supervision, condition of the operators, failed to correct a known problem, physical environment, decision-making error, skill-based error.
Mpumalanga province	22	6.49%	Organisational climate, organisational policy, inadequate supervision, condition of the operators, failed to

			correct a known problem, physical environment, decision-making error, skill-based error.
North West province	30	8.85%	Organisational climate, organisational policy, human resources, inadequate supervision, condition of the operators, failed to correct a known problem, physical environment, decision-making error, skill-based error.
Western Cape province	43	12.68%	Organisational climate, organisational policy, human resources, inadequate supervision, condition of the operators, failed to correct a known problem, physical environment, decision-making error, skill-based error.

Table 8 shows that Gauteng (34.81%) also had the highest number of the most prevalent latent and active failures identified using the HFACS framework. Limpopo (14.75%) has a relatively high number of the most prevalent latent and active failures identified compared to the Western Cape, Free State, North West, and Eastern Cape (12.68%, 8.26%, 8.85%, and 7.38% respectively). A similar number of latent and active failures were identified in KwaZulu-Natal and Mpumalanga provinces (6.78% and 6.49% respectively). The Free State and Gauteng provinces were the only provinces that reported cases that involved routine violations. KwaZulu-Natal, Limpopo, and Mpumalanga provinces did not report any cases that involved human resources.

Figure 8:

Number of Fatal General Aviation Occurrences within Provinces in South Africa (2015-2017)



As can be seen from Figure 8, Gauteng province had the highest number of fatalities (n = 7). Mpumalanga and KwaZulu-Natal provinces had low fatalities (n = 3; 2) respectively. The Free State, Limpopo, and the North West provinces reposted one fatality each. The Western Cape and Eastern Cape Provinces had zero fatal GA occurrences between 2015 and 2017.

Table 9:

Pilot-in-Command Licence Type Distribution among General Aviation Operations in South Africa (2015-2017)

Pilot-in-Command Licence type	**Frequency**	**Percentage**
Commercial pilot licence	19	39.58
National pilot licence	8	16.67
Private pilot licence	17	35.42
Student pilot licence	4	8.33
Total	**48**	**100**

Table 9 presents pilot-in-command licence type distribution among GA operations in South Africa. It shows that 39.58% of the operators held a commercial pilot licence, while 8.3% held a student pilot licence. Furthermore, 35.4% and 16.7% held a national pilot licence and a private pilot licence respectively.

Figure 9:

Geographical Distribution of Adverse General Aviation Occurrences across Pilot-in-Command Licence Type (2015-2017)

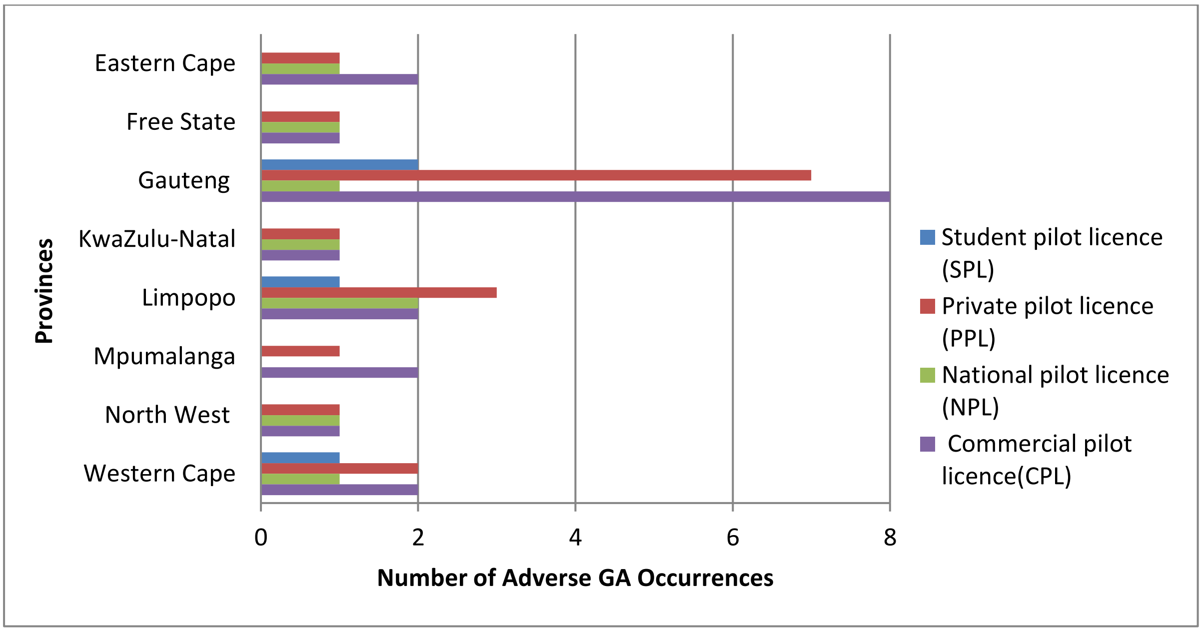


Figure 9 shows that out of a total of 48 adverse occurrences in South Africa between the years 2015-2017, Gauteng province had the highest number of adverse occurrences involving commercial pilot licence holders (n = 8). The Eastern Cape, Limpopo, Mpumalanga, and Western Cape provinces had two adverse occurrences each involving commercial pilot licences.

The Free State, KwaZulu-Natal, and the North West provinces each reported one occurrence involving commercial pilots. National pilot licence holders had a low number of adverse occurrences across most provinces and accounted for one adverse occurrence each in the Eastern Cape, KwaZulu-Natal, Gauteng, Free State, North West, and Western Cape provinces. Limpopo province had two adverse occurrences involving national pilot licence holders. Gauteng, Limpopo, and the Western Cape had high numbers of adverse occurrences involving private pilot licence holders (*n* = 7; 3; 2) respectively. The Eastern Cape, Free State, KwaZulu-Natal, Mpumalanga, and North West, reported one adverse occurrence each involving private pilot licence holders. Gauteng, Limpopo, and Western Cape were the only provinces to report adverse occurrences involving student pilots (*n* = 2; 1; 1) respectively.

Figure 10:

Fatal General Aviation Occurrences in South Africa across Pilot-in-Command Licence Type (2015-2017)

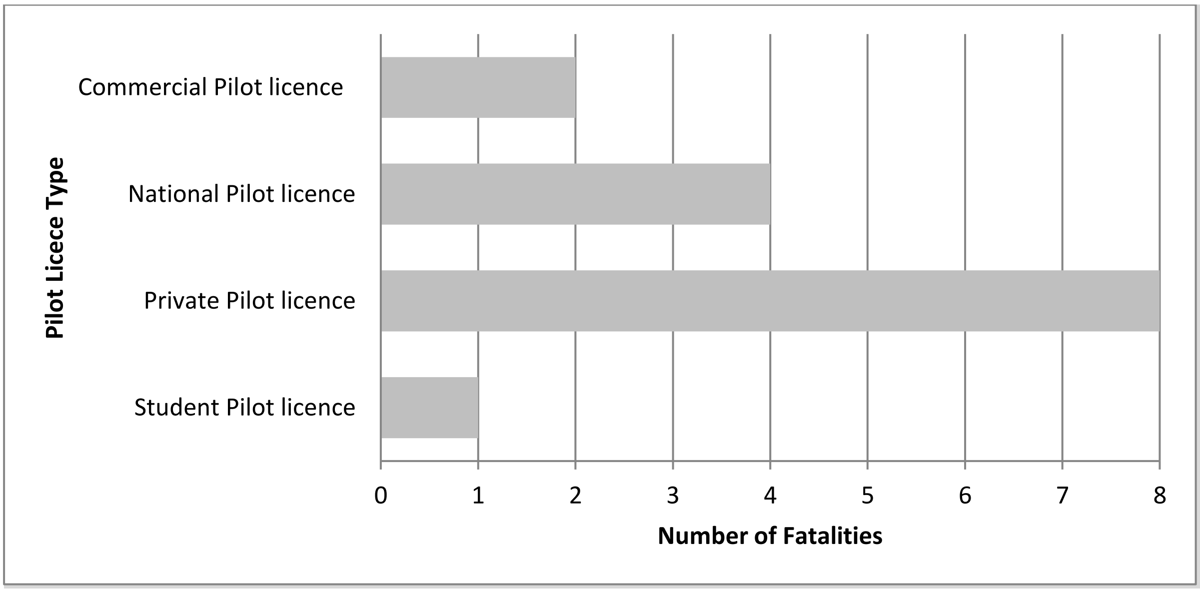


Figure 10 shows that private pilot licence holders experienced the highest number of fatalities, with eight out of 15 total fatalities occurring among this group of pilots. National pilot licence holders had notable fatalities, with four out of 15 total fatalities. Commercial pilot licence holders reported two total fatalities, indicating a relatively low rate of fatalities. Student pilot licence holders had the lowest fatalities, with only one fatal flight operation recorded between the years 2015-2017.

Figure 11:

Fatal General Aviation Occurrences in South Africa across Province and Pilot-in-Command Licence Type (2015-2017)

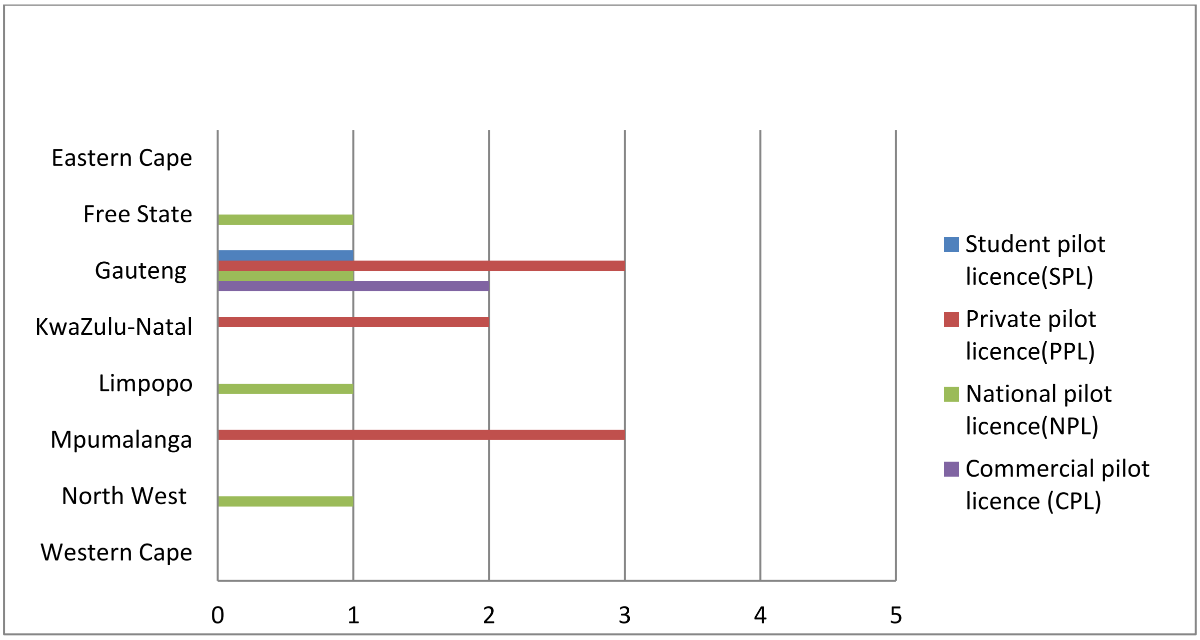


Figure 11 shows that private pilot licence holders had the highest number of fatalities, with eight out of 15 total fatalities. Three of the fatalities took place in Gauteng and Mpumalanga provinces. KwaZulu-Natal had two fatalities involving private pilots. National pilot licence holders were also implicated in a high number of fatalities, particularly in the Free State, Gauteng, Limpopo, and North West, with each province reporting one fatality. Gauteng was the only province that had a fatal accident involving a student pilot licence holder (n = 1). Gauteng was the only province that recorded fatalities involving commercial pilot licence holders (n = 2). The Eastern Cape and Western Cape provinces had zero fatalities between the years 2015 and 2017.

4.4 Quantifying Probabilistic Inference

Although conventional HFACS frameworks can effectively identify both active and latent factors that impact adverse institutional occurrences, links cannot be quantified effectively. In contrast, the use of Bayesian methods within the framework enables such quantification.

Thus, one can determine the probabilistic influence of a specific variable due to the presence of another related factor. Causal relationships are computed amongst variables by employing parameter learning in this model, therefore facilitating a clearer understanding of their interconnections. This study utilised both SPSS v.29 and Microsoft Excel 2024 to perform the Bayesian calculations.

The progression of this project led the researcher to conclude that a significant gap exists in our understanding of the relationship between latent failures (organisational influences, unsafe supervision, preconditions for an unsafe act) and active failures (unsafe acts) in GA mishaps (accidents, serious incidents, and incidents). This gap presented an opportunity to investigate further while employing a novel method to analyse GA HFACS data. The method involved the application of Bayes' theorem, as discussed earlier in the study. It utilised conditional probability analysis, based on prior occurrences of both latent and active failures (extracted from 48 reports). This approach allowed for a more precise examination of how specific latent systemic failures are associated with certain unsafe acts. Bayes' theorem enables researchers to address questions related to conditional probabilities, while reducing errors associated with overestimation or underestimation in calculations (Li et al., 2019). The unsafe or active failures analysed were limited to decision errors (46 cases) and skill-based errors (42 cases), as these were determined to be unintentional. The research subsequently addressed the following research questions:

4.4.1 RQ2:

What latent failures and active failures impact GA accidents, serious incidents, and incidents individually?

4.4.2 RQ3:

What latent and active failures impact GA accidents and serious incidents combined?

Bayes' theorem was utilised to examine and identify conditional probabilistic relationships between active failures (such as unsafe acts) and latent failures (organisational influences, unsafe supervision, and preconditions for unsafe acts) within the context of the GA HFACS analysis. This probabilistic approach allowed the researcher to explore how the presence of specific latent systemic failures increases the likelihood of particular active failures occurring within GA mishaps. The dataset for this analysis was derived from 48 finalised investigation reports spanning the years 2015 to 2017, ensuring a comprehensive examination of recent trends and contributing factors in GA accidents, serious incidents, and incidents.

Furthermore, it is important to note that previous research in HFACS has established that the occurrence and classification of HFACS error types are influenced by the severity of the mishap (Wiegmann et al., 2022). For instance, as the severity of an aviation mishap increases, certain types of errors or failures may become more prominent, while others may appear less frequently. This relationship between error types and mishap severity underscores the importance of incorporating nuanced methodologies, such as Bayes' theorem, to account for varying probabilities based on the context and severity of the incident. By applying this analytical approach, the study aimed to provide a clearer understanding of how latent and active failures are interconnected and how these relationships contribute to different outcomes within GA. For instance, it was found that more serious occurrences, such as accidents, are related to decision errors, while less serious occurrences are related to skill-based errors.

The application of Bayes' method provided results with greater depth and significance by uncovering meaningful insights from the categories within the GA HFACS database. This approach went beyond the simplistic attribution of occurrences to mere human error, instead offering a more nuanced understanding of the relationships between latent and active failures. By accounting for the broader systemic context, Bayes' method enabled a more detailed exploration of the factors contributing to GA mishaps.

The results presented in this section were derived from the implementation of Bayes' theorem, which allowed the calculation of accurate conditional probabilities by incorporating prior probabilities for both latent and active failures. This probabilistic approach ensured that the analysis considered the complex interplay between systemic (latent) issues and operational (active) errors. The findings, as summarised in Table 10, reflect the robustness of this method in identifying patterns and relationships that might otherwise be overlooked in traditional analyses.

According to Gelman & Shalizi (2013); P(ActivelLatent) = P(Active) x P(Latent I Active)/P (Latent). This modified formula provided the results to the question "Given a latent systemic failure what is the probability of an active failure?"

Therefore, in the analysis of reports, the dataset showed that out of the 48 occurrences, DE was cited 46 times, giving the P(DE) = 0.95. Given the 46 DE-related occurrences, inadequate supervision was cited 42 times giving the P (inadequate supervision | DE) = 0.91. Out of a total of 48 GA mishaps in this period, inadequate supervision was reported 42 times, giving P(inadequate supervision) = 0.88. These three variables were plugged into the formula to yield: P(DE l inadequate supervision) = (0.95) x (0.91) / (0.88) = 0.98

Thus, these results conclude that given an inadequate supervision failure within the system, the probability of DE is high at 98%. With this value, the researcher is able to observe the power of the depth in how much a latent failure can impact the probability of an active failure or error type. Prior probabilities are shown in Table 10 as this was necessary in calculating the results of the conditional probabilities. The table shows all 25 latent failure cases amongst the four levels of the GA HFACS database.

Table 10:

Frequency of Active (Unsafe Acts) and Latent (Unsafe Supervision, Precondition, and Organisational Influences) Failures across 48 GA Mishaps (2015-2017)

Failure Type	Total Mishaps	Prior Probability (%)
Organisational Influences (Level 4)		
Resource management	6	12.5
Human resources	17	35.4
Budget restrictions	2	4.2
Equipment issues	9	18.8
Organisational climate	36	75.0
Structure of command	2	4.2
Company policy	36	75.0
Company culture	2	4.2
Organisational process	4	8.3
Deadline pressure	1	2.1
Oversight	3	6.3
SOPs	8	16.7

Unsafe Supervision (Level 3)	42	87.5
Inadequate supervision		
Planned inappropriate operation	8	16.7
Failed to correct a known problem	19	39.6
Supervisory violation	1	2.1
Preconditions for Unsafe Acts (Level 2)		
Physical environment	48	100.0
Technological environment	6	12.5
Condition of operators	37	77.1
Adverse mental state	6	12.5
Adverse psychological state	1	2.1
Physical/mental limitations	2	4.2
Personnel factors	7	14.6
Crew/resource management	7	14.6
Personal readiness	0	0.0
Unsafe Acts (Level 1) Decision errors	46	95.8
Skill-based errors	42	87.5

Table 10 summarises the frequency and prior probabilities of active (unsafe acts) and latent failures (preconditions, unsafe supervision, and organisational influences) identified across 48 general aviation mishaps between 2015 and 2017. Among active failures, decision errors were reported more frequently (95.8%) than skill-based errors (87.5%). For latent failures, the physical environment was the most frequently cited precondition (100%), followed by inadequate supervision (87.5%) under unsafe supervision. Within organisational influences, organisational climate and company policy were the most common failures (both 75%).

The table provides prior probabilities for each failure type, which, along with the necessary prior conditional probabilities, enabled the application of Bayes' theorem to calculate conditional probabilities, offering deeper insights into the relationships between latent and active failures.

Table 11:

Conditional Probabilities for a GA Accident, Serious Incident or Incident

Failure Type	P (Accident | latent failure)	P (Serious Incident | latent failure)	P (Incident | latent failure)
Organisational Influences (Level 4)			
Organisational climate	0.6256	0.1587	0.1905
Company policy	0.6767	0.1323	0.1323
Unsafe Supervision (Level 3)			
Inadequate supervision	0.5766	0.1905	0.1905
Failed to correct a known problem	0.5175	0.1140	0.6838
Preconditions for Unsafe Acts (Level 2)			
Physical environment	0.7297	0.1190	0.2976
Condition of operators	0.6406	0.1503	0.1252
Unsafe Acts (Level 1)			
Decision errors	0.5518	0.1944	0.1167
Skill-based errors	0.5361	0.4898	0.1905

The application of Bayes' theorem revealed varying levels of conditional probabilities for the impact of latent and active failures on GA accidents, serious incidents, and incidents, as shown in Table 11. Among the latent failures, the physical environment demonstrated the highest probability of contributing to accidents (P = 0.7297), indicating it had a substantial impact compared to its influence on serious incidents (P = 0.1190) and incidents (P = 0.2976). Similarly, company policy showed a strong association with accidents (P = 0.6767), with relatively lower probabilities for serious incidents (P = 0.1323) and incidents (P = 0.1323).

For unsafe supervision, inadequate supervision was significantly associated with accidents (P = 0.5766), alongside equal contributions to serious incidents and incidents (P = 0.1905). Interestingly, failure to correct a known problem displayed a unique pattern, with a higher probability of contributing to incidents (P = 0.6838) compared to accidents (P = 0.5175) and serious incidents (P = 0.1140).

Preconditions for unsafe acts also highlighted important findings: the condition of operators had a substantial influence on accidents (P = 0.6406), but a notably lower impact on incidents (P = 0.1252) and serious incidents (P = 0.1503). Among the active failures, decision errors showed a stronger association with accidents (P = 0.5518) and serious incidents (P = 0.1944) compared to incidents (P = 0.1167). Conversely, skill-based errors presented an interesting distribution, with a relatively high probability for serious incidents (P = 0.4898), followed by accidents (P = 0.5361) and incidents (P = 0.1905).

To better illustrate the level of impact that these latent and active failures have on different outcomes, the probabilities highlight critical trends. For instance, failures such as physical environment and company policy demonstrate a strong predisposition toward accidents, while failure to correct a known problem poses a greater risk for incidents. Statistical evaluation of the conditional probabilities could provide further insight into the plausibility of these relationships, with future analyses potentially including visual representations such as bar graphs to compare the relative impacts of the identified failures. These findings underscore the importance of addressing specific latent and active failures in mitigating the risks associated with GA mishaps.

Chapter 5: Discussion

The overarching aim of this study was to delve into the critical issue of safety in South African GA and to shed light on the underlying factors that contributed to adverse GA occurrences in South Africa between the years 2015-2017. This study utilised a comprehensive analysis of 48 archived investigation reports to identify latent factors that led to active failures within the sector. The application of the HFACS framework aimed to systematically categorize and assess the impact of the factors contributing to accidents, serious incidents, and incidents. Furthermore, this study quantified the probabilistic influence of specific variables due to the presence of another related factor.

The obtained outcome showed that a total of 414 factors were identified using the HFACS framework. In the 48 reports analysed, 309 (74.64%) were at the organisational level and 105 (25.36%) were at the frontline or operational level. Additionally, the descriptive statistical data analysis results were produced by the IBM Statistical Package for Social Sciences (SPSS) version 29 program. An examination of the thematic content analysis results, descriptive statistics, and Bayes' methodology will be presented in this chapter. Understanding these findings has the potential to inform targeted safety interventions and policy improvements in the South African GA sector and beyond. Subsequently, recommendations from findings and future studies, strengths and limitations of the study, and conclusions are discussed.

5.1 Contextualizing the Results

Regarding the results, the findings of this study provide a comprehensive understanding of the latent and active human failures contributing to accidents, serious incidents, and incidents in the South African GA sector between 2015 and 2017. The raters engaged in self-study to acquaint themselves with the HFACS framework and pertinent topics related to the phenomena under exploration, prior to beginning the coding work. The primary investigator underwent training that commenced with definitions and tables sourced from Shappell and Wiegmann (2017), supplemented by insights from ICAO (2010) Annexure 13 on Aircraft Accident Investigations. Each factor in the HFACS framework was rated independently on a scoring scheme with a ranking of 1 to 10. Following individual evaluations by each rater, an inter-rater reliability assessment was performed by calculating the percentage agreement for each factor. Subsequently, a second round of rating was undertaken to enhance agreement levels towards a desirable threshold (~0.80). The top 10 HFACS categories and sub-categories of human resources, organisational policy, organisational climate, inadequate supervision, failed to correct a known problem, physical environment, condition of the operators, decision errors, skill-based errors, and routine violations account for 339 out of 414 (82%) of the contributory organisational and human-related failures. They provide a solid foundation for the underlying causes of GA accidents, serious incidents, and incidents in South Africa between 2015 and 2017.

The analysis from the organisational influences level, specifically the human resources sub-category, indicated that there is a shortage of highly skilled pilots and instructors capable of maintaining proficiency. The importance of this issue is revealed by instances where instructors entrusted underprepared student pilots with solo flight operations. These student pilots often demonstrated poor judgement and failure to uphold safety protocols. This finding corroborates previous research findings which found that poor individual ready state is strongly associated with skill error, decision-making error, and habitual violations (Guo et al., 2021). Studies have revealed the significant impact of recruitment and training on the operator's well-being, psychological state, and attachment to the organisation within the airline industry (Alola & Alafeshat, 2021).

Additionally, Lubner et al. (2011) found that licensing and the lack of qualified personnel, ineffective training, and safety management systems are fundamental challenges in the African civil aviation sector. The shortage of highly skilled pilots and instructors capable of maintaining proficiency could contribute to Africa's continued struggle with high adverse occurrences and subsequently result in a diminished reputation in global civil aviation. To address this effectively, GA stakeholders should invest in regional and strategic collaborations within Africa, such as shared training facilities. This will establish common best practices and inspire innovative solutions that will ensure the sector has a skilled workforce. Innovation collaboration creates faster and better ideas through knowledge transfer, absorption, and appropriation (Pereira et al., 2021; Sonnesjö Nyqvist & Woodward, 2024).

The results from this study identified organisational climate as an important issue in GA. Organisational culture might include norms, shared values, policies, communication styles, behaviour patterns, or attitudes toward safety. These organisational identifiers can guide and influence the decisions made by front-line employees. Thus, organisational climate can manipulate the overall performance within the organisation. Hollnagel (2018) found that an organisation that prioritizes efficiency over safety can lead to procedural deviations, increased stress, and the likelihood of human error. Investigation report 31 shows that the flight instructors (FI) failed to correct a known problem (high-speed approach) suggesting a possible prioritization to allow the student to “work through it” over immediate safety. In GA, landing accidents involving high-airspeed landing have resulted in high numbers of fatal-serious injuries compared to mishaps with no evidence of high-airspeed landing (Boyd, 2019).

Other studies suggest that mishaps are caused by broader structural issues rather than isolated supervisory negligence or pilot error (Guo et al., 2021). It is plausible that the organisational climate within the GA sector discourages or stigmatizes instructors from taking control or views taking control as a reflection of their teaching abilities (or lack thereof). If the instructor had taken control when they first noticed the high speed on approach, the accident might have been prevented. The instructors might have been hesitant to take control earlier because they feared being seen as overly controlling or questioning the students’ abilities. No studies were found that have specifically assessed the impact of the organisational climate within the GA sector on the attitudes, behaviours, or decision-making processes of FIs when remotely monitoring solo flight operations.

However, previous studies found that a positive organisational culture influences employee performance, work attitudes, and significantly decrease the likelihood of error (Pathiranage, 2019).

Organisational influences accounted for the highest number of accidents, followed by serious incidents, and incidents. The prevalence of organisational influences suggests that GA safety is shaped by institutional decision-making and processes. These findings align with Reason’s (1997) SCM where systemic failures at higher levels create latent conditions for active failures at the frontline. The HFACS framework further corroborates this by demonstrating that unsafe acts are merely the manifestation of deep organisational weaknesses. The data from the current study suggests that organisational weaknesses cause catastrophic outcomes such as serious injuries, fatalities, and significant aircraft damage (Ma et al., 2023). Serious incidents that were caused by organisational influences could have resulted from senior management decisions to reduce instructor staffing, resulting in instructors being assigned an excessive number of students. This cost-cutting strategy could lead to inadequate supervision or a decline in student performance and subsequently increase the risk of serious incidents.

Furthermore, previous studies suggest that operational safety is dependent on the decisions made by leaders and management because they are responsible for establishing safety policies, allocating resources, and prioritising risk management (Ayiei et al., 2020; Mukhezakule & Tefera, 2019). In relation to incidents, there is evidence from previous studies suggesting that incidents remain comparatively lower because they often involve near misses that do not immediately escalate into accidents due to mitigating factors, such as pilot experience and real-time corrective actions (Idowu, 2022). A commercial aviation flight simulator study by Lounis et al. (2021) found reduced human error incidents and accidents among expert pilots because they had better attention span, perceptual efficiency, and visual attention compared to novices. The current study's findings show that commercial pilot's licences accounted for 19(39.58%) adverse occurrences and two fatalities.

In contrast, national pilots accounted for eight (16.67%) adverse occurrences and seven fatalities, and private pilot's licences accounted for 17 (35.42%) adverse occurrences and five fatalities. The adverse GA occurrences and number of fatalities amongst different licence types in South Africa between 2015 and 2017 may reflect the mitigating effect of pilot experience. Furthermore, the literature suggests that 80% of aviation accidents occur within the GA sector and are attributed to the pilot's inability to maintain situational awareness and linked to the different licence requirements, particularly between private and commercial pilot licence holders (Annamalai et al., 2021; Boyd et al., 2021). While commercial pilots undertake mandatory training every six months, GA pilots are required to train only every 24 months (Lopes et al., 2024). However, it is difficult to draw firm conclusions from the current study because of the absence of data such as flight hours per licence category.

The role of physical environmental factors in adverse GA occurrences was another crucial factor. The prevalence of physical environmental factors suggests that South Africa's diverse geographical and meteorological variability presents inherent challenges to GA operations (Munene, 2016; Ramee et al., 2021). GA safety is not solely dependent on individual competency, but also on the broader environmental context. Factors such as visibility, obstructions, terrain weather conditions, and visual flight rules-into-instrument meteorological conditions (VFR-into-IMC) emerged as contributory to adverse GA occurrences. Adverse weather conditions impair attention, perceptual-motor functions, judgement, and decision-making processes (Taylor et al., 2016).

While the physical environment factors are external, they share conceptual overlap with the conditions of operators. Conditions of operators are often internal to the operator but precipitated by external stressors, such as maintaining a perfectionist approach, adverse weather conditions, crew resource management, health and wellness, self-efficacy, and work-life-balance. These factors have been found to increase the probability of error (Flin & O'Connor, 2017). In addition, complacency, distractions, and disorientation were among the dominant preconditions identified in the analysis. This indicates that cognitive and physiological limitations are critical determinants of pilot performance (Shappell & Wiegmann, 2022). Harry and Sweller (2016) argue that proving causation between cognitive overload and unsafe acts remains methodologically complex. However, mental health is increasingly gaining attention in organisations as it is closely linked to cognitive well-being. Literature suggests that improving employee quality of life and addressing mental health concerns can enable organisations to increase engagement, and satisfaction, and decrease turnover and error rates (Suyantiningsih et al., 2018).

Given the tendency to place responsibility and blame on frontline workers in the event of an adverse occurrence, it was no surprise that decision-making errors, skill-based errors, and routine violations were found to be among the most prevalent unsafe acts. Unsafe acts represented the most direct and observable failures in aviation (Shappell & Wiegmann, 2022). This finding is consistent with prior research indicating that pilot judgment and decision-making are important factors in aviation safety outcomes (Flin & O'Connor, 2017; Kelly & Efthymiou, 2019). Furthermore, the study’s findings revealed that while decision-making and skill-based errors were reported across various provinces, routine violations were absent in the Eastern Cape and Western Cape Provinces. An interesting finding is that these were the only provinces in South Africa that did not report any fatalities between 2015 and 2017. Literature suggests that habitual deviations lead to the normalization of deviance and have been found to be four times more likely to be associated with fatal accidents than any other unsafe acts (Liu et al., 2013; Shappell & Wiegmann, 2003). The relatively high prevalence of preconditions for unsafe acts and unsafe acts in the GA sector suggests that frontline personnel operate in environments where safety constraints are often compromised (Luo & Gao, 2022).

The results from the trends of adverse GA occurrences between 2015 and 2017 revealed that there was an increase in accidents over the years. It is plausible that this increase over time correlated with negative publicity within the aviation industry during this time. The aviation industry faced reputational damage and corruption scandals involving South African Airways during this period (De Widt et al, .2024). This created uncertainty within the sector which could have affected investment decisions and long-term planning. This could have resulted in reduced funding for safety initiatives, training programmes, and infrastructure development. While these primarily affected commercial airlines, these events could have discouraged potential investments or deterred skilled individuals from entering the profession (Wana, 2023). A potential consequence of this could have been a shortage of experienced pilots, flight instructors, or maintenance personnel, thus increasing the likelihood of operational errors.

However, despite the rise in accidents, the data indicated that serious incidents and incidents remained low in 2015 and 2016, only increasing slightly in 2017. This suggests that while accident rates rose, safety culture and reporting mechanisms may have improved in GA. Incident reporting, particularly within commercial airlines, has enabled hazard identification, improved safety management systems, and decreased the likelihood of major accidents through learning from experience (Sieberichs & Kluge, 2021). This explains the increase in reported serious incidents and incidents in the South African GA sector in 2017 and the drastic decrease in accidents in the same year.

The geographical distribution of adverse GA occurrences in Figure 7 indicates that the Free State, Kwazulu-Natal, Mpumalanga, and North West provinces collectively accounted for the lowest proportions of adverse occurrences (n = 3; 6.3%). Additionally, none of these provinces reported occurrences involving student pilots. A plausible explanation is that extensive theoretical and practical training protocols effectively equip student pilots with the requisite competencies before they are permitted to engage in flight operations. However, another reasonable explanation might involve the underreporting of occurrences within these provinces. In contrast, Gauteng province reported the highest number of adverse general aviation occurrences (n = 18; 37.5%). This could be attributed to economic growth and the fact there are more GA airports and flight schools in the province. Matshediso (2014) found a strong correlation between economic development and air travel demand in South Africa.

A notable finding from the study is that GA occurrences in Gauteng disproportionally involved commercial pilots. This is unexpected as higher training levels and flight experience should theoretically lead to fewer adverse occurrences. A possible explanation could range from limits of expertise, automation-induced complacency, or overconfidence among experienced pilots (Brown, 2016; Gawron, 2019). A phenomenon like automation bias may lead commercial pilots to develop risk-tolerant behaviours. However, it is essential to note that without further information on the specific aircraft type involved and automation-related factors, it is challenging for the researcher to substantiate these findings.

The analysis revealed that private and national pilots accounted for high numbers of fatalities (n = 8; 4) respectively. Research shows that pilots with less experience and total flying hours are often less equipped to handle emergencies and are often involved in fatal accidents (Doskow, 2012). However, this research finding creates a complexity since the private, national, and student pilots who were involved in adverse general aviation occurrences in the Eastern and Western Cape Provinces had zero fatal accidents. This anomaly suggests that regional factors, such as structured oversight and emphasis on safer operational practices, contributed to these results. Other factors like conducting flight operations during the daylight hours or during optimal weather conditions could have played a role (Munene, 2016; Zhang et al., 2024). However, an element of chance cannot be ignored and these findings might represent a statistical anomaly given the smaller sample size. Specific variables such as pilot decision-making under pressure, emergency response, operational environment, and training experiences across all provinces would be needed to draw firmer conclusions.

The quantitative analysis found a substantial impact of physical environment on accidents, with a conditional probability of 0.7297. This suggests that environmental factors, such as weather conditions, terrain, and air traffic controller play a significant role in contributing to accidents. This is particularly relevant in South Africa where the diverse geography and climate can pose unique challenges to pilots (Munene, 2016). Company policy also emerged as a critical factor with a strong association with accidents (P = 0.6767). This highlights the importance of effective organisational policies in mitigating risks. In South Africa, the aviation industry is subject to various regulations and this finding emphasises the need for airlines and operators to prioritize policy development and strict implementation strategies. The role of unsafe supervision, particularly inadequate supervision, was also significant, with a conditional probability of 0.5766 for accidents. This reinforces the importance of effective leadership and supervision in ensuring safety (Ayiei et al., 2020). The preconditions for unsafe acts, in particular the condition of operators, also had a substantial influence on accidents (P = 0.6406). This highlights the importance of ensuring that pilots and other operators are fit to fly and perform their duties safely. In South Africa, where there may be challenges related to fatigue, stress, and other health factors, the findings emphasise the need for effective management of operator condition.

Interestingly, the analysis revealed that failure to correct a known problem had a higher probability of contributing to incidents (P = 0.6838) compared to accidents (P = 0.5175) and serious incidents (P = 0.1140). This suggests that GA personnel may have a tendency to downplay known problems. Among the active failures, decision errors showed a stronger association with accidents (P = 0.5518) and serious incidents (P = 0.1944) compared to incidents (P = 0.1167). This suggests that decision-making errors, such as navigational mistakes or failure to follow procedures, have serious consequences. In Africa, previous research findings suggest challenges related to the training and experience of personnel (Lubner et al., 2011). The study's results can inform the development of targeted interventions, such as training programmes, policy revisions, and safety management systems, to mitigate these risks and improve overall safety performance.

5.2 Recommendations from Findings and for Future Studies

This study moves beyond the traditional focus on pilot error to identify deeper systematic contributors to GA safety risks. The key themes that emerged ranged from organisational influences, environmental conditions, and cognitive factors. The results confirmed that human error is not an isolated phenomenon, but a consequence of broader systemic weaknesses. Therefore, the GA sector needs a multi-tiered approach to risk management and safety interventions rather than an over-reliance on individual error mitigation strategies. The South African GA sector needs to strengthen its reporting culture, enhance supervision, and implement effective safety management systems. In addition, the fluctuation in GA occurrences over time suggests that aviation safety is influenced not only by human errors or internal operational factors, but also by broader external conditions. Future researchers should explore whether policy changes, political issues, or economic constraints contribute to the decrease or increase in accidents, serious incidents, and incidents.

To enhance the generalizability of the findings, future studies should consider longitudinal studies that go beyond the study's selected timeframe (2015-2017). Future researchers should track how organisational policies evolve and impact accidents, serious incidents, and incidents over time. Another recommendation is a comparative analysis between South African GA trends and those in other countries to identify unique regional risk factors. Furthermore, the current study did not delve into specific pilot demographics that could potentially influence human factors such as age, total hours on flight, flight environment familiarity, recency of flight, night or day flight experience, stress levels, and time of adverse occurrence. Future research could benefit from incorporating these demographics because pilot licence type alone is not the sole determinant of safe flight operations.

5.3 Strengths and Limitations of the Study

In conclusion, the significance of this research lies in its potential to inform both academic research and practical aviation safety initiatives on contributing factors to adverse GA accidents, serious incidents, or incidents in Africa, particularly in South Africa. In addition, the Civil Aviation Authority (CAA) and GA operators may utilise these findings to refine safety protocols. This will potentially increase levels of safety awareness and reduce the likelihood of similar occurrences in the future. In addition to these strengths, it is important to acknowledge several limitations in the study.

Firstly, the HFACS categories rely heavily on subjective interpretations of human and organisational factors. Prior research has criticized the HFACS for inconsistencies in application, suggesting that even trained raters might categorise the same incident differently due to varied personal interpretations of abstract factors like organisational policies and supervisory violations. In addition, although aircraft investigators are highly trained and competent, some bias may still be present due to their interpretations. Therefore, while the HFACS coding was applied by trained raters, differences in interpretation could lead to inconsistent coding of accidents, serious incidents, and incidents. In other words, differences in rater perspectives may lead to varying HFACS categorizations of the same adverse occurrence.

The qualitative nature of the study and the potential for investigator bias could impact the objectivity of the results. The qualitative data may reflect perceived rather than actual safety issues as they are based on subjective interpretations of events. Reliance on qualitative data might make it difficult for other researchers to replicate the exact methodology. Additionally, other researchers may fail to obtain identical results if the study were to be replicated, especially in thematic content categorization. In relation to investigator bias, it is also possible that aviation investigators introduced organisational bias by underreporting or overemphasizing certain types of errors based on organisational values or operational pressures. In addition, pilots and aviation professionals may report occurrences differently based on their perspectives and experiences, which could introduce variability into the data.

Lastly, the reliance on investigation reports from a limited timeframe, a small sample size, and the geographical location may limit the accuracy, validity, and generalizability of the results. The specific context of South Africa's GA sector may not be directly transferable to other countries with different economic conditions, safety standards, or cultural factors. Furthermore, the study did not incorporate other variables such as pilot demographics, which could influence safety practices, pilot experience, flying hours, or regional operational protocols. These variables could have enhanced the study's applicability to other populations or settings.

5.4 Conclusion

This study has a vital role in enhancing GA safety in South Africa as it provides safety specialists and academics with an extensive investigation of the latent and active failures that cause adverse occurrences. The findings suggest that latent organisational influences such as resource constraints, inconsistent regulatory enforcement, and ineffective training programmes were identified as contributory factors to aviation safety lapses. Preconditions for unsafe acts such as environmental stressors, weather conditions, and cognitive factors were also found to be responsible for safety lapses. At the individual level, decision errors, skill-based errors, and routine violations were prevalent and often exacerbated by cognitive overload and deviations from SOPs.

Although economic and political factors were not investigated within the scope of this study, one striking finding from the data is that the fluctuation of GA occurrences over time (2015-2017) suggests that broader external economic and political factors have an impact and role to play in the South African GA sector.

Recommendations from findings suggest that the GA sector implements a multi-tiered approach to risk management and safety interventions rather than an over-reliance on individual error mitigation strategies. To reduce human-related adverse occurrences, the GA sector needs training programmes that focus on the importance of decision- making under pressure, error management, and encourage a safety reporting culture. Furthermore, future policy reforms need to prioritize consistent regulatory frameworks to mitigate fluctuations in GA occurrences over time. Lastly, data-driven approaches such as Bayes' theorem can be integrated into routine safety assessments as this approach can help to track evolving safety trends and measure the effectiveness of implemented safety interventions over time.

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Appendix A: Report Cover Page

Masters in Psychology – Research Proposal/Report Cover Page

Surname: Tshuma

First name/s: Sindy Phanankosi

Student no.: 542603

Supervisor: Dr. Preven Naidoo

Title: An Exploration of General Aviation Occurrences in South Africa (2015-2017): Application of the Human Factors Analysis and Classification System Using Bayes' theorem.

Total Word Count: 24 883 (excl. Reference List, appendices etc)

Declaration

I, Sindy Phanankosi Tshuma, know and accept that plagiarism (i.e., to use another's work and to pretend that it is one's own) is wrong. Consequently, I declare that

The research report is my own work.

I understand what plagiarism is, and the importance of clearly and appropriately acknowledging my sources.

I understand that questions about plagiarism can arise in any piece of work I submit, regardless of whether that work is to be formally assessed or not.

I understand that a proper paraphrase or summary of ideas/ content from a particular source should be written in my own words with my own sentence structure, and be accompanied by an appropriate reference.

I have correctly acknowledged all direct quotations and paraphrased ideas/ content by way of appropriate, APA-style in-text references. I have provided a complete, alphabetized reference list, as required by the APA method of referencing.

1

I understand that anti-plagiarism software (e.g. Turnitin) is a useful resource, but that such software does not provide definitive proof that a document is free of plagiarism.

I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as his or her own work. I am aware of and familiar with the University of the Witwatersrand's policy on plagiarism

I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this is not my own unaided work, or that I failed to acknowledge the source of the ideas or words in my writing.
The word count (excluding the Reference List, etc) given above is correct.

2

Appendix B: Ethics Certificate

MACQUARIE University
SYDNEY · AUSTRALIA

Certificate

March 10, 2023

This is to certify that **Ms. Sindy Phanankosi Tshuma** has successfully completed the Macquarie University Human Research Ethics Online Training Module for the Social Sciences and Humanities.

Macquarie University

Appendix C: Example of Percentage Agreement Calculations

Factor	Rater 1	Rater 2
<u>**Organisational Influences**</u>		
Resource management:	8	7
(comments regarding management of human resources, budget, equipment, and facilities, etc.)		
Organisational climate:		
(comments regarding prevailing structure of command, policies of hiring and firing, organisational justice, values, and belief, etc.)	9	9
Organisational processes:	10	10
(Comments regarding operational schedule, time management, planning, standard operating procedures, standards, documents, and procedures, etc.)		
	#MATCH	2
	Total	3
	IRR	0.666667

Appendix D: Ethics Clearance Certificate

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

SCHOOL OF HUMAN AND COMMUNITY DEVELOPMENT ETHICS COMMITTEE
CONSTITUTED UNDER THE UNIVERSITY HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: MAORG/23/10W**
PROJECT TITLE:	An Exploration of General Aviation Occurrences in South Africa (2015-2017): Application of the Human Factors Analysis and Classification System and Bayesian Network Modelling.
INVESTIGATOR	Tshuma Sindy (542603)
SCHOOL/DEPARTMENT OF INVESTIGATOR	SHCD/Psychology
DATE CONSIDERED	14 June 2023
DECISION OF THE COMMITTEE	Approved unconditionally
RISK LEVEL	No Risk
EXPIRY DATE	31 December 2025

ISSUE DATE OF CERTIFICATE [redacted] 03 June 2023 **CHAIRPERSON** [redacted] ____________________
(Dr Aline Ferreira Correia)

cc: Dr Preven Naidoo (Supervisor) *Dr Preven Naidoo*

DECLARATION OF INVESTIGATOR

To be completed in duplicate and **ONE COPY** returned to the Chairperson of the School/Department ethics committee.

I/we fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure be contemplated from the research procedure as approved, I/we undertake to submit an amendment of the protocol to the Committee.

______S.P Tshuma______________________
Signature

_____06__/____July___/______2023
Date

Appendix E: Example of Qualitative Analysis

Investigation Report No: 40

Type of Occurrence: Accident

Date of Accident: 3 February 2016, at approximately 0945Z
Pilot in command licence type: Private pilot
Location: Brakpan Aerodrome (FABB), Gauteng Province, South Africa
Occupants: 3 (pilot and 2 passengers, all fatally injured)

SOUTH AFRICAN CIVIL AVIATION AUTHORITY

Section/division: Accident and Incident Investigations Division — Form Number: CA 12-12a

AIRCRAFT ACCIDENT REPORT AND EXECUTIVE SUMMARY

Approved				Reference:	CA18/2/3/9520		
Aircraft Registration	ZS-PME	**Date of Accident**	3 February 2016		**Time of Accident**	0945Z	
Type of Aircraft	Piper PA-32-300			**Type of Operation**	Private (Part 91)		
Pilot-in-command Licence Type		Private Pilot Licence		**Age**	63	**Licence Valid**	Yes
Pilot-in-command Flying Experience		**Total Flying Hours**		4130.90		**Hours on Type**	388.6
Last Point of Departure		Brakpan Aerodrome (FABB), Gauteng Province					
Next Point of Intended Landing		Entabeni Lodge, Limpopo Province					
Location of the accident site with reference to easily defined geographical points (GPS readings if possible)							
500m past the end of Runway 36 at FABB (GPS position 26° 13, 35.54"S 028° 17' 54.06"E) Elevation 5300ft AMSL							
Meteorological Information	Wind: 300°/10°kt; Temperature: 27°C; Dew point: 10°C; Visibility: CAVOK; Clouds: Few						
Number of People On-board	1+2	**No. of people Injured**	0		**No. of people killed**	3	
Synopsis							

On 3 February 2016 at approximately 0945Z, the pilot accompanied by two passengers took off from Runway 36 at Brakpan Aerodrome (FABB) after the aircraft's fuel tanks were refuelled to full capacity with 84 gallons (United States Gallons). This was followed by a pre-flight inspection that was carried out on the aircraft. According to eyewitnesses at Wattville township, the aircraft was flying very low over the residential area; and it had appeared as if the aircraft was having trouble gaining height. The aircraft's right-hand main landing gear wheel then impacted the top section of the street light pole, where after, the right-hand wing dropped downwards and impacted a brick wall, causing the wing-tip to break off. The right wing then impacted the roof of a shack. The aircraft rolled over into an inverted attitude before the right-side wing collided with a tree, causing the wing to separate from the aircraft. The aircraft's main wreckage came to rest approximately 120 metres from the first point of impact. A post-impact fire erupted during the accident sequence when the aircraft collided with the tree. Some of the local community members who had witnessed the accident helped pull out the occupants from the main wreckage and had attempted to extinguish the fire using buckets filled with water. The pilot and the two passengers were fatally injured during the accident. The aircraft was destroyed during the impact sequence as well as by the post-impact fire that erupted thereafter.

The investigation revealed that although the aircraft was within its weight limit, it was operated close to its maximum weight limit, outside of its centre of gravity (CG) limit, and at high-density altitude, leading to a poor take-off and climb performance which resulted in a crash.

Probable Cause

The aircraft was operated close to its maximum weight limit, outside of its centre of gravity (CG) limit, and at a high-density altitude, leading to a poor take-off and climb performance which resulted in a crash.

Contributing factors

Poor or no pre-flight planning.

Initial Coding:

1. Pilot error

2. Weight issues

3. Centre of gravity exceeded

4. Environmental factors: High-density altitude

5. Poor pre-flight planning

6. Mechanical issues: Aircraft performance issues

Category formation:

Human error

- Pilot error

- Poor pre-flight planning

Aircraft factors

- Weight issues

- Centre of gravity limit exceeded

- Aircraft performance

Environmental factors

- High density altitude

Theme identification:

- Human factors: pilot error, poor pre-flight planning

- Environmental factors: mechanical issues, high density altitude

Theme development:

1) Unsafe Acts: pilot error

2) Environmental factors: technical environment (weight issues, centre of gravity limit exceeded) and (physical environment: high density)

3) Human Resources: Training issues (poor pre-flight planning)