# The potential of Speech-to-text technology in enhancing efficiency in the aviation sector in South Africa

**Kagiso C. Mainganya**

**A research proposal submitted to the Faculty of Commerce, Law and Management, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Management in the field of Digital Business**

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# ABSTRACT

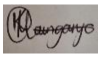
This research report evaluates the potential of speech-to-text technology to enhance efficiency in the aviation sector in South Africa. It examines how this technology could improve operational and flight efficiency, impact customer service, and address potential implementation barriers. Key focus areas include - the accuracy of speech-to-text conversion, especially in noisy environments like cockpits and air traffic control towers as well as, the technology's ability to adapt to various accents and aviation-specific jargon. The report also highlights the urgency of cybersecurity measures to protect sensitive flight data. A thematic analysis was conducted with a focus on dynamic capabilities and the General Systems Theory framework.

# KEYWORDS

Speech-to-text technology, Aviation sector in South Africa, operational efficiency, customer service, cybersecurity, noise reduction, accents, aviation jargon.

# DECLARATION

I, Kagiso C. Mainganya, declare that this research report is my work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Management in the field of Digital Business at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Name: Kagiso C. Mainganya Signature: 

Signed at ……Kempton Park……

On the …15th … day of …February… 2024..

# DEDICATION

This report is dedicated to my family, with a special tribute to my mother, whose unwavering grace and resilience have been the cornerstone of my family’s upbringing. Her remarkable strength and boundless love provided a supportive environment that allowed us to pursue our dreams and achieve academic and personal milestones. It is through her sacrifices and the values she instilled in us that we have been afforded the privilege to study and advance in our respective fields.

My mother's role in our lives extends beyond that of a caregiver; she has been a mentor and a beacon of hope, guiding us through challenges with wisdom and patience. Her commitment to our education and overall well-being has been relentless, often putting our needs ahead of hers, ensuring we had every opportunity to learn, grow, and flourish.

The journey, to this point in our lives, reflects her belief in the power of education and the essential nature of hard work and determination. She taught us to face adversity with courage and to embrace life's opportunities with open arms. Her example of grace under pressure and her ability to find joy and gratitude in even the smallest of victories have been a guiding light, inspiring us to strive for excellence in all we do.

This dedication is a tribute to her and an expression of gratitude to my entire family, whose collective support and encouragement have been instrumental in my achievements. Their sacrifices, love, and unwavering faith in my abilities have been the driving force behind my accomplishments, and it is to them that I owe my success.

# ACKNOWLEDGEMENTS

I sincerely thank the aviation community for their valuable contribution to this research. Their willingness to engage in the interview phase enriched the study and provided coverage of perspectives and insights that were instrumental in shaping this research's outcomes.

Furthermore, I must acknowledge the Air Traffic and Navigation Services (ATNS) for their openness and support in this research project. ATNS played a pivotal role in facilitating a comprehensive understanding of the subject matter by allowing me access to their staff members as participants. This partnership reflects ATNS's commitment to fostering research and its dedication to advancing knowledge, for development, within the aviation sector.

I am profoundly grateful to Dr. Pius Oba, Professor Nixon Ochara and Ayanda Magida for their unwavering mentorship and guidance throughout this journey. Their expertise, critical insights, and encouragement were fundamental to the success of this research. Their dedication to nurturing scholarly growth has impacted my academic and personal development.

On a more personal note, I extend my heartfelt thanks to my family, mother, husband, siblings, and children for their endless patience and support during this challenging period. The sacrifices made, and the strength provided by their prayers and encouragement have been a source of immense comfort and motivation. Their belief in my capabilities and their unconditional love have been the core of my resilience and perseverance.

Lastly, but most importantly, I offer my profound thanks to God, for I have reached this point through His grace and blessings. The power of prayer and faith has guided me throughout this journey, shaping me into the individual I am today. The journey of this research has been a testament to the strength derived from faith; I am eternally grateful for this.

This acknowledgement is a small token of my immense gratitude towards all who have contributed, supported, and believed in this research topic and me. The journey has been enriched by each one of you, and for that, I am forever thankful.

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## 1.1 Statement of purpose

The potential of Speech-to-text technology in enhancing efficiency in the aviation sector in South Africa.

## 1.2 Background of the study

Air traffic control (ATC)

Air Traffic Control is a service by which aircraft are given instructions, either on the airport manoeuvring area or a specific airspace under an air traffic controller's responsibility. Air traffic controllers can provide - control, flight information, and advisory services to aircraft - in controlled and uncontrolled airspace. The orderly departure and arrival of aircraft at an airfield or airport are governed by air traffic controllers, who also ensure aircraft' safe separations and altitudes while in flight, by keeping them apart.

In South Africa, air traffic control is provided by Air Traffic and Navigation Services SOC Limited (ATNS). ATNS serve 6% of the global airspace, and a significant portion of the Southern Indian and Atlantic Oceans (Hogana, 2023); they also provide air traffic, navigation, training, and aviation-related services. Nine Airports Company South Africa (ACSA) and 12 additional aerodromes serve as ATNS operating bases in the country (Hogana, 2023).

Flight Progress Strips (FPS) are used to track flights under a specific air traffic controller's airspace. Air traffic controllers use flight progress strips as an efficient way - to annotate a flight, keep a record of the instructions issued, ensure that other air traffic controllers see what is occurring at any time, and transmit this information to other controllers who are taking over the control position.

The flight progress strip is attached to a plastic holder that is called a "strip holder"; strips are used together to create the "strip board", which is then used to illustrate all the aircraft that air traffic controllers' control in a particular area of the airspace or at a specific airport. The colour of the strip holder itself has a particular meaning: blue is used to annotate the outbound flights, pink is used for inbound flights, and white is used to show overflights as well as local and training flights (Weber, 2021).

Essential information needed to keep track of an aircraft:

- Aircraft identification (flight number or aircraft registration);
- Aircraft type using the International Civil Aviation Organisation (ICAO) designators;
- Point of departure and arrival;
- Assigned flight level; and
- Time (contact or departure).

Additional information, however, can also be added based on the type of service offered by the airspace that the aircraft is flying in:

- Persons on board
- Fuel endurance
- Type of approach

The information contained on the FPS is either received through a filed flight plan for scheduled flights or communicated verbally on live frequency for non-scheduled flights. Filing of flight plans in South Africa can be done through an online portal called - File to Fly.

The primary purpose of this research is to ascertain if filing of the flight plan can be completed employing speech-to-text from information received through frequency communication for in-flight filing. This information will be inserted in the relevant fields of the FPS, after that, it will be printed out by the air traffic controller without having to write down the information or type it in manually. Currently, the process is done manually when each aircraft makes contact with the air traffic controller, however, this process is time-consuming and could lead to errors.

The use of speech-to-text conversion could enable the rapid transfer of flight information to a flight progress strip that will be used on the stripboard to monitor flights, within an air traffic controller's area of responsibility. To update flight information in real-time, this technique includes training the current algorithms to identify spoken phrases and translate them into written text, as well as use systems to convert spoken language into text, rapidly and accurately (Sohail, 2022). These systems may be programmed to detect aviation terminology and local pronunciations, making it possible to accurately transcribe flight information from spoken communication (Sohail, 2022).

To thoroughly investigate this possibility, one must first examine how two-way radio communication is conducted between air traffic controllers and pilots in the aviation industry.

Context of the study

Background on pilot and air traffic controller’s communication

One of the most essential aspects of air traffic control is being able to engage in clear and concise communication between air traffic controllers and pilots. This communication is done by using voice-over-radio communication, either on Very High Frequency (VHF) bands for line-of-sight communication or High Frequency (HF) bands for long-distance communication (Kaigarula, 2013). The voice connections over VHF are crystal clear, however, due to radio waves travelling in a straight line, their range is constrained by the globe's curvature and potential obstacles like hills and mountains. The height from which a VHF broadcast originates, as well as the height of the receiving station, define the signal's range. The distance will be minimal if the transmitter and receiver are both on the ground, although, having two stations in the air substantially extends the signal's range (Kaigarula, 2013).

Research studies have explored the impact of antenna height on VHF/UHF communication coverage distances, acknowledging that the geographic obstacles and the Earth's curvature limit line-of-sight transmission. A study conducted in Baghdad City, for example, examined the effects of single and dual antenna systems on the range of radio line-of-sight data links, acknowledging the influences of weather and terrain changes on coverage distance (Kareem & Abbas, 2019).

The distance between an aircraft and a ground-based station, such as an air traffic controller control tower, is in the middle. The initial communication is done by using a call on the assigned frequency, saying - *"Requesting start if on the ground or* *requesting to enter a specific airspace if already airborne''* - while giving the air traffic controller their call sign and position. When the air traffic controller is able to identify where the transmission is coming from, activation of the pilot's flight plan is initiated as well as the details that have been provided to the air traffic controller on the flight progress strip. Furthermore, a transponder code will be provided for surveillance units, as well as details about other nearby known traffic that could affect the flight.

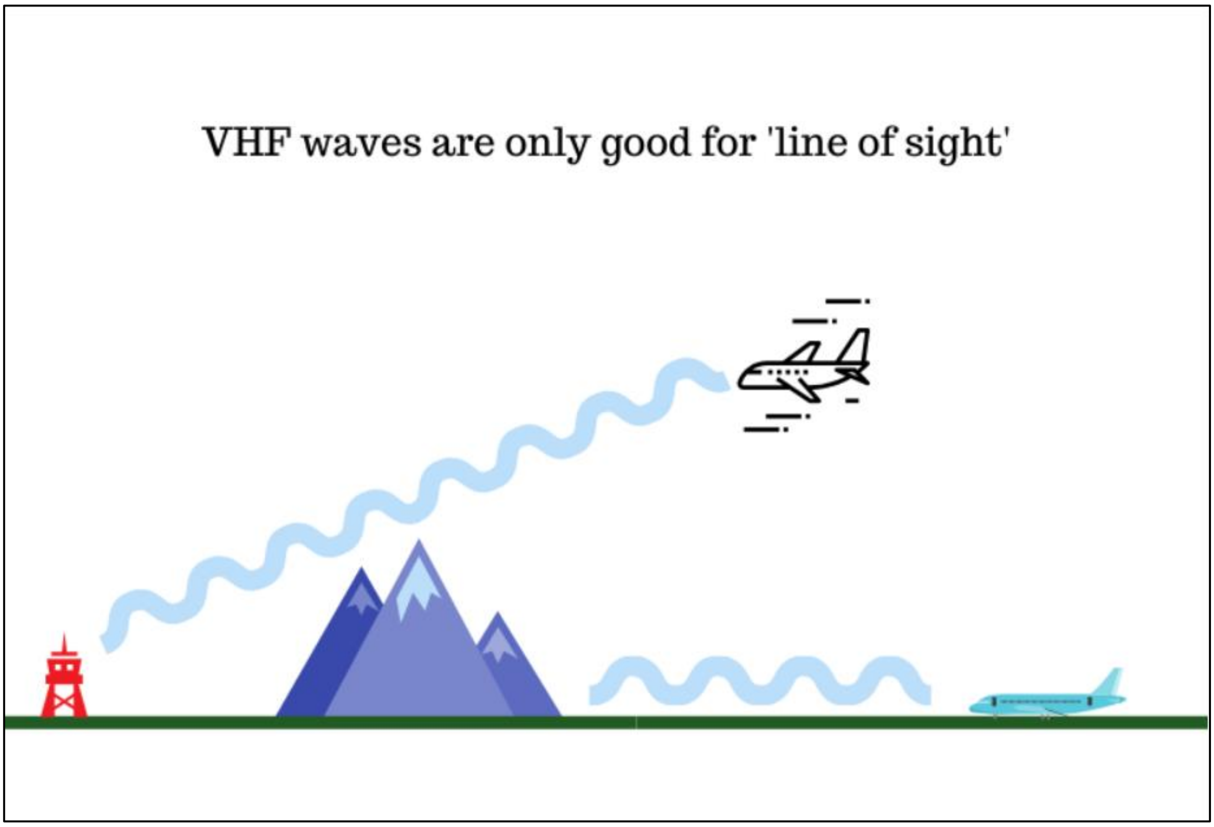


*Figure 1: Very High Frequency Communication waves (Page, 2020)*

VHF receivers are excellent when flying over areas with standard radio masts to transmit and receive messages. VHF communications are the best options when the flight is over the ocean, however, when the curvature of the globe prevents the use of VHF, a more basic device is required to receive the transmissions.

The characteristics of VHF line-of-sight propagation in various atmospheric conditions have been investigated, revealing that factors such as weather and environmental conditions significantly influence radio signal propagation, affecting the received signal strength and, consequently, the communication range (Igwe, 2022). HF radio waves can travel considerably further beyond VHF radios, although weaker than the latter's transmissions. HF radio waves can travel longer distances, even over the tallest mountains, because they can bounce off the ionosphere and return to Earth.

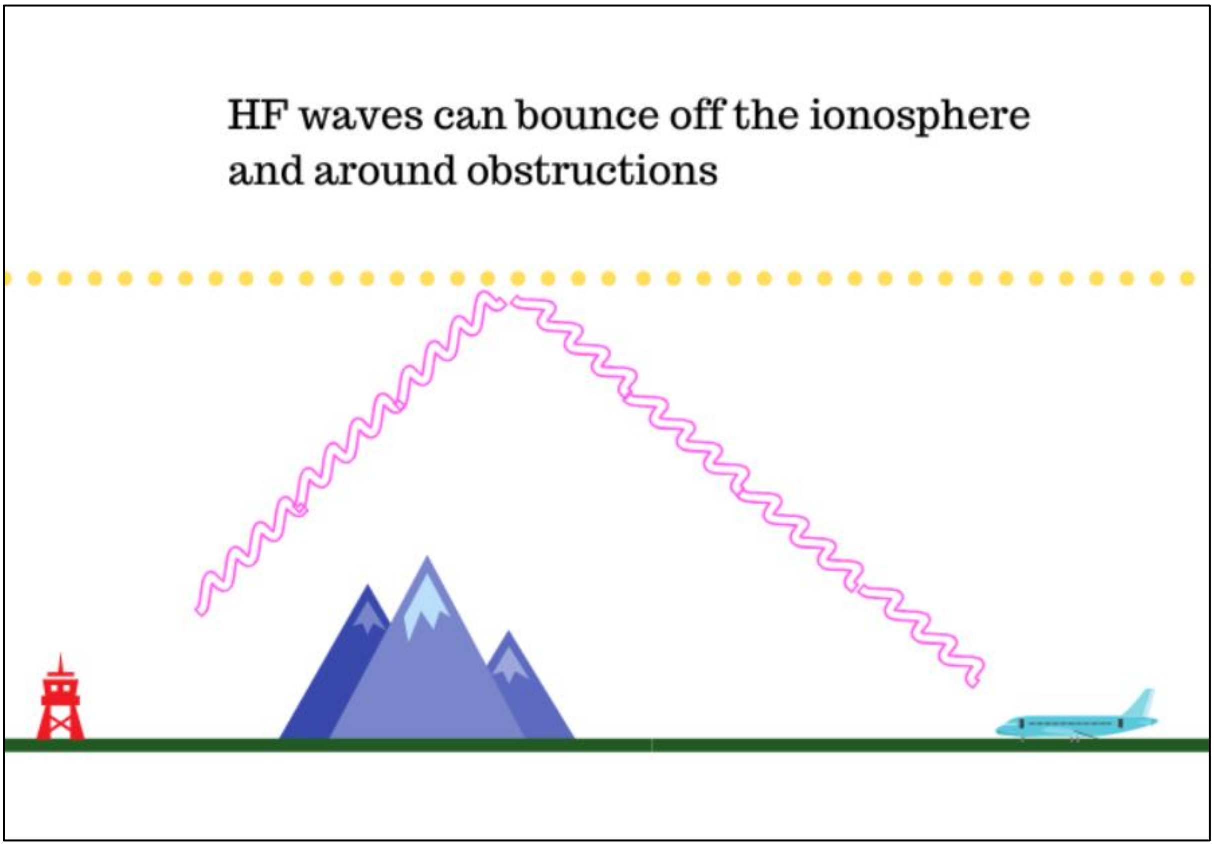


*Figure 2: High Frequency communication waves (Page, 2020)*

## 1.3 Research problem

Implementing speech-to-text conversion is one area where AI technology could have a significant influence. AI technology has advanced significantly in recent years, and the National Airspace System (NAS) is exploring the integration of AI to enhance operations performance, including - safety, security, efficiency, and resilience. This exploration involves understanding AI's capabilities and preparing for its insertion into the NAS to optimise spectrum utilisation and improve communication systems (Stroup & Niewoehner, 2019).

An integration of speech-to-text technology, therefore, could be applied in the aviation sector in South Africa to translate spoken flight information into text, which is then used in creating flight progress strips for air traffic controllers. The successful integration of this technology could improve data transfer accuracy and speed, eventually promote aviation industry efficiency and safety. This research investigates the possible outcomes of an integration of speech-to-text technology into the aviation sector in South Africa. It explores - the benefits, potential challenges, system integrations and effects - on customer services.

A variety of AI tools are available for speech-to-text in the aviation industry. These consist of Automatic Speech Recognition (ASR) technology – a technology that converts spoken words into written text using Machine Learning (ML) techniques. It is beneficial in loud settings with much background noise, like air traffic controller towers (Li, Y., Li, S., & Lu, X. 2019). ML algorithms are used by natural language processing (NLP) technology to understand and interpret human language. It may be used to identify crucial spoken information like - flight numbers, times of departure, and destinations (Maynard et al., 2021).

In addition, artificial neural networks are used in deep learning to handle massive volumes of data and increase the precision of speech-to-text technologies. These networks may be used to train speech-to-text algorithms on grammar and terminology unique to the aviation industry (Sohail, 2022). Amazon Transcribe, Google Cloud Speech-to-Text, and Microsoft Azure Speech Services are just a few examples of speech-to-text products that use AI; these services convert spoken language into text using advanced ML algorithms.

There have been significant advancements in technology, despite this, the aviation sector in South Africa continues to face challenges related to operational efficiency and customer service. Air traffic controllers manage a high volume of verbal communications, which can lead to inaccuracies, miscommunications, and delays. Integrating speech-to-text technology presents a potential solution to these issues, offering real-time transcriptions that can enhance communication accuracy, streamline operations, and improve customer interactions. Implementing this technology in the aviation sector, however, has its challenges, including - technical limitations, cost implications, and the need for extensive training.

This research investigated the potential of speech-to-text technology to enhance efficiency in the South African aviation sector. Specifically, it explored how this technology can improve operational and flight efficiency, in air traffic control and customer-service interactions. Additionally, the study identified the barriers to the technology’s successful implementation and proposed strategies to overcome these challenges. By addressing these issues, the research seeks to provide a comprehensive understanding of the feasibility and benefits of adopting speech-to-text technology in South Africa's aviation industry.

## 1.4 Research questions

The use of speech-to-text technology was investigated to promote air traffic controllers' workload reduction and increase communication accuracy. The adoption of this modern technology could result in increased safety and effectiveness for the aviation industry. The following questions were researched to gather the information:

1. How can integrating speech-to-text technology in air traffic control systems influence operational and flight efficiency in South Africa?
2. How can the use of speech-to-text technology impact customer service efficiency in the aviation sector in South Africa?
3. What potential barriers could arise in successfully implementing speech-to-text technology in the aviation sector in South Africa?

## 1.5 Justification/Rationale of the study

This study assessed the process of converting spoken words into written text using speech-to-text technology. This technology could be used in aviation to provide flight information for FPS, which air traffic controllers use to track aircraft movement. By employing this technology, controllers may efficiently and correctly update the strips without the need for human input.

This research provides valuable insights for aviation stakeholders, including air traffic controllers, customer-service teams, regulatory bodies, and technology providers. By highlighting the potential benefits, challenges, and recommendations of integrating speech-to-text technology, the study, hence, aims to inform decision-making processes and encourage the adoption of innovative solutions that can enhance the overall efficiency and safety of the aviation sector in South Africa.

## 1.6 Delimitations of the study

The research addresses the operational difficulties that air traffic controllers face, such as manual transcription and slower response rates, as well as the traditional or analogue operating procedures. It does not address additional aspects that may influence the aviation sector, such as those related to - the environment, security, rapid technical development, change management, and user acceptance.

The research topic is the potential use of speech-to-text in enhancing efficiency in the Aviation sector in South Africa, however, no focus is placed on - the possible effects on the already available resources, associated costs, as well as the time it would take to fully transition, to using this new technology, effectively.

The research also used data from various sources, including academic journals, industry publications, and other representations from the aviation industry, however, due to insufficient and inconsistent data, as well as data restrictions, the investigation's precision could have been reduced.

## 1.7 Assumptions

The theoretical foundations of air traffic controller communication methods and flight plan procedure’s statements in aviation were examined and substantiated by the responses from the respondents. A justification for the research technique, which is addressed from a critical authenticity research context, was presented after a rationale for the theoretical framework was established.

The results of the research on speech-to-text technology will be presented in chapter four, followed by the discussion and interpretation of the results in chapter five. The study's implications for the civil aviation regulators, the aviation sector, and ATNS are discussed in the conclusions; this section also summarises the research's significant findings relating to the potential of speech-to-text technology in enhancing efficiency in the aviation sector in South Africa. Additionally, there are recommendations for various stakeholders, for future research, as well as considerations of the study's identified limitations.

## 1.8 Chapter outline

The background on air traffic control, communication methods, the research rationale, the research problem, the research questions, as well as the assumptions and delimitations, were outlined in this chapter. This was done to provide a context to assist in full comprehension of the research conducted on the potential of speech-to-text technology in enhancing efficiency in South Africa's aviation sector.

# CHAPTER 2: LITERATURE REVIEW AND THEORETICAL FRAMEWORK

## 2.1 Introduction

This chapter covers the theoretical literature that was critically reviewed to concisely outline the context on the topic of technology for speech-to-text conversion.

The focus area of the review is on the potential of speech-to-text technology to enhance efficiency in the aviation sector in South Africa. The reviewing of several research pieces of literature assisted in demonstrating how various technologies have been used for speech-to-text conversions, bringing out their strengths and challenges.

## 2.2 Background discussion

This research aimed to assess how speech-to-text technology can be used to provide efficient communication in South African air traffic control operations. The primary purpose, hence, was to improve efficiency for controlling aircraft within the South African airspace. In other words, the goal was to investigate whether it is possible to convert voice communications received through radio transmissions, from pilots, into text, then be incorporated into flight plans which air traffic controllers could use to keep a visual picture of the aircraft in their airspace.

Flight planning involves optimising various elements, such as aircraft performance, atmospheric conditions, and operational constraints, to ensure fuel efficiency and safety and all these are achieved by communication (Soler, Olivares, & Staffetti, 2015). A flight plan is a comprehensive outline of a proposed aircraft trajectory detailing the journey from departure to destination. It is a crucial aviation document concerning various aspects such as routes, altitudes, headings, fuel consumption, and anticipated times for different flight segments. These plans are not only essential for the safe and efficient operation of flights but also for ensuring compliance with air traffic control regulations and coordination with various aviation stakeholders. They are active and may change due to unforeseen circumstances like weather changes or operational constraints, necessitating real-time adjustments and coordination among pilots and air traffic controllers. The process of creating a flight plan that outlines a proposed aircraft trajectory is known as “flight planning”. To ensure efficiency, this work is usually completed before the date of departure, considering factors such as weather, airspace, traffic, and passenger comfort.

The safety of the aircraft and its passengers is the main objective of a flight plan. It goes without saying that precise route planning and fuel spending are essential for a safe flight. Research by Akgündüz et al. (2018) stated that deconflicted air traffic planning with speed-dependent fuel consumption formulation helps minimise costs and ensure flight safety by incorporating conflict and collision avoidance and maintaining minimum safe separation distance between aircraft. Air traffic controllers also use a flight plan to ensure the consideration of every flight’s safety in their airspace. With access to flight plans, air traffic controllers can predict aircraft movement, plan suitable separation, and issue essential instructions to prevent conflicts and ensure safety.

In addition, flight plans are crucial to search and rescue operations. Filed flight plans give regulators essential information about the anticipated path in the event of emergencies or aircraft disappearances, assisting them in efficiently directing search efforts and allocating resources. A study by Xie and Zhong (2016) examined how efficient path-planning algorithms in air traffic management can help planes avoid severe weather conditions, restricted areas, and moving obstacles, thus, ensuring the safety of cabin crews and passengers.

In the last ten years, the development of speech-to-text technology has been remarkable. This technology is quickly taking over many areas of life, primarily because of the development and application of AI, however, there is still some room for improvement. Srinivasan and Balasundaram (2019), discuss the challenges of applying standard speech recognition engines to the air traffic control communication domain. They concluded that speech-to-text systems can interpret everyday English words used in aviation, but they need help with aviation jargon (Srinivasan & Balasundaram, 2019).

Speech-to-text methodology

In the aviation context, a program's capacity to convert spoken language into written language is variously known as - speech recognition, Automatic Speech Recognition (ASR), computer voice recognition, or speech-to-text (Li et al., 2016).

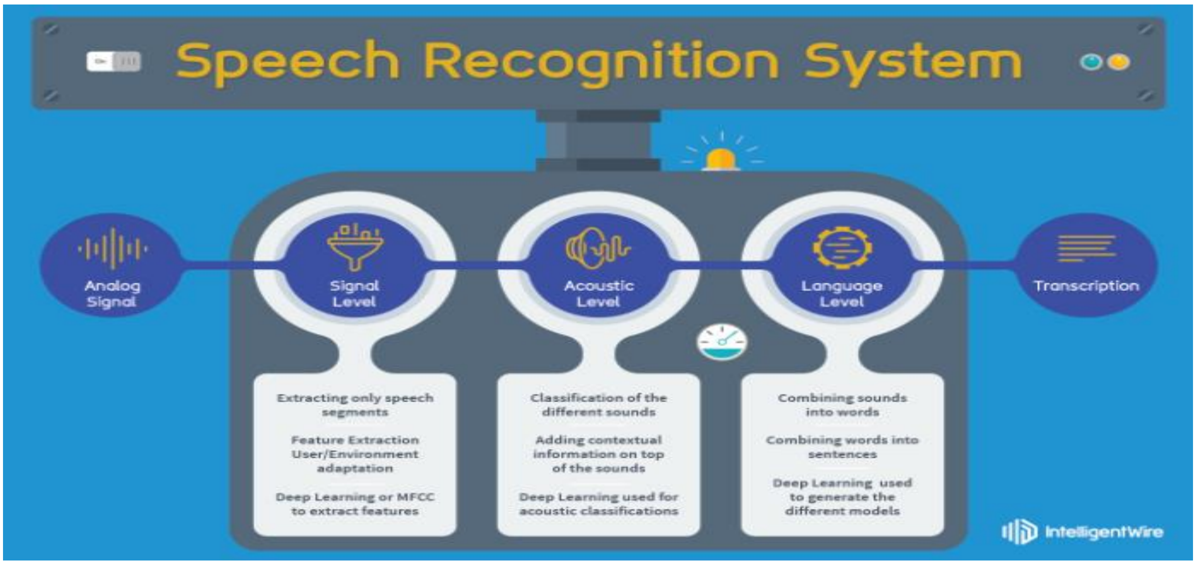


*Figure 3: Speech Recognition System (Alvarez & Carmiel, 2017)*

Various technologies can be used for ASR. According to a book by Li et al. (2016), the complexity of human speech is regarded as one of the most challenging areas of computer science since it combines languages, mathematics, and statistics. High-tech automatic speech recognition converts voice signals to the appropriate text or command after identifying and comprehending the words (Shi, 2021).

According to research by Helmke et al. (2018), air traffic control has seen a rise in the popularity of ASR applications in recent years. Getting enough relevant data to train a speech recognition model is essential to achieve this, as thousands of hours of air traffic controller conversation are logged each day (Helmke et al. (2018). In addition, transcribing these data sets requires a lot of resources, since it involves both writing down the spoken-words' order, then interpreting their pertinent semantics.

The process of ASR involves the identification and extraction of the language model, the acoustic feature, and the acoustic model, hence, a key component of speech recognition is extracting and identifying the auditory characteristics. Information compression and signal deconvolution are involved in extracting and identifying the auditory characteristic (Shi, 2021). Various techniques and computer approaches can be used to translate voice into text and increase transcription accuracy. The most common ones are - Natural Language Processing (NLP), Hidden Markov Models (HMM) and Speaker Diarization (SD).

AI is used in NLP to communicate with a framework using a natural language, such as English. In their study, Bhatia et al. (2023), explained that when people need a robot or machine to follow instructions and hear options based on conversation, NLP is necessary; it controls how computers interpret and understand human speech. With natural language processing (NLP), robots can now read, speak, and do tasks like subject organisation and interpretation (Bhatia et al., 2023). In real life, the most well-known applications of NLP are remote assistants, which are similar to Apple's Siri, Google Assistant, and Amazon's Alexa.

The Markov Chain Model asserts that a given state's existence, and probability, depends on its current condition and not its previous versions. A Hidden Markov Model (HMM) is an enabler which includes hidden events, such as part-of-speech tags, into a probabilistic model. In contrast, a Markov Chain Model is appropriate for visible events, such as text inputs. HMMs are used as sequence models in speech recognition, labelling each item in the sequence (words, syllables, phrases, among others). These labels build a mapping with the input given, enabling the Model to choose the best label order (Deshmukh, 2020).

Speaker diarization, (SD) or "who spoke when," assigns classes to audio or video recordings based on speaker identity. To facilitate speaker adaptive processing, SD algorithms were first created for speech recognition on multi-speaker audio recordings. Over time, these algorithms have proved valuable as a stand-alone tool for supplying speaker-specific meta information for applications like audio retrieval. Recent years have seen breakthroughs in SD due to the introduction of deep learning technology, which has revolutionised research and practices, throughout speech application fields (Park et al., 2022), however, Its application for distinguishing between pilots and air traffic controllers needs to be researched.

According to published research, speech-to-text technology is being used more frequently in various industries, and the results are positive; for instance, the technology is applied in the healthcare industry to record doctor-patient conversations and provide adequate data management (Raghupathi & Raghupathi, 2018). In the following sections, the prospect of moving to speech-to-text technology is discussed from various reviewed research documents.

## 2.3 The integration of speech-to-text technology in air traffic control systems and its influence on operational and flight efficiency

Converting spoken instructions into text has the potential to improve communication in air traffic control, eliminating misunderstandings, saving time, reducing human error and enhancing efficiency (Lin et al., 2022). Traditional or manual transcribing techniques are often tedious and have the potential for mistakes to occur, however, these audio recordings could be automatically converted into text format with the help of AI.

### 2.3.1 The accuracy required for effective operational efficiency

The transcription of flight information using speech-to-text technology has the potential to significantly increase accuracy and efficiency in the aviation sector in South Africa. This technology can speed up data entry and improve data accuracy by automating the transcription process, which will help in many parts of aircraft and air travel management. A research paper by Badrinath and Balakrishnan (2021) presents an automatic speech recognition model tailored to the Air Traffic Control domain, highlighting its potential to enhance system safety, operational performance, and training through accurate air traffic controller communications transcription. The model's ability to extract critical operational information from transcribed text promises significant efficiency improvements in aviation operations (Badrinath & Balakrishnan, 2021).

The most appropriate way to integrate speech-to-text technologies into the current flight information management systems requires complex legislative procedures and constant review to guarantee compliance with ethical standards. Speech-to-text systems could be trained to identify aviation jargon, accents from different regions, and various languages (Jahchan et al., 2021). Since the technology can learn from large datasets and develop its identification of idiosyncratic input abilities over time, this flexibility improves the accuracy and reliability of transcriptions in the aviation sector, where accurate and clear communication is essential for flight safety.

Matarneh et al. (2017), present an extensive review of different speech recognition systems, including the use of Google's speech recognition technologies. Future advancements in speech-to-text technology have been facilitated by these researchers' strategy of using AI techniques to increase accuracy and reduce delays. Accuracy, Application Programming Interface (API), performance, speed in real-time, reaction time, and compatibility - were the primary criteria used in their comparison. The many variables used in comparison, for the process, allowed them to describe the differences and similarities in depth, hence, the authors could make a thorough choice in selecting the best system for speech recognition. Machine learning has various learning techniques - supervised or unsupervised learning - that can be used to study and mimic how information can be transcribed accurately. This information could then be transferred to flight progress strips and operated by the air traffic controller for flight planning.

In their study, Matarneh et al. (2017), highlight the advantages and advances made in machine learning techniques. The study described how these algorithms could examine big datasets while learning and advancing with each encounter; this skill has made voice recognition systems more precise and efficient. Accurate and efficient information is crucial to the aviation sector as it could be used for flight planning, billing, emergency situations and possibly search and rescue. Extensive audio recordings are made during flight operations due to the multiple communications between the pilots, air traffic controllers, and ground employees.

Big data technologies are instrumental in collecting and processing all this data, as they use velocity, variety, veracity and volume. According to Elgendy and Elragal (2014), Big Data are datasets that are challenging to manage with conventional tools and procedures because they are not only large but also highly variable and rapidly changing. Big Data analytics, or the application of advanced analytics techniques to large datasets, can be used to deliver such value (Elgendy & Elragal, 2014).

### 2.3.2 The potential Improvements required on the current systems

To ensure that integration is done correctly and seamlessly, improvements on the current systems or model are required to increase precision and effectiveness. To get a seamless system integration, the system must allow for smooth communication between the flight planning system and the speech-to-text service. APIs offer a standardised approach for integrating various software parts, and this was researched by Dudhagara and Joshi (2017).

Another critical aspect that must be improved is how the system is customised. Customisation of the speech-to-text service is frequently possible using APIs. This can entail training the service about terminology unique to the aviation industry or configuring the service to work in various languages, in accordance with the needs of the flight crew (Amato & Gaeta, 2013). Aviation communication takes place in real time, and everything moves at a fast pace, therefore, using a speech-to-text API, real-time communication transcription must be made accessible.

During this process, sometimes, connectivity could be lost, hence, redundancy is required. Ensuring high system availability and redundancy is crucial in aviation, although offline capabilities may also be necessary in the event of network failures; Cunningham et al. (2017), researched how APIs can enable seamless integration to cloud-based speech-to-text services. The authors described the Cloud-Based Speech Technology for Assistive Applications (CloudCAST) platform, which offers speech recognition services that can be integrated into various applications. The adaptability of such platforms could be beneficial in aviation for creating assistive technologies as CloudCAST helps users communicate with their gadgets more efficiently by providing voice recognition services for assistive technology apps (Cunningham et al., 2017).

Endsley (2017), states that a critical aspect is how the system handles faults and how safe it is, especially with cyber-attacks, unstable networks, and electricity challenges; an appropriate system must include reliable systems for mistake detection and correction, cyber security checks and accuracy checks to reduce risks.

### 2.3.3 The improvements required for flight efficiency

The transfer of information between pilots and air traffic controllers is an essential part of aviation operations. A flight plan details, such as - the aircraft's identity, the point of departure, the routing, destination, and estimated arrival time - are often included in the conversation (Sohail, 2022). The controlling and maintenance of aircraft safety depends heavily on this information, therefore, this data must be transcribed accurately. In using speech-to-text technology, real-time data processing and analysis may be supported, while transcription of flight information is being done. Transcribing audio data into text allows for easy integration of the information into various aviation systems, including flight planning, operational control, and incident reporting (Sohail, 2022). This integration will promote faster information retrieval, data exchange, and decision-making.

Speech-to-text technology can improve how effectively flight plan data is captured. The technology could lessen the possibility of human errors that come with manual transcribing. There are still several research gaps, even though current literature has explored various areas of speech-to-text technologies. Al Smadi et al. (2015) investigated the use of neural networks in speech recognition, emphasising the crucial nature of a reliable, robust system with high accuracy, against noise. Such technologies are vital for the reliability of speech-to-text systems in environments, like aviation (Smadi et al., 2015).

### 2.3.4 Proposition one

Compared to manual or traditional techniques, information accuracy from speech-to-text technology is crucial for influencing operational and flight efficiency. This might offer real-time transcribing services to improve flight operations, safety, and communication.

## 2.4 The impact on customer-service efficiency, in the aviation sector, from speech-to-text technology.

Applying speech-to-text technology integration in aviation entails seamless integration of several software components to make it easier for air traffic controllers to use, essentially, for efficiency for customer services.

### 2.4.1 Speech-to-text seamless integration

The practical implementation of speech-to-text integration in aviation systems may be understood by identifying the technical details of speech recognition, its weaknesses, and prospective areas for development. The efficiency of speech-to-text technology will depend on technological factors, such as speech recognition precision and resistance to noise. Habeeb et al. (2020), researched the ensemble technique for noise reduction in ASR. Their paper concluded that ASR systems frequently produce poor accuracy for the noisy speech signal, therefore, to increase the final ASR accuracy, they suggested an ensemble approach that combines information from several noise reduction filters rather than depending on a single filter for optimal noise reduction (Habeeb et al., 2020).

Additionally, system adaptability has increased due to the application of machine learning. The adaptability of speech-to-text systems may be increased by programming the technology to recognise various languages, dialects, and accents (Silling, 2019). This technology will be beneficial for pilots flying in from different countries with multiple accents, hence, the technology must be able to recognise and process it. The system must absorb the data, identify a particular accent, and it must still be able to transcribe the utterance, accurately.

Machine learning techniques aid in reducing delay in speech-to-text technologies, in addition to enhancing accuracy. Sohail (2022), further state that these systems could provide near real-time transcription by quickly processing and transcribing speech input, which is a capability that is essential in many applications, from voice assistants to transcription services.

For stakeholders and customers using these systems to make educated decisions, it is crucial, however, to evaluate the cost-benefit analysis, productivity advantage, and future research changes in operational procedures (Basak et al., 2023). There are various types of speech-to-text integration software available, but the most accurate and cyber-safe software is required for aviation. Due to the aviation industry's severity and flight safety standards, the integration needs to be highly efficient to add value for improvements in customer service and satisfaction.

### 2.4.2 Human factors are an element in improving customer service

The broad term "human factors" focuses on understanding human behaviours, abilities, and limits. It has a significant impact on the way speech-to-text technology can be used in aviation. The connection between humans and machines is crucial when discussing human factors. Understanding how speech-to-text integration affects - air traffic controller performance, mental workload, and situational awareness - is essential as this cascade down to how the customer will receive it. According to a study by Wickens, Hollands, Banbury, & Parasuraman (2015), the design and integration of speech-to-text systems can be guided by research on human factors to enhance human performance. The focus areas of human factors include, user acceptance and usability, as well as workload and fatigue.

As early as the 1980s, Davis (1989), argued that users' adoption of technology is a crucial component in its acceptance and usage. The Technology Acceptability Model (TAM), maintains that significant markers of user acceptability are perceived efficiency and perceived usability. For error handling, when designing the system, one must keep in mind, how to deal with and convey speech recognition mistakes. This might include redundant systems for essential information, visual feedback, or opportunities for correction and customer surveys. Context-aware design means the system must be built to manage noise levels and terminology unique to the aviation industry. This involves filtering out background noise and comprehending unusual phraseology and accents; it also includes recognising when a pilot is declaring an emergency and alerting the system so that it can be noted by the air traffic controller and emergency vehicles can be placed on standby.

Norman (2013), contends that usability is a crucial factor, and the speech-to-text system should be simple to use, simple to learn and straightforward. Lee & Kirlik (2013), elaborate that intuitive and simple-to-use interfaces may be made using aviation-centred design techniques to understand the demands of air traffic controllers and pilots. Understanding how speech-to-text integration could improve user experience in aviation systems is essential; meaning that aviation professionals must be able to use the technology after receiving the required training.

A study by Endsley (2017), focuses on pilot engagement and possible workload savings as it examines how speech recognition in the cockpit might be implemented. It also considers the possibility of misunderstandings and poor communication brought on by software flaws. Wingelaar-Jagt et al. (2021), researched the impact of workload and fatigue in aviation. The findings revealed that workload and fatigue are serious problems affecting both flight crew and air traffic controllers in the aviation industry. Reduced performance, lower situational awareness, and increased mistake rates might be the results of increased workload and fatigue.

Speech-to-text technology can assist by reducing this workload, as proven by Bolton et al. (2014); these researchers demonstrated in their work, how speech-to-text can automate certain operations to lighten the workload. Automating audio conversation transcriptions can lessen the workload, therefore, essentially reduce the number of fatigue reports filed. This will help both the pilot and the air traffic controller as the system could be trained to detect signs of fatigue in both parties. Kong et al. (2021), researched how the system may be able to detect warning signs of speaker fatigue through the integration of speech-to-text and ML algorithms, enabling early intervention. Even in circumstances when a speaker's voice is altered by exhaustion and tiredness, machine learning can reliably recognise his/her voice, hence, enhancing overall accuracy in scenarios such as long-duration repetitive work and emergency rooms (Kong et al., 2021).

In their work, Shen and Wei (2021), focused on air traffic controller fatigue and proposed a deep learning framework, integrating active learning into speech feature extraction; their study demonstrated the potential of using advanced ML techniques to detect speech signal fatigue; whereas, Wu and Sun (2022), proposed a speech-based fatigue-state detection method for air traffic controllers, highlighting the effectiveness of ensemble learning methods in fatigue detection.

### 2.4.3 Seamless integration of speech-to-text

Badrinath and Balakrishnan (2021), concluded in their research, that using a variety of data sources during training led to more applicable models, or models that performed better on test datasets from various sources. The data could come from those identified below and more.

Speech Data: A large quantity of recorded speech data, sometimes referred to as a 'corpus', is an essential component of speech-to-text systems (Reece et al., 2023). This data should preferably be collected from aviation communications to ensure that the system learns to recognise the specific terminology and phraseology used in aviation.

Transcripts: Accurate transcripts of such speech are required, in addition to speech data. Kocour et al. (2021), describe a pipeline for automatic processing of ATCO pilot audio communication. The critical component of this pipeline is a speech-to-text transcription system that requires real-world air traffic controller data for accurate performance (Kocour et al., 2021). Their research provides the "ground truth" that the machine learning algorithms use, to figure out how to translate spoken words to their written equivalents (Vashisht et al., 2021).

Noise Data: Noise data must be incorporated into the training process to develop a reliable system that can correctly transcribe speech in actual aircraft conditions. This may include background noise coming from the cockpit, air traffic control centres, or other sources of noise unique to the aviation industry. Blatt et al. (2022), proposed a system trained to identify call-signs in noisy air traffic controller transcripts and convert them into the standard format, a crucial aspect of dealing with aviation noise. Valentini-Botinhao and Yamagishi (2018), explored speech enhancement for TTS systems, focusing on noise suppression and dereverberation, which could be adapted for aviation speech-to-text systems.

### 2.4.4 Proposition two

The potential improvement in slow operations or services due to speech-to-text integration can improve safety and customer satisfaction, which are likely to lead to enhanced safety margins across the aviation industry.

## 2.5 Potential barriers to the successful implementation of speech-to-text technology in the aviation sector

The use of speech-to-text technologies is a great tool, but not without issues; this is because when used to transcribe information, especially flight plan information, speech-to-text technology has both advantages and barriers.

### 2.5.1 Accuracy Challenges

Basak et al. (2023), highlighted that accuracy is still a significant issue despite the possible benefits of the technology. Accents, dialects, or poor pronunciation may cause transcription problems. These technologies may need to be improved to accommodate background noise, which is common in flights; ignoring these elements may result in inaccurate transcription of crucial flight information, which would have serious repercussions. This could lead to air traffic controllers requiring correct flight levels written down, which might show two aircraft being at the same level and could result in a crash.

The capacity to operate in noisy situations, such as cockpits and control towers, is a crucial technological component. Hansen and Hasan (2015), demonstrated in their study, the challenges and viable solutions in using ASR systems in noisy environments, such as the aviation industry. Their findings indicated that noise-robust ASR systems might increase communication accuracy and, consequently, improve safety in aircraft operations as noise reduction and cancellation methods are crucial to producing correct transcriptions (Hansen & Hasan, 2015).

Another aspect of aviation speech is the different accents and unique aviation jargon. Pilots and air traffic controllers worldwide have various languages, and the aviation industry uses its own jargon and phraseology. An article by Rosa (2023), speaks about the universal language of aviation and to fully understand these distinct set of languages, the system must be trained to detect and transcribe them accurately. Lyons (2013) suggested that for this to happen, the technology must be easily integrated with current aviation systems; for instance, it should work with both flight planning programs and air traffic controller software.

Endsley (2017), emphasises the essential nature of dependability of the technology and its backup systems. Dependability is crucial as aviation mistakes have tremendous negative implications for operations, therefore, it is necessary to have backup systems and contingency plans in place. All aspects of a working day in the aviation industry are documented for record-keeping, and these need to be readily accessible.

### 2.5.2 Cybersecurity Risks

As AI technologies are implemented, there is an increased danger of cyber-attacks. Strong cybersecurity safeguards are necessary to protect critical flight data against loss or manipulation when using AI-powered transcription services (Abomhara & Koien, 2020).

Recently, the websites of 14 main US airports were reportedly attacked by hackers in October 2022, making them briefly inaccessible. Denial of service (DoS) is intended to disrupt the systems that customers use to check flight schedules and other information. This kind of cyber-attack typically works by overwhelming or flooding a targeted machine with requests until regular traffic cannot be processed, resulting in a denial of service to additional users. Fortunately, the affected systems was not handling security for transport, internal airline communications, or air traffic control (Ellichipuram & Ellichipuram, 2022).

When using AI technology, security is a significant problem. Unfortunately, due to the increasing danger of cyber-attacks, strong cyber-security precautions are needed to employ AI-based transcription services (Mohammed, 2020). Applications using AI may be exposed to malicious attacks, which might result in false information which could compromise major elements of the system (Kaur et al., 2023). The accuracy of the technology must be improved constantly, cyber-security needs to be strengthened, and robust regulatory and ethical frameworks need to be constantly reviewed and developed.

### 2.5.3 Addressing Regulatory Complications

There needs to be thorough regulatory guidelines for AI applications in aviation to ensure the adoption of such technologies. To establish ethical standards, these technologies require extensive legal procedures and ongoing monitoring (Bird et al., 2020). An area of law known as "Air Law" is focused on the legal and commercial issues related to air transport operations. This is a set of regulations that control how the world's governments and the public may benefit from aviation's usage of the airspace (Aviation Management - International Air Law, 2023). The use of speech-to-text based on AI would need to be endorsed as part of the Air Law procedures and regulations that would be practised across the aviation community for standardisation.

The integration of speech-to-text technology in aviation has the potential to result in significant improvements in efficiency and safety. To ensure its ethical and secure use, it is crucial to abide by all applicable rules and regulations. ICAO provides aviation technology adoption rules, and compliance with these laws is essential to maintain the safe and legal operations of aviation systems (Dempsey & Milde, 2017). It is necessary, hence, to constantly review all relevant laws and regulations and ensure compliance prior to implementation. ICAO would closely monitor the integration of speech-to-text technology as it has a direct influence on aircraft safety. The FAA's Human Factors Design Standard (HFDS), for instance, provides crucial design guidelines that could be applicable to speech-to-text systems (FAA, 2016). With regard to the use of modern technology in aviation, the EASA also has strict regulations (EASA, 2023); for instance, EASA's human factors and safety regulations, which prioritise usability, efficiency, and safety, would need to be complied with by speech-to-text systems. The usage of speech-to-text technology may be impacted by data privacy requirements set out by the ICAO, FAA and EASA. The storing of data and user permission would require consideration of regulations like the General Data Protection Regulation (GDPR) in the EU (EU GDPR, 2016).

It is crucial that the speech-to-text technology used in aviation abide by every rule and regulation that apply. This would ensure that such technology, not only improves efficiency but also promotes safety, complies with regulations, and eventually earns the trust of the aviation industry.

### 2.5.4 Required training before full adoption

**Technical Training:** The staff will require training on the technical use of the technology, which would include understanding its operation, troubleshooting, and interpreting its outputs (Silling, 2019).

**Communication Training:** Given that the technology is focused on converting speech into text, there should also be a need for training on producing clear and effective speech to ensure accurate transcription. This may be pertinent for air traffic controllers and pilots, where communication clarity is essential (Lin et al., 2022).

**Procedure Integration:** Staff will also need training to integrate the use of the technology into existing procedures. This will involve understanding how the output of the technology (the text) fits into their communication and decision-making processes (Sohail, 2022).

**Adaptation Training:** Given that technology continuously evolves, the aviation industry would need to consider ongoing training to adapt to updates and improvements in speech-to-text technology.

**Change Management:** Lastly, the introduction of speech-to-text technology may lead to resistance among personnel due to the change that the technology would bring in their working procedures, therefore, change management training that helps staff understand the benefits and necessity of the technology would be a necessity (Silling, 2019).

### 2.5.5 Proposition three

It is evident that AI has prepared the way for the next advancements in accurate speech-to-text technology by creating the foundation for increasingly precise and responsive systems that can be used to transcribe information for efficient usage in flight planning.

Rapid advancements in technology may address any barriers and clear the way for the effective use of these technologies in aviation.

## 2.6 Analytical Framework

Two theoretical frameworks were applied to address the research questions to understand and address the potential of speech-to-text technology in enhancing efficiency in the aviation sector in South Africa - the General Systems Theory framework and Dynamic Capabilities Theory framework.

A broad theory regarding the dynamics of complex systems in nature, culture, and science is known as Systems Theory. It is a framework that may be used to examine, evaluate, and explain any collection of items that cooperate to achieve a single objective. Companies that are both organic and inorganic (such as those made from data elements, like aviation) can benefit from using the Systems Theory. The General System Theory (GST), published by Ludvig von Bertalanffy in 1968, marked the beginning of systems research.

The systems model is composed of four fundamental components - output, process, input, and feedback - as displayed in Figure four below. The desired result, outcome, or objective, is represented by production; the word "process" refers to the actions that take place to change inputs into desired outputs; the raw materials or resources that will be converted into the final product are known as “inputs”, and the control element is “feedback”. To get the intended outcome, the method and inputs must be changed if the desired output is not initially obtained (Lai & Lin, 2017).

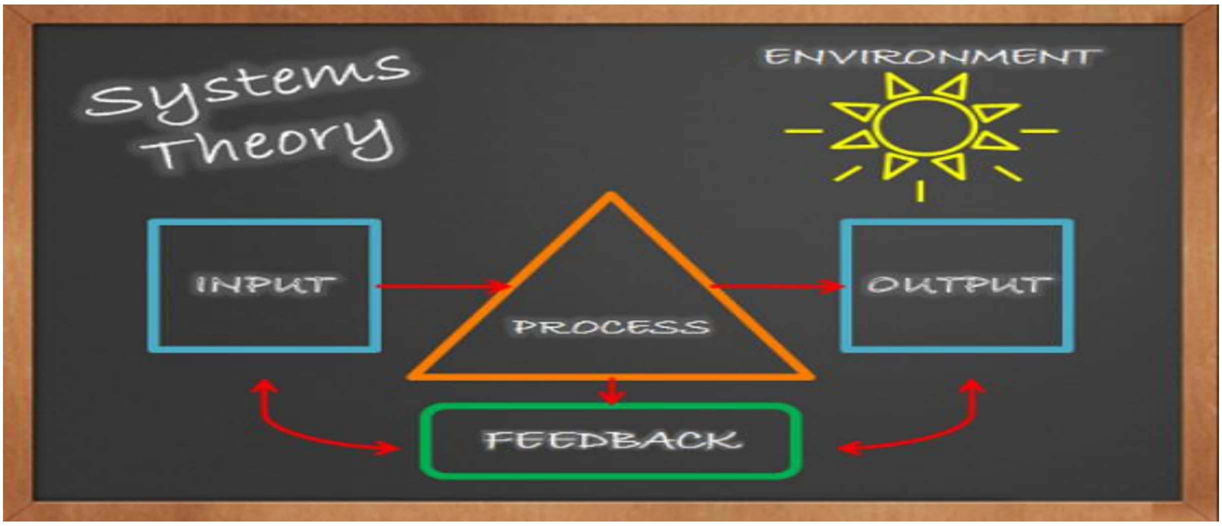


*Figure 4: General Systems Theory (Lai & Lin, 2017)*

**Dynamic Capability** is a company's ability to integrate, build, and reconfigure its internal and external skills to address rapidly-changing environments (Teece, 2023). The potential of speech-to-text technology in the aviation industry may be applied using the Dynamic Capabilities Theory. The framework is based on ideas that are broadly applicable enough to be used in any organisational situation. It also consists of sets of small foundations that researchers and practitioners can use to solve emerging problems (Teece, 2022); the report by this states that newly-implemented company models and the strategies that go along with them depend on the company's capacity for change. Identifying and closing capability gaps through internal development, acquisition, or collaboration, in this situation, is necessary. To avoid organisational pride overstating management's perceptions of the company's fitness, a study of current capabilities in terms of their applicability, requires an impartial point of view.

Yudistira et al. (2022), add that Dynamic Capabilities Framework focuses on an organisation’s ability to sense and identify opportunities and threats then - seize opportunities, and minimise threats - while maintaining competitiveness through resource - tangible and intangible - management.

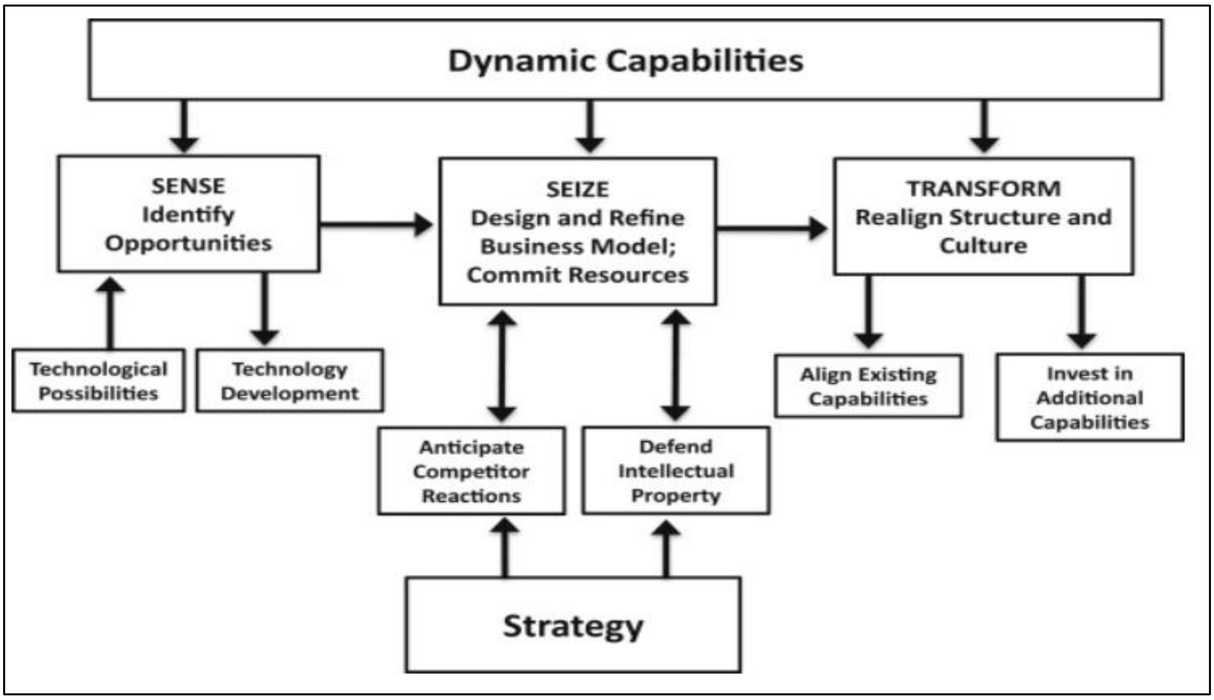


*Figure 5: Business models and Dynamic capabilities (Teece, 2018)*

### 2.6.1 Theoretical Framework

**The General Systems Theory Framework** was applied to assess the potential of speech-to-text technology in enhancing efficiency in the aviation sector in South Africa.

The Systems Theory suggests that a change in one sub-system, such as introducing speech-to-text technology in air traffic control, can influence the entire system's performance. Lin et al. (2022), demonstrated that speech-to-text technology could enhance communication in air traffic control, leading to improved operational efficiency. In other words, the application of speech-to-text technology in flight operations could initiate a system change that could lead to more efficient operations (Silling, 2019). Systems Theory would interpret this as a synergistic effect, where a change in one part of the system (for example, flight operations) could positively impact the entire system.

In customer service, speech-to-text technology can lead to efficient interactions, improving overall customer satisfaction (Sohail, 2022). This change can be understood using the System Theory as a modification within the customer service sub-system, that then has system-wide implications. To further make all this possible, machine learning was introduced when integrating speech-to-text technology in aviation for speech recognition (Sohail, 2022). In terms of speech recognition, machine learning techniques, particularly deep-learning models like recurrent neural networks (RNNs) and convolutional neural networks (CNNs), have shown promise, showing the system's ability to recognise certain accents and speech patterns and even reduce background noise.

Potential barriers to the implementation of speech-to-text technology, such as - inaccuracy, technical incompatibility, regulatory non-compliance, and urgent need for personnel training - were analysed using the System Theory. These barriers are components of the more extensive system that might resist change or require modifications to implement the technology successfully (Silling, 2019). The accuracy of speech-to-text transcription has been improved over time using machine learning models, which understand the specific context and terminology of aviation communication. Additionally, predictive analytics have been enhanced by ML, enabling predictive text and corrections, reducing the time needed for manual text editing, and improving overall efficiency (Wang et al., 2018). Advanced ML models can speed up real-time speech processing, which is essential in scenarios involving time-constrained flight planning (Amodei et al., 2015).

The **Dynamic Capabilities Theory** informed this study because of its ability to investigate the potential of Speech-to-text technology in enhancing efficiency in the aviation sector in South Africa.

To conduct a thorough study of two dynamic capabilities in the airline industry, Martin (2016), combined the literature on dynamic capabilities with the literature on alliance management capabilities. The findings showed a positive connection between the two competencies in this study and firm fitness, when they are applied during sustained performance. The two skills in the research had different natures - one was dual-purpose, and the other was dynamic - which may have contributed to the differences in their responses to external circumstances.

Integrating speech-to-text technology into air traffic control systems using Dynamic capabilities theory, therefore, will likely lead to improved operational efficiency. From the dynamic capabilities perspective, this requires not only acquiring the technology but also integrating it into existing communication procedures and training the staff on the new system. The positive impact of speech-to-text technology on flight operations efficiency would depend on the company's ability to integrate the technology into its processes and train pilots on its use (Silling, 2019).

Dynamic Capabilities Theory suggests that the potential for improved efficiency in customer service lies not just in the technology itself but in how it is incorporated into the company's customer service operations. This might involve developing new procedures, training staff, and continuously improving these practices, in response to evolving technology and customer expectations (Sohail, 2022).

According to the Dynamic Capabilities Theory, any barriers must be addressed through strategic management competencies which would involve, developing new skills, obtaining and integrating additional resources, and responding to altered regulatory needs. If these issues are attended to, companies might effectively integrate speech-to-text technology and access its potential benefits. (Silling, 2019).

### 2.6.2 Conceptual Framework

In the research on the potential of speech-to-text technology in enhancing efficiency in the aviation sector in South Africa, Dynamic Capabilities Theory and Systems Theory were used as the basis for a conceptual framework, hence, the research merged the two theories.  The foundation of the ontology of the Dynamic Capabilities Theory rests on a systematic view of the company approach, as the theory, controversially, uses systems thinking as a metaphorical point of reference (Liboni et al., 2022). Systemic approaches, which see purposeful learning and design process as a non-linear movement of causal loops, can help managers create dynamic capabilities in a unique way (Liboni et al., 2022). These researchers suggest a framework based on systemic techniques to manage and build organisational dynamic capabilities while drawing attention to the conceptual foundations, as it includes the systems approach to learning and design into the Dynamic Capabilities Theory's management principles based on two distinct systemic techniques (Liboni et al., 2022).

Acquisition of Speech-to-text technology

Acquisition of the technology is the intended initial stage of integrating it into the aviation system; it involves identifying the technology's potential, evaluating its relevance, and investing in its procurement (Lin et al., 2022). Additional research on, Automatic Speech Recognition for Air Traffic Control Communications, revealed how to extract operational data from air traffic controller voiced communication data using an artificial speech recognition model (Badrinath and Balakrishnan, 2021).

Figure six below shows that the model was built on a new machine-learning technology that uses recurrent neural networks and follows an end-to-end voice recognition architecture (Badrinath & Balakrishnan, 2021). These researchers' goal was to - understand the effects of the language model, parameter fine-tuning, transfer learning, and training with more data. They also considered the possibility of extracting operational information using NLP approaches.

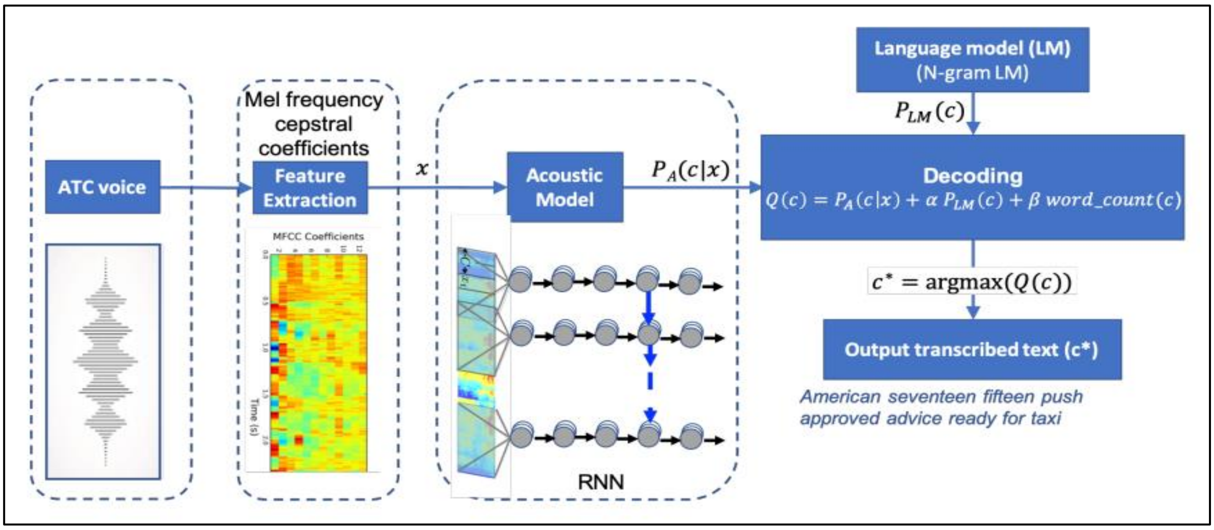


*Figure 6: ASR System Model Architecture (Badrinath & Balakrishnan, 2021)*

## Integration into Sub-systems

This stage involved deploying the technology in various sub-systems, including air traffic control, customer service, and flight operations (Sohail, 2022). The integration must be carefully managed to ensure the technology fits in with existing processes and practices, thus, aligning with the dynamic capabilities theory's concept of integrating additional resources. Badrinath and Balakrishnan (2021), found that adopting more robust language models, semi-supervised learning, better priors, or context, and training the model with more transcribed air traffic controller voice data might all increase the accuracy of speech-to-text models for the air traffic controller’s domain. These improvements may increase transcription accuracy, opening the door to valuable applications like - real-time safety monitoring and incorporating speech-activated air traffic controller assistants.

## Training and Development

Successful implementation of the technology requires training and developing the staff to use the technology effectively. This step is crucial for harnessing the full benefits of the technology, which aligns with the idea of creating and deploying strategic capabilities in the Dynamic Capabilities Theory. Research by Delaney (2015), assisted these procedures, as it detailed - the advantages and difficulties of managing technological development, the training issues that come with recent technology and its potential, as well as, the intended negative effects it can have on the workers, if there is no proper communication of the digital transformation strategy.

Efficiency Outcomes

The goal with this concept is to enhance efficiency in the aviation sector in South Africa; this could be measured in terms of - improved communication accuracy, reduced misunderstandings, better customer interactions, and improved flight operations (Lin et al., 2022; Sohail, 2022; Silling, 2019). Various literature has shown that speech-to-text is a growing subject in aviation as an observation was made on the need for enhanced efficiency for, flights, communication methods and customer service. Kopald et al. (2013), researched the application of automatic speech recognition technology with air traffic management, looking at the at how it could reduce air traffic controller workload without making them feel redundant.

The feedback and adaptation stage involved assessing the impact of the technology and making necessary adjustments. This corresponds with the Systems Theory's view of a system as a dynamic and adaptive entity. In research conducted by Delaney (2015), the report argued that organisations should adapt to a constantly changing environment to satisfy the demands of their customers, if they want to be competitive in a global market. The author continued that to remain competitive, a company must develop and adjust its technology and processes to stay ahead of its competitors. Organisations must develop the ability to deploy recent technologies and handle the difficulties that may arise as changes of this kind can benefit a company greatly, although, they can also bring several challenges that must be overcome to produce an effective result (Delaney, 2015). Managing technological change can be challenging, however, if organisations plan, communicate, handle conflicts, and keep an eye on all areas of the change made, it will improve their likelihood of successfully executing these transformations (Delany, 2015).

## 2.7 Conclusion of Literature Review

According to the available research, speech-to-text technology has a lot of potential to increase efficiency in the South African aviation industry. This conclusion results from a thorough review of previous research that had concentrated on several aviation sub-systems, such as air traffic control, customer service and flight operations.

These studies have repeatedly asserted how this technology can improve communication speed and accuracy (Lin et al., 2022; Sohail, 2022; Silling, 2019); for example, the implementation of speech-to-text technology in the context of air traffic control might decrease communication errors, enhancing both safety and operational efficiency (Lin et al., 2022). Incorporating speech-to-text technology for customer-service operations offers opportunities for increased service efficiency, thereby, potentially increasing customer satisfaction rates and reducing response times (Sohail, 2022).

In addition, studies have also articulated some barriers to the adoption of speech-to-text technologies. To take advantage of the technology, for instance, the aviation industry must address several barriers, including those relating to technological compatibility, regulatory compliance, as well as, the requirement for extensive training before and during the implementation stage; indicating that, although the technology can potentially increase productivity and decrease human error, it also has issues that need to be resolved (Silling, 2019). The accuracy of the technology must be constantly improved, cyber-security needs to be strengthened, and robust regulatory and ethical frameworks need to be developed. Furthermore, the capacity to integrate, develop, and adjust internal and external competencies, to handle quickly the changing contexts, are essential for the practical application of speech-to-text technology.

These discussions demonstrate the literature's convincing support for the potential benefits of speech-to-text technology, however, its successful implementation in the aviation industry will require a thoughtful and careful approach that addresses systemic integration and dynamic organisational capabilities’ development.

# CHAPTER 3: RESEARCH METHODOLOGY

## 3.1 Introduction

This chapter describes the methodology employed to investigate the potential of speech-to-text technology in enhancing efficiency in the aviation sector in South Africa. It covers the - research design, population and sample selection, data collection methods, data analysis techniques, and measures to ensure reliability, validity, and dependability.

## 3.2 Research Approach

A qualitative approach was selected for this research and interviews were conducted to gather insights and opinions from experts in the aviation industry. According to Creswell and Clark (2017), this approach provides a comprehensive understanding of the research problem.

Investigative research is primarily aimed at gaining a deeper understanding of a relatively under-explored topic or phenomenon. The use of speech-to-text technology in South African aviation, particularly in air traffic control, is a developing area of research and, therefore, warrants an investigative approach. When little prior data is available, this design is helpful for seeking more knowledge on complex problems (Boru, 2018).

## 3.3 Research Design

A research design provides a roadmap for the collection, measurement, and analysis of data (Creswell, 2009). The Technology Acceptance Model, (TAM) which was propounded by Davis (1989), served as the study's foundation framework; the Model's hypothesis states that essential factors influencing technology adoption are the perceived effectiveness and perceived ease of use. The Model, hence, was used to investigate how aviation professionals see the usefulness and accessibility of speech-to-text technology can improve aviation operations and safety in South Africa.

A case study technique was used as this research is exploratory in nature. This method enables a thorough investigation of a specific situation or scenario, such as an airport or air traffic control facility, thereby, facilitating an understanding of the complexity of using speech-to-text technology (Yin, 2013). The technique provided comprehensive information on the practical uses and difficulties in exploiting these technologies.

Various issues need to be examined when investigating the possibilities of speech-to-text technology - efficiency, accuracy, safety, and flight planning - are some of these structures; the creation of quantifiable indicators or alternatives was required for investigating them. Efficiency, for instance, might be quantified by the amount of communication time saved, and safety by a decline in communication errors.

The main research questions guiding this research project focused on - understanding how speech-to-text can be applied in aviation, what the perceived benefits and challenges are, and how these technologies can be integrated into current aviation systems to improve accuracy, safety, and flight planning.

## 3.4 Data Collection Methods

Primary Data

Interviews were used to gather in-depth data on the complexity of the aviation industry's beliefs, attitudes, and behaviours. Open-ended questions were used for the interviews, giving participants the opportunity to extensively express their opinions in their own words (Roller, 2022).

Focus-groups discussions and interviews were primarily used to gather data. An in-depth investigation was made possible by using semi-structured interviews, and participants' discussion was facilitated in focus groups; these data collection methods were supplemented with observations and document analysis. The semi-structured interviews were conducted with industry experts and stakeholders to investigate their insights regarding the integration of Speech-to-text technology, and to discuss likely challenges, implications, and predictions.

Secondary Data

Secondary data was compiled from academic journals, industry reports, government publications, and case studies, facilitating the contextualisation and authentication of the primary data. An evaluation of relevant publications, including policy papers, technical reports, and case studies regarding AI, Big Data, and speech-to-text in aviation, was conducted. According to Morgan (2022), document analysis is a methodical process for examining documents in both physical and electronic form.

## 3.5 Population and Sample Selection

Sample and sampling method.

Professionals in the aviation industry, such as pilots, air traffic controllers, operations managers, investigators, and aviation engineers, made up the sample for the research. A purposeful sampling approach was used to choose people with appropriate expertise or understanding of AI, Big Data, and speech-to-text technologies in the aviation industry. This sampling method helps a researcher to concentrate on demographic features that are relevant to a study (Tongco, 2007).

In qualitative research, the sample size is frequently flexible. Marshall, Cardon, Poddar, and Fontenot (2013), suggest that informational concerns, not statistical ability, should be used to decide the sample size in qualitative investigations. The target sample selected comprised of - three air traffic controllers, three operations managers, three airline personnel or pilots, three aviation engineers and three aviation safety experts. A purposive sampling technique, hence, was used to select these participants, who have substantial knowledge and experience in the domain of aviation and technology (Palinkas et al., 2015).

## 3.6 The Research Instrument

Depending on the participants' preferences and availability, in-depth interviews were done either in person or over Microsoft Teams conferencing to gather the qualitative data. To keep the interviews focused on the goals of the study, an interview guide with open-ended questions was developed dwelling on the potential of speech-to-text technology in enhancing efficiency in the aviation sector in South Africa.

## 3.7 Procedure for Data Collection

Initially, 15 key aviation personnel were selected, however, only 14 were interviewed. These interviews focused on gathering detailed information, through the open-ended questions, and at the same time, offering the freedom for the participants to give further information and opinions, should they wish to do so. After 14 interviews, no additional information was forthcoming from the participants, indicating that saturation point has been reached, and that further interviews were not necessary.

## 3.8 Data Analysis Strategies and Interpretation

Analysing the data after it was gathered through interviews was crucial to comprehend and derive outcomes. An inductive thematic analysis was used to examine the qualitative data collected this research. The analytical process was performed through investigating and reporting on themes within the data, which in turn, led to an interpretation of the topics' various aspects in relation to the research questions (Braun & Clarke, 2006).

Nowell et al. (2017), maintain that thematic analysis is an effective qualitative technique when working with research teams and evaluating large qualitative data sets. This step-by-step process offered a thorough explanation and practical way to carry out an analysis of data collected during interviews; this allowed for a reliable analysis in conjunction with a framework.

Following Braun and Clarke's (2006) recommendations, the data analysis followed six steps:

- Transcribing of the interviews' information based on speech-to-text technology;
- Comprehension of the data;
- Creation of preliminary codes;
- Searching for common themes from the answers;
- Evaluating those themes; and
- Defining and labelling themes.

To guarantee reliability and validity, the Guba (1981), criteria of credibility, transferability, dependability, and confirmability were applied to the data collected on the potential of speech-to-text technology in enhancing efficiency in the aviation sector in South Africa. To achieve these requirements, methods - including triangulation, member verification, and giving rich, detailed descriptions - were used.

## 3.9 Possible limitations and challenges

There are several limitations and challenges in this research on the potential of Speech-to-text technology in enhancing efficiency in the Aviation sector in South Africa, as this concept is new and needed extensive exploring.

**Subject matter Complexity**: Aviation on its own is a complex industry with various procedures and regulations governing it. To add to this, AI is highly complicated and developing quickly. Combining quantitative data may have made it easier to identify and calculate implications due to the depth and variety of qualitative data and the complexities of the recognised industry and the technology required.

**Time-consuming:** The data collection and analysis processes took a lot of time, since they required thorough transcription and analysis of the in-depth interviews. The literature review, and the interview sessions needed to be done procedurally, paying attention, also, to proper time management to meet the target dates and to work around the schedules of the identified participants.

**Subjective and Bias**: Qualitative research is subjective, hence, data interpretation may be biased as a result. Participants' own biases may also influence their perceptions, which might undermine the reliability of the results.

**Resource Limitations**: Speech-to-text for air traffic control conversion can be costly and resource-intensive due to the demand for specific skills, the time-consuming nature of the process, and the strict regulations around aviation. Adopting speech-to-text technology would require extensive trials before fully converting and going live without a manual contingency plan.

**Expertise in Technology:** Knowledge of AI, Big Data, and speech-to-text technologies is required for the research. The level of understanding and analysis was constrained by some of the participants' need for more technical skills. The aviation safety managers understand regulations and procedures but need to gain more knowledge of technology as was demonstrated during the data-collection process.

**Data Security and Privacy:** Speech-to-text discussions in the aviation industry may entail private or confidential flight and workspace data being shared. There are legal and ethical concerns with how this data would be handled, who it can be shared with and what can be shared. This had an impact on the data that can be collected.

**Rapid Changes**: Technology moves rapidly with advancements happening daily; this means that technology has probably advanced further, and aviation industry regulations and procedures may have changed by the time the study is released, thereby, possibly, making some specific results outdated.

## 3.10 Quality Assurance

The research method rested on dependability, validity, and reliability to guarantee the quality assurance and authenticity of the findings. It was crucial to carefully evaluate these factors in the context of the possible use of speech-To-Text technology in aviation.

The research ensured that the interview questions were straightforward and that the document analysis was done methodically to ensure the reliability and validity of the study. To ensure trustworthiness of the results in qualitative research, according to Nowell et al. (2017), it is necessary to ensure credibility, transferability, dependability and confirmability. To increase the study's credibility, member checking, in which participants confirm the results, and triangulation, which makes use of several data sources, including interviews and document analysis, were used.

Transferability

This refers to whether the research is applicable in various settings. Transferability may be evaluated with the use of substantial, in-depth descriptions of the setting and participants (Roller, 2023). The level of detail of the data can be increased by the participants' specific expertise and experience in the fields of aviation and technology.

The extensive expertise and of the participants and the in-depth explanations of the individuals assisted in ensuring that the results of the research could be applied to readers' own situations. The sampled individuals understand aviation and developments in technology regarding AI and Big data, therefore, their contributions can be transferred to aviation sectors in the African regions, which in turn could lead to efficiency across all areas of the industry.

Credibility

To give a study credibility, the research ensured that it measured what it said it would, by using methods like member checking, in which participants examine and verify the veracity of their data and interpretations (Roller, 2023).

Once all the interviews were concluded, the data, findings and analysis were shared with the participants for their input and to ensure the accuracy was preserved before the results were included in the final research. This ensured that the credibility of the study was maintained.

Dependability

To ensure dependability, the researcher provided an audit trail that involved a thorough explanation of the study processes as they were documented and tracked (Roller, 2023). Should there be changes or additions to the conclusions, based on changes in aviation regulations or technology advancements, those will also be documented before the compilation of the final research report. This process would include, for example, details on why particular participants were selected and how their expertise aided in the research.

Confirmability

The degree to which participants' experiences and ideas, rather than the researcher's traits and preferences, contributed to the conclusions, is referred to as confirmability. Reflexivity, which involves the researcher reflecting on his/her own biases and assumptions, can help with this (Roller, 2023).

If the responses received are analysed incorrectly or influenced due to the researcher's preferences towards developments in technology and how speech-to-text would affect their division in aviation, it could affect the confirmability of the research findings. This means that the researcher, for instance, should not view this research as culminating in less work for pilots and air traffic controllers but potentially more work for the regulator and technical department. The results, hence, should speak for themselves.

## 3.11 Ethical Considerations

Ethical principles, including informed consent, confidentiality, and the opportunity to withdraw, were respected throughout the research process. Before the study began, informed permission was gathered from each participant. Pseudonyms will be used to protect the participants' identity, thereby, maintaining confidentiality. The data will be kept private and safe to preserve participants' anonymity.

## 3.12 Conclusion

This research presents a thorough and in-depth approach to investigating the potential of speech-to-text technology in enhancing efficiency in the aviation sector in South Africa. The knowledge collected through this research could have a significant impact on how these technologies are understood and used to improve aviation efficiency and safety.

The understanding of how the integration of speech-to-text technology in air traffic control systems influences operational and flight efficiency will aid in effective controlling. Furthermore, the interrogation of how the use of speech-to-text technology will impact customer service efficiency in the aviation sector will improve customer satisfaction and feedback. Lastly, addressing the potential barriers affecting the successful implementation of speech-to-text technology will advance the aviation industry in South Africa.

Consistency Matrix regarding the research methodology

| RQ | State research question | Proposition | State proposition | Data collection | Data Analysis Method |
|---|---|---|---|---|---|
| **1** | How can integrating speech-to-text technology in air traffic control systems influence operational and flight efficiency in South Africa? | 1 | Information accuracy from using speech-to-text technology, as compared to manual or traditional techniques, is crucial for influencing operational and flight efficiency. | Interview Questions<br><br>6, 9, 10 | Thematic analysis |
| **2** | How can the use of speech-to-text technology impact customer service efficiency in the aviation sector in South Africa? | 2 | An improvement in slow operations or services due to speech-to-text integration can improve safety and customer satisfaction, which in turn, will enhance safety margins across aviation. | Interview Questions<br><br>4, 7 | Thematic analysis |
| **3** | What potential barriers could arise in successfully | 3 | Rapid advancements in technology may address these | Interview Questions | Thematic analysis |

| | | | | | |
|---|---|---|---|---|---|
| | implementing speech-to-text technology in the aviation sector in South Africa? | | barriers and clear the way for the effective use of these technologies in aviation. | 8,11,12 | |

*Table 1: Consistency Matrix: Research questions, propositions, data collection and data analysis*

# CHAPTER 4: PRESENTATION OF FINDINGS

## 4.1 Introduction

This chapter delineates the insights derived from a meticulous inductive thematic analysis, underpinning a qualitative investigation into the integration and implications of speech-to-text technology within the aviation sector of South Africa. Anchored by the theoretical underpinnings of General Systems Theory and Dynamic Capabilities Theory, this inquiry explores the multifaceted dimensions of technological adaptation in aviation. It aims to contribute to the broader discourse on technological innovation and systemic resilience in complex operational environments.

The genesis of this analysis lies in the comprehensive interview regimen articulated in Chapter Three, which was meticulously designed to capture a broad spectrum of perspectives and experiences from within the South African aviation industry. The questions were formulated with a dual purpose: to elicit rich, descriptive narratives that reveal the current state of speech-to-text technology usage and to probe the potential for future integration within the operational and strategic frameworks of the industry.

Building upon the foundational literature review presented in Chapter Two, this chapter addresses three core propositions that emerged as central themes in the discourse on technology integration within aviation systems. Each proposition serves as a lens through which the data is examined, facilitating a structured yet flexible approach to the analysis. The thematic analysis process involved an iterative cycle of data coding, theme identification and categorisation, allowing for a nuanced exploration of the complexities and intricacies inherent in adopting speech-to-text technologies.

The findings of this research are systematically presented through a series of tables, each corresponding to one of the propositions. These tables serve as a concise visual representation of the key themes and categories that emerged from the data, offering a clear and accessible overview of the primary insights gleaned from the analysis. Following each table, a succinct narrative elaborates on the findings, providing context, interpretation, and a deeper understanding of the implications of these insights.

In essence, this chapter offers a comprehensive synthesis of the qualitative data collected, analysed, and interpreted through the prisms of General Systems Theory and Dynamic Capabilities Theory. By weaving together, the thematic threads extracted from the interviews, this analysis illuminates the potential pathways and challenges for adopting speech-to-text technology in South African aviation, contributing valuable perspectives to the ongoing dialogue on technological innovation and systemic adaptation in complex industries.

## 4.2 Findings pertaining to proposition one

| **Proposition 1** | **Information accuracy from using speech-to-text technology, as compared to manual or traditional techniques, is crucial for influencing operational and flight efficiency.** | | |
|---|---|---|---|
| | **Categories** | **Key findings** | **Themes** |
| **General Systems Theory and Dynamic Capabilities Theory framework** | Effective operation of Speech-to-text<br><br>Improvements in current systems<br><br>Improvements for flight efficiency. | Instant data input and output, backup power, reliability<br><br>Technology development and system upgrades<br><br>Improved flight plan procedures. | Enhanced operational efficiency, real-time transcriptions, and accuracy.<br><br>Infrastructure upgrades, new technology, less human error<br><br>Real-time data processing, accuracy, and delays. |

*Table 2: Proposition One thematic analysis findings*

The thematic analysis conducted on the interview data provides compelling evidence that the adoption of speech-to-text technology is likely to significantly revolutionise the South African aviation sector, primarily by elevating the accuracy of information capture and processing. In an industry where precision is paramount, and the margin for error should be exceedingly narrow, the potential for speech-to-text technology to enhance operational and flight efficiency, cannot be overstated. The gravity of ensuring accurate in-flight data is highlighted by the dire consequences that even minimal inaccuracies could trigger, ranging from operational disruptions to critical safety risks.

A response from one of the participants stated - *“Efficiency of filing flight plans, meaning that you have more flight plans that can be filed in much quicker time so that it takes away the manual processing of flight plans, meaning that resources can be utilised elsewhere, so it frees up the human, but you also have real-time feedback. I would like to believe this because if a flight plan is filed speech to text, I imagine that it should be able to then give the filer immediate feedback on whether that particular flight plan was filed correctly or submitted successfully, as opposed to still waiting for human intervention that's going to go and check it and compare it within the parameters and give feedback. So, I think it would help us with the efficiency and provide the filer, which is the pilot in this case, with real-time feedback on their submission.”*

The accuracy with which speech-to-text technology could transcribe complex aviation communications would minimise the likelihood of human error, a prevalent risk factor in the manual transcription processes. In automating the transcription of pilot communications, air traffic control instructions, and other critical aeronautical communications, speech-to-text technology provides a reliable foundation for error-free information exchange. One of the managers stated - *“To reduce the number of errors once the models get better, increase the efficiency in which flight plans can be recorded from pilot to air traffic controller.”* Reducing human error, therefore, is a step towards enhancing operational efficiency and a significant leap in bolstering flight safety and reliability.

The full-scale implementation of speech-to-text technology within the South African aviation landscape, however, depends on addressing specific requirements, such as upgrading existing infrastructure and advancing relevant technologies. Successfully deploying speech-to-text systems requires a robust technological infrastructure capable of supporting highly-reliable audio capture and processing, along with integrating speech-to-text solutions into the existing aviation IT system. This necessitates substantial investments in technological development and infrastructure upgrading to create an environment required for the ideal functioning of speech-to-text technology.

## 4.3 Findings pertaining to proposition two

| Proposition | An improvement in slow operations or services due to speech-to-text integration can improve safety and customer satisfaction, therefore will enhance safety margins across aviation. | | |
|---|---|---|---|
| | **Categories** | **Key findings** | **Themes** |
| **General Systems Theory and Dynamic Capabilities Theory framework** | Data for System integrations | Depth of understanding, more AI and machine learning research, technology improvements, | Cost implications, limited infrastructure, old flight system models, systems' adaptability. |
| | Customer service improvements | Streamlined process, better user experience, less miscommunication, reduced delays. | Reduced workload, less fatigue, improved safety margins and productivity |

*Table 3: Proposition Two thematic analysis findings*

The integration of speech-to-text technology within the South African aviation industry is increasingly being recognised as a critical innovation, poised to elevate safety standards and customer satisfaction significantly. This assertion is substantiated by the insights collected from comprehensive interviews and the subsequent thematic analysis, which highlight the comprehensive benefits of speech-to-text technology. Among the most compelling advantages is the potential to alleviate the workload of air traffic control's personnel. By automating the transcription of communications, speech-to-text technology will likely reduce the mental burden on air traffic control's staff, thereby mitigating the risks associated with human fatigue, which is a critical factor in maintaining operational integrity and safety.

The streamlined operational processes facilitated by speech-to-text technology are, moreover, likely to lead to more efficient service delivery. In the fast-paced aviation environment, delays and inefficiencies impact operational costs and erode customer satisfaction. By enabling more swift and seamless communication and data processing, speech-to-text technology is likely to reduce service delays, enhancing the overall passenger experience, significantly. This improvement in operational speed directly contributes to improved customer satisfaction, as passengers benefit from smoother and more reliable services.

One participant stated - "*So there are numerous benefits, but one that might be beneficial in terms of making sure that we are efficient is to reduce the air traffic controllers' workload and improve situational awareness in terms of giving the air traffic controller more time to focus on the task that requires the human intervention more than anything else, rather than monitoring whether they feed back or read back from the pilot has been received correctly for sometimes, call signs are a bit similar.*''

The adoption of Speech-to-Text technology in the South African aviation sector represents a significant leap forward in operational efficiency, safety, and customer service. By reducing air traffic controllers' workload, streamlining operations, and ensuring high levels of data accuracy, speech-to-text technology stands as a testament to the transformative power of innovation in enhancing the foundational aspects of aviation, as stated by most of the respondents. The continued focus on technological advancements and machine-learning research is likely to lead to more robust and effective speech-to-text solutions, hence, further solidifying their role as a crucial tool in pursuing excellence in aviation safety and customer satisfaction.

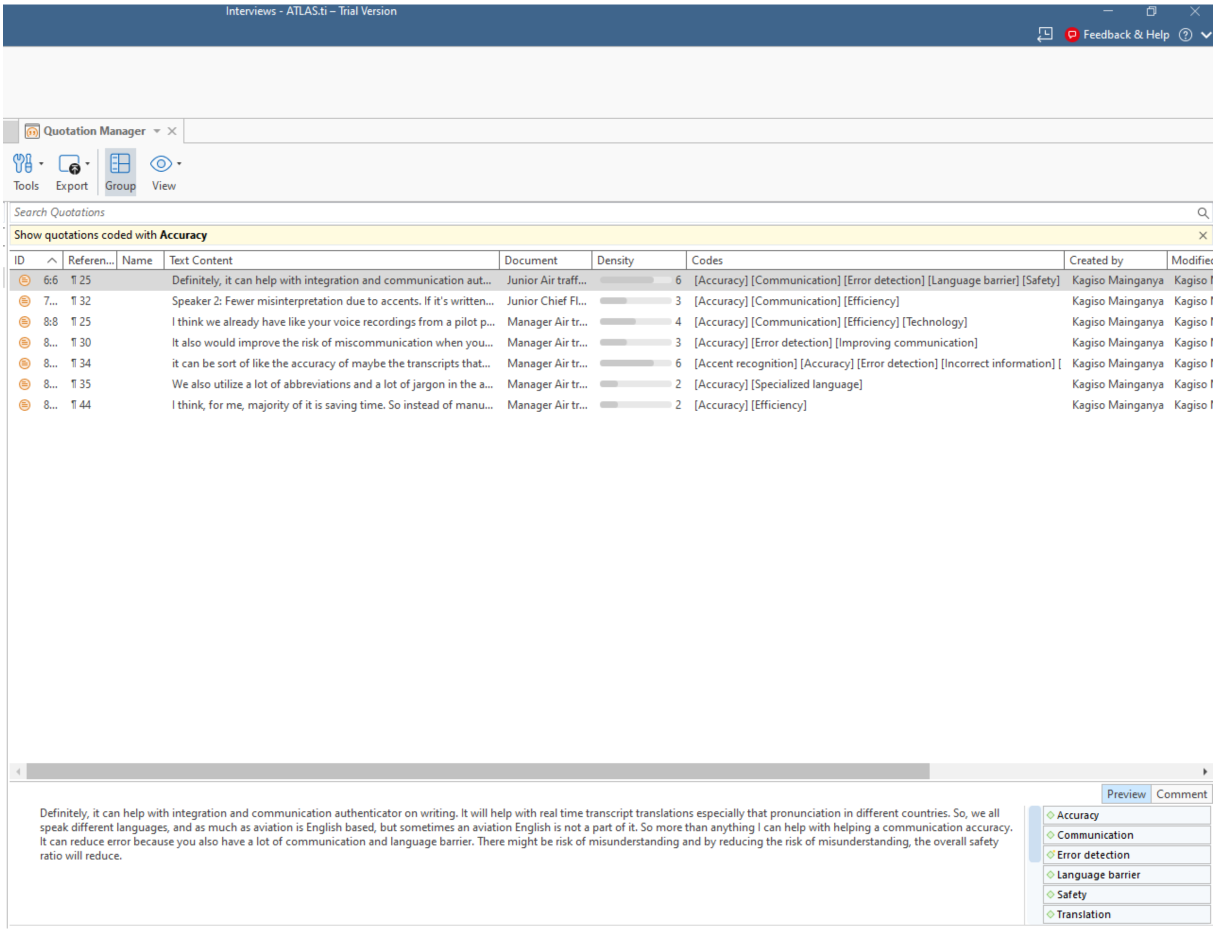


*Figure 7: Quotations pertaining to Accuracy from the Interview Participants*

## 4.4 Findings pertaining to proposition three

| **Proposition** | **The rapid advancements in technology may be able to address barriers and clear the way for its effective use in aviation.** | | |
|---|---|---|---|
| | **Categories** | **Key findings** | **Themes** |
| **General Systems Theory and Dynamic Capabilities Theory framework** | Accuracy challenge and limitations<br><br>Cyber-security | Data reliability and backup systems availability and testing<br><br>Cyber-attacks, data manipulations, and security | Accents, ATC Jargon, background noise and human intervention<br><br>System reliability, safeguarding and safe storage. |

| | | | |
|---|---|---|---|
| | Regulatory compliance | Policy updates and regulations changed. | Drafted guidelines, regular updates, |
| | Training and Awareness | New procedures, unknown changes, new systems, safety assessments | Training, skills development, change management, risk assessment |

*Table 4: Proposition Three thematic analysis findings*

The thematic analysis derived from the responses to the interview questions describes a complex landscape that is shaped by rapid technological advancements, presenting both significant opportunities and challenges for the integration of speech-to-text technology, in the aviation industry. These advancements have the potential to address and overcome prevalent difficulties, such as - human transcription errors, the inaccurate recognition of diverse accents, resulting in the minimisation of disruptive noise interference and factors that have historically hampered the effectiveness of speech-to-text systems within the dynamic and often unpredictable aviation environment.

According to the respondents, innovations in AI are likely to lead to sophisticated speech-to-text systems capable of distinguishing and accurately transcribing speech with various accents, thereby catering to the global nature of the aviation workforce. A participant stated - *"The context of South Africa, for example, the different dialects that we have, is challenging for speech-to-text applications that do exist. These are improving over time. But with different dialects, accents, and tones, we could still pick up various errors, but as the technology improves, it could get better but, mainly around accents, dialects, which have been causing issues."*

The rapid pace of technological change introduces a set of new challenges, particularly concerning the requirement for a seamless integration of speech-to-text technology, with existing aviation systems.

There were, however, challenges that were also highlighted. A participant warned that *"with any technology, there's a potential of someone abusing that technology because this will be cloud-based or something like that. It is vulnerable to hacking, although* *there will be means and ways of ensuring that that doesn't interfere with the system. But should someone manage to hack the system or the system just malfunctions, we need to have procedures on how to revert to the old ways of doing things without harming our passengers or even the reputation of the aviation sector."*

A senior flight instructor stated that the collection of software and hardware platforms across the aviation sector necessitates robust and flexible speech-to-text solutions that can be customised to fit within the diverse technological ecosystems without disrupting ongoing operations, but also highlights that South Africa is far from achieving this.

The successful adoption of speech-to-text technology centres on comprehensive training programs for aviation personnel. More than half of the respondents emphasised that these programs must cover the operational aspects of speech-to-text systems and drew attention to the necessity of maintaining situational awareness and manual transcription skills, as essential backups. This dual focus would ensure that human operators remain prepared to intervene, when necessary, even as reliance on technology increases.

Another point from the interviews was that regulatory compliance and policy updates are critical considerations in speech-to-text technology integration. Aviation is a highly-regulated industry, and any technological innovations must be rigorously evaluated to ensure they meet stringent safety and security standards.

A response regarding regulations and policies from one participant was - *"ICAO, which is the International Civil Aviation Organisation, probably needs to investigate speech-to-text further and then provide the industry with the standards and recommended practices for the technology to be adopted by the various states. So, if you look at the technology we use in aviation within South Africa, it's regulated by part 171. So, it would be good if those regulations are kind of amended or adapted to support artificial intelligence."*

These regulatory bodies and aviation authorities, therefore, must work closely with technology providers and industry stakeholders to update existing policies and establish new guidelines that reflect the capabilities and limitations of speech-to-text technology.

## 4.5 Summary of the Findings

The findings pertaining to the thematic analysis conducted on the interview responses indicate that speech-to-text technology could significantly enhance operational efficiency and safety in aviation in South Africa. This technology could improve information accuracy and reduce service delays, leading to increased customer satisfaction. This realisation is based on the themes induced from the participants' responses, however, rapid technological advancements also present challenges in integrating speech-to-text into existing aviation systems, thereby, requiring adaptation to new technologies and regulatory compliance. Even though the integration of the technology shows potential and is promising, the speech-to-text technology must navigate the evolving challenges for a successful implementation and installation of an appropriate API for the system.

# CHAPTER 5: DISCUSSION OF FINDINGS

## 5.1 Introduction

This chapter focuses on the findings and discussions of the research conducted. This process will involve the presenting of a thorough examination of the findings and engaging in a critical discussion on the role of speech-to-text technology in enhancing efficiency within the South Africa's aviation sector. By reviewing a diverse range of research publications, this section aims to interpret the implications of these findings and integrate them within the broader context of the aviation industry's operational dynamics and technological route.

Central to this discussion are three foundational propositions which emerged during the literature review phase.

1) Information accuracy from using speech-to-text technology, as compared to manual or traditional techniques, is crucial in influencing operational and flight efficiency.

2) An improvement in slow operations or services due to the introduction of speech-to-text integration can improve safety and customer satisfaction, which in turn, will enhance safety margins across aviation.

3) The rapid advancements in technology can address these barriers and clear the way for the effective use of these technologies in aviation.

The findings from these propositions serve as the focal points of this chapter, building upon the preliminary evidence presented earlier in the report that discusses the benefits of speech-to-text technology and various other issues. The discussions will focus on the necessity of a systematic and carefully-orchestrated implementation strategy tailored to the unique needs and challenges of the South African aviation industry. This process will demonstrate the urgency of a systemic integration and the leveraging of dynamic organisational capabilities.

The chapter, therefore, will provide a detailed exposition of the insights gained from this qualitative research, focusing on the thematic areas explored during the interview process. The deliberations will offer an in-depth analysis of these findings, placing them within the broader conversation on speech-to-text technology's potential to transform communication in aviation. By addressing the propositions outlined in the literature review, these discussions aim to validate the initial hypotheses and expand the understanding of speech-to-text technology's complex impact on the aviation sector, laying the groundwork for future innovations and strategic implementations in this field.

## 5.2 Demographic profile of respondents

In total, 14 participants gave consent to be interviewed. The list included - junior and senior air traffic controllers from ATNS, engineering technicians from the technical department, full-time helicopter and fixed-wing aircraft pilots, chief flight instructors from different flying schools, ATNS' safety investigation personnel, engineering personnel from the research department and air traffic controller management. The participants, therefore, were quite diverse, ranging from different age groups, ethnicities, genders, races, and years of experience.

Their responses showed how the different participants relate to artificial intelligence based on their understanding and how it would impact their daily operations. The majority of the participants, however, leaned towards the same conclusions and similar themes were picked up early in the interview process, especially, around the challenges and benefits of speech-to-text.

## 5.3 Discussion pertaining to Proposition One

As compared to manual or traditional methods, the integration of speech-to-text technology in the South African aviation industry was identified as having the potential to play a crucial role in enhancing information accuracy, which is vital for operational and flight efficiency.

Accuracy and Efficiency in Communication:

The aviation industry relies heavily on accurate communication for safety and efficiency. Speech-to-text technology can significantly reduce the likelihood of miscommunication that might occur with manual methods; for instance, accurate transmission of flight data, instructions, and clearances, is critical in air traffic control. A study by Martynova (2021), titled - *The Role of Communication in the Aviation Industry* - revealed how critical communication is, in ensuring flight safety.

A company based in North Dakota, Appareo, specialises in electronics and has already started looking into speech recognition systems for aviation. The context-specific training work that Appareo has done, using cutting-edge artificial intelligence development approaches to produce an AI that knows the aviation industry jargon, is quite remarkable (Aviation Speech Recognition System - Appareo, 2023). If speech-to-text systems can transcribe communications with high accuracy, thereby, reducing the potential for human error, it will be a game changer for aviation.

During the interviews, one of the highlights from the participants' responses, was how speech-to-text technology can significantly reduce misinterpretations in communication, which is crucial for aviation safety. A mention was made that this technology can help reduce misunderstandings caused by accents or rapid speech, especially, during high-stress situations and in high-noise volume locations.

Efficiency in data processing and management is crucial; traditional methods of data entry and processing are often labour-intensive and prone to human error. Speech-to-text technology, however, automates these processes, leading to more efficient and accurate data handling. This is particularly beneficial for flight planning and air traffic management, where real-time data accuracy is crucial, and delays can have cascading effects on operational efficiency. Valdés et al. (2018), during their study - *Aviation 4.0: More Safety through Automation and Digitization* – assert that the critical performance areas of aviation might be improved in this new era. In an industry where safety standards are so high and margins for improvement are so small, this new period may indicate a change in safety improvement (Valdés et al., 2018).

One participant maintains that - *"speech-to-text can help with integration and communication authenticator on writing. It will help with real time transcript translations* *especially with pronunciation in different countries. So, we all speak different languages, and as much as aviation is English-based, but sometimes an aviation English is not a part of it. So more than anything, it can help with communication accuracy. It can reduce errors because you also have a lot of communication and language barriers. There might be a risk of misunderstanding, and by reducing the risk of misunderstanding, the overall safety ratio will increase."*

From systemic integration and dynamic organisational capabilities perspectives, the connection of aviation operations is essential, since speech-to-text technology will serve as a pivotal component for improving communication efficiency. At the same time, the connection will demonstrate the adaptive response of the aviation industry to integrate and use this technology effectively, hence, enhancing real-time data processing and decision-making capabilities. A study conducted by Dutta (2019) - *Exploring Dynamic Capabilities: A Systems Thinking Approach* - investigated the crucial roles that three organisational theories play - in the development and upkeep of evolving skills, organisational identity (how the aviation industry sees itself), organisational awareness (how this new technology will be promoted within the community), and organisational division (how the different aviation sectors will adopt speech-to-text).

<u>Improvements to the current systems</u>

The technology will have some challenges, as the participants also stated during their interview sessions. These challenges include - how the technology will handle various accents and dialects, and how it will ensure accurate transcriptions in noisy environments such as control towers and cockpits, as these can affect the accuracy of the transcriptions. Future enhancements and continuous improvements in AI and machine learning, however, algorithms were isolated as being crucial to addressing these challenges; these will enhance the overall effectiveness of speech-to-text systems in aviation. Badrinath and Balakrishnan (2021), researched into automatic speech recognition for air traffic control communications and identified - techniques to use more robust language models, semi-supervised learning, better knowledge or context, and more transcribed air traffic controller voice data - to train the model to increase the accuracy of the ASR models for the air traffic controller domain. The report further stated that these improvements may increase the accuracy of transcription, opening up valuable applications, such as voice assistants for air traffic controllers and real-time safety monitoring (Badrinath & Balakrishnan, 2021).

There is also the cost aspect that needs to be considered. By improving operational efficiency and reducing the time spent on manual data entry and verification, speech-to-text technology can also be cost-effective for aviation operators. The savings from the cost-reduction can be channelled into other safety or efficiency-improving measures. Bouchard and Villaume (2018), published an article on how new technology may help airlines cut pricey fuel consumption and meet environmental regulations. In their article, they maintained that changing today's static flight planning into a more dynamic one, which would enable airlines to maximise every bit of operational savings by making improvements in the flying, is one potentially effective approach (Bouchard & Villaume, 2018). To do this, airlines must be able to send real-time data from the aircraft to advanced analytics systems on the ground, and this will allow them to continuously modify flight plans to accommodate for any unique flying conditions that an aircraft is experiencing and, in the end, enhance fuel use (Bouchard & Villaume, 2018). This research was done in 2018, therefore, there is a possibility that further improvements in this aspect, since technology has been evolving, significantly.

There are some financial and technological considerations to be noted with the implementation of speech-to-text and, although the benefits are clear, the participants also pointed out economic and technological challenges, especially in regions with older aircraft fleets and limited resources. Integrating speech-to-text technology requires significant investment, which might be a barrier to its widespread adoption in certain areas, especially, in African countries and regional airports, as highlighted by the participants. Research by Samunderu (2023), stresses how Africa needs to catch up with its counterparts in other developing countries, in terms of infrastructural coverage. Most African airports' inadequate infrastructure is seen as the leading cause of the continent's ongoing failure to realise its clear economic potential, and due to a lack of funding, these infrastructure issues are unlikely to be resolved soon; this will inevitably result in the persistence of infrastructure challenges (Samunderu, 2023).

Improved Flight Safety

The accurate processing of flight information directly impacts on flight safety. Speech-to-text systems can provide pilots and air traffic controllers with accurate transcriptions of communications, reducing the likelihood of errors that could lead to safety challenges. Any accurate data helps in making informed decisions, particularly, in air transport emergency situations where quick and reliable information is essential. Huang and Pitts, (2019), researched how automated speech recognition technology could support in-flight weather-related communication for general aviation pilots. In their research, it was established that determining the minimal requirements before adoption into practice requires further research and the results may be used to inform choices about the usage and selection of applications in more busy and challenging fields (Huang & Pitts, 2019). This would be in a complex working environment, such as O.R Tambo International Airport, which deals with several flights per day.

Speech-to-text technology would also support pilots and controllers by providing a written transcript of verbal communications, serving as a reliable reference point, and reducing cognitive load. An investigator who was one of the participants of this current study highlighted how this technology would reduce the time it takes to complete an investigation, as the transcripts would be readily available.

Other participants - senior air traffic controllers and flight instructors - stressed how speech-to-text technology could streamline operations, although, one of the chief flight instructors was worried that this technology would be too much to grasp for the student pilots who were still figuring out how to be comfortable in the cockpit. A study by Zuluaga-Gómez et al. (2023), discusses the lessons learned during their research on robust automatic speech-understanding systems in aviation when trying to gather hours of transcripts from air traffic control transmissions. It highlights how minor errors could give out incorrect transcripts, for example, **“descent to two thousand”** and **“descend two two thousand”** (Zuluaga-Gómez et al., 2023). These are some of the linguistic factors that need to be taken into consideration when training for use of the technology.

From the perspective of the systemic integration and dynamic organisational capabilities’ frameworks, it is essential to improve on the safety matrices with advanced technologies continuously. The Systems Approach considers the role of speech-to-text technology in the broader context of aviation safety systems and its integration contributes to reducing communication errors, which are critical in high-stress environments. Dynamic Capabilities, on the other hand, focuses on the aviation sector's ability to evolve its safety protocols and procedures in line with technological advancements, ensuring continuous safety improvements.

Proposition One - Conclusion

The integration of speech-to-text technology in South African aviation aligns with the industry's continuous pursuit of safety and efficiency. Its ability to provide accurate, real-time transcription of verbal communications mitigates risks associated with manual data handling, aimed at enhancing operational efficiency, and supporting the overall safety of flight operations.

Furthermore, the accuracy of information processing that this technology offers is integral to the safety, efficiency, and cost-effectiveness of aviation operations. The quality of data processed through speech-to-text technology is critical, and accurate transcriptions ensure reliable information for decision-making processes, which is crucial for maintaining high safety standards in aviation operations. From the available literature and from the responses of the participants, it was, however, evident that more work needs to be done to win over the trust of potential users.

## 5.4 Discussion pertaining to Proposition Two

An improvement in slow operations or services due to communication barriers, can improve safety and customer satisfaction, which will enhance efficiency across the aviation industry.

Required Data for Speech-to-text Integrations

Speech-to-text systems will help expedite the flow of information, reducing operational delays for operational efficiency, and this can be done if there is a seamless integration and collection of data; for instance, rapid transcription of pilot-ATC communications can streamline flight clearance and adjustments, directly impacting operational speed and efficiency. The responses from the participants emphasised how the new technology will be welcomed but must be tested prior to its adoption. Prasad (2022), conducted a study that recommended an easy, yet, effective modular method based on repetition to expedite the training of air traffic controllers. Basically, the articulated point of the findings was that by combining several AI-powered modules, would enable the creation and integration of a pseudo-pilot agent into the controller training process, illustrated by the figure below. After processing the controller's voice communications, the system produces a spoken prompt that corresponds with the pilot's phraseology from the original transmission. The approach is primarily reliant on air traffic controller databases and open-source AI technologies, which can demonstrate the approach’s simplicity and repeatability (Prasad, 2022).

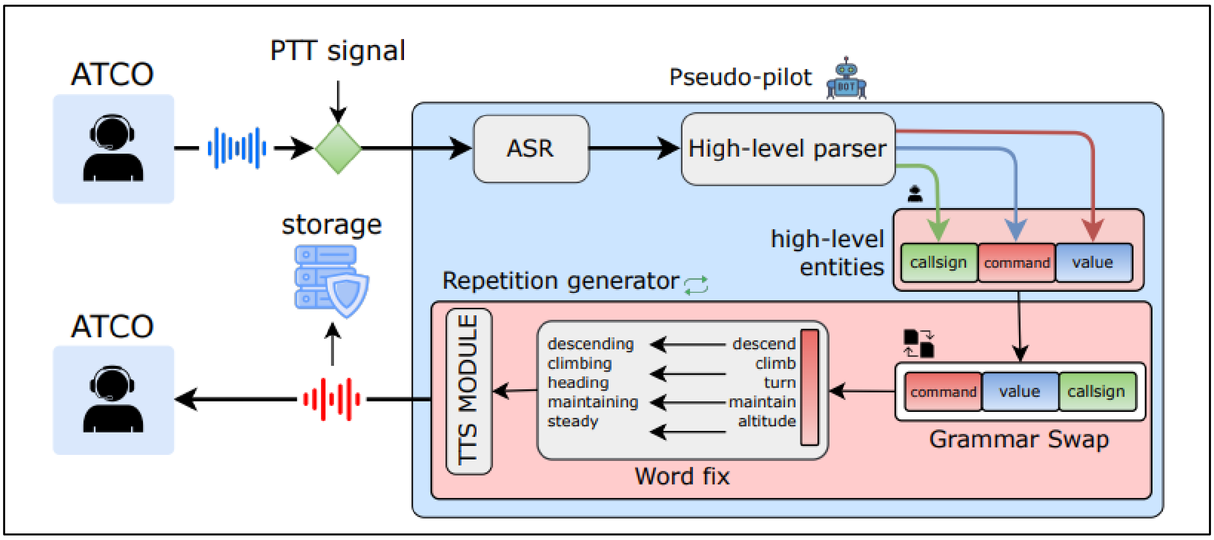


*Figure 8: Overall pipeline for simulating a pilot for air traffic controller training (Prasad, 2022)*

Based on the Figure 8, following the conclusion of the Press-To-Talk (PTT) signal, an air traffic controller issues a transmission, which is then captured to initiate the pipeline. Subsequently, the voice-to-text and high-level entity parser modules extract and transcribe the voice communications of the air traffic controller-related entities. The output then becomes used to the structured language of the "pilots." The speech synthesiser then uses the produced text to produce a WAV file that contains the spoken textual prompt. Finally, a pseudo-pilot response is generated, which can give relevant feedback to the trainee air traffic controller (Prasad, 2022).

When investigating and searching for the correct data for speech-to-text technology integration with the aviation systems, the critical areas of focus include - developing robust data integration systems, customising speech recognition to handle aviation-specific terminology, and ensuring the technology is adaptable to diverse accents and noisy environments. These improvements necessitate ongoing collaboration between technology developers, aviation experts, and regulatory bodies to ensure a seamless integration and adherence to safety standards.

Enhancing voice recognition models for air traffic control systems, with limited sample sizes, was the basis of a study by Lin et al. (2021). The study noted that small training sample sizes are a constant challenge in the training of practical ASR models for air traffic control systems, since the work of gathering and annotating speech samples requires domain expertise (Lin et al., 2021). Additionally, their study created an enhanced end-to-end deep-learning model to solve the unique difficulties of ASR in the air traffic controller domain, and an innovative training strategy based on pre-training, and transfer learning was put forth to address the problem in their study. First, a method for learning speech representations from unlabelled samples for a given dataset was proposed - unsupervised pre-training. A masking method was used to increase sample variation while preserving overall trends and to complete the supervised ASR task eventually; transfer learning was then used to refine pre-trained or other optimised baseline models (Lin et al., 2021).

The experimental findings of Lin et al., (2021) showed that, with a complete character error rate that is just one-third of what can be achieved with supervised training, the ASR performance is greatly improved on all three datasets. The results also confirmed that the suggested tactics are applicable to different ASR techniques (Lin et al., 2021). This research proves that a fully functioning speech-to-text system can be integrated into aviation with the correct dataset and the required amount. One of the participants of the current research, also highlighted that Big Data would be beneficial for gathering aviation corpus.

Once the system has learnt to overcome the accents and noise background, it will be easier to integrate, but with this observation came the questions on the challenges such as - the cost implications, the limited infrastructure that is available, the old flight system models in the towers and the aircraft and the systems' adaptability to the new technology and user experience.

Highlighted also was the technological adaptation from the users and the training of the aviation industry in this new era of business operations. The adoption of speech-to-text technology requires proper training for personnel to maximise its benefits. Training programs should focus on familiarising staff with the characteristics of this technology, including - its limitations, instances of best use cases and how it will improve operations - if used to its full potential. Air traffic staff, hence, need to undergo extensive training before being validated to work alone in a control position.

A similar process, therefore, should apply prior to the speech-to-text technology is implemented; the training process must first start in the simulator and moves to on-the-job training. Alsahli (2022), wrote a journal article on the essential nature of simulator-based training in air traffic control. In the article, it was concluded that a critical component of air traffic control training is simulator-based instruction (Alsahli, 2022). Simulation training helps the students become confident, improves practice in a safe environment, and improves skill development and display.

In addition to enhancing teamwork, simulation training aids in understanding human behaviour, therefore, the training for speech-to-text should be conducted in a simulator environment prior to it being used on live traffic and the organisational culture needs to be changed and aligned with a digital sense for more straightforward adaptation. In a study by Halpern et al. (2021), it was discovered that organisational readiness directly impact digital change as well as innovation, which in turn impacts digital transformation. Their results also demonstrated that increasing the rate of innovation required for digital transformation at airports may be achieved through an effective development of organisational readiness (Halpern et al., 2021). This aligns with the participants' responses that adequate training and awareness should be considered for an effective integration of speech-to-text in the aviation industry, in South Africa.

Improvements in Customer Service

Improvements in operational speed and service efficiency through the integration of speech-to-text technology can significantly enhance safety and customer satisfaction in the aviation sector. This technology can streamline data processing, reducing delays and errors, which are critical for operational safety and efficiency. Speech-to-text technology can significantly reduce the workload on air traffic controllers by automating routine data-entry tasks, thereby, allowing controllers to focus more on monitoring and decision-making aspects.

This reduction in workload can, in turn, decrease the chances of human error, thus, enhancing operational safety. This technology offers quicker, more accurate information dissemination for customer service, enhancing passenger experience and trust. Tegar et al. (2018), conducted an analysis on how customer satisfaction increases by improving customer services; the conclusion was that - assurance, tangibility, responsiveness, empathy, and reliability - influence customer satisfaction (Tegar et al., 2018). According, therefore, to their study, if the speech-to-text technology conforms to assurance and is functioning accurately, its tangibility and reliability and reducing air traffic controller workload, will be a significant step toward improving operations and leading to customer satisfaction. From their report and observations, airlines need to optimise their performance and pay attention to service performances quality, to get better outcomes, although, it is also necessary to analyse every aspect of service quality (Tegar et al., 2018); their findings proved, in addition, that a streamlined process will assist in customer satisfaction.

When looking at the improvement in slow operations or services, from adopting speech-to-text integration, through the lens of the systemic integration and dynamic organisational capabilities' frameworks, it was demonstrated that customer satisfaction will improve through this technological integration. Systems Theory examines how speech-to-text technology enhances the overall customer experience by reducing delays and improving service quality. At the same time, Dynamic Capabilities Theory highlights the aviation industry's agility in adopting new technologies to meet changing customer expectations and maintain a competitive advantage.

Proposition two - conclusion

The integration of speech-to-text technology in aviation operations not only improves the efficiency and speed of services but also contributes to enhanced safety and customer satisfaction. These improvements align with the industry's continuous efforts to maintain high safety standards while improving the overall passenger experience.

Future implications and research, nevertheless, need to be taken into consideration as advancements are ongoing, and the development of speech-to-text technology may further improve accuracy and reliability; if relevant transformations are implemented, they will have long-term positive effects on aviation safety and efficiency. Continued investment in this technology, hence, is essential for maintaining the competitive edge and safety standards of the aviation industry.

These aspects collectively demonstrate how speech-to-text technology can revolutionise aviation operations, making them safer, more efficient, and customer-centric.

## 5.5 Discussion pertaining to Proposition Three

The rapid advancements in technology have the potential to address the challenges associated with the implementation of speech-to-text systems in South African aviation, paving the way for their effective usage.

Challenges with Accuracy

With any new technology, there will be teething issues in the beginning and some uncertainties; the significant concerns raised by the participants have to do with the accuracy challenges and its limitations when it comes to accents and real-time data processing. Technological advancements are continuously improving the accuracy of speech-to-text systems, and developments in natural language processing and machine learning algorithms are enhancing the ability of these systems to understand various accents, dialects, and aviation-specific terminologies, thereby overcoming one of the main limitations of the current technology.

Dhavala (2017), conducted a study - *The Use of Synthetic Voice to Improve Communication between Air Traffic Controllers and Pilots*. In the findings, it was proposed the using of synthetic voice communication to replace natural speech contact between air traffic controllers and pilots (Dhavala, 2017). This could alleviate the challenges the participants highlighted regarding different accents. Pilot-controller misunderstanding has been identified by the ICAO as a serious safety risk, therefore, artificial voices will ease the additional mental strain of understanding a challenging accent and decrease reaction times (Dhavala, 2017). In other words, if the system is taught to listen to the data only, and the accent has already been filtered out by this system, then, there will not be any challenges with different dialects and accents to contend with.

Additionally, there are further enhanced machine learning ability for greater accuracy. Advanced machine-learning models are increasingly capable of understanding complex speech patterns and diverse accents, significantly improving the accuracy of speech-to-text systems. This is crucial in aviation, where precise communication is essential for safety. There are various reports on advancements in machine learning and one was produced from a study by Sohail (2022) titled - *A Machine Learning Framework for Automatic Speech Recognition in Air Traffic Control Using Word Level Binary Classification and Transcription.*

A study by Vashisht et al. (2021) focused on speech recognition by making use of machine learning. The findings, detailed a system that had been created which can translate between Hindi and English and could recognise human speech as well as audio clips. The researchers offered choices to convert audio data from one language to another, and the result would be in text format (Vashisht et al., 2021). If their system functions optimally, it can be programmed to be used for aviation to counter the accents and aviation jargon used and to translate it to standard text for transcriptions.

<u>The risk associated with Cyber-security</u>

The challenge with any technological advancement is the risks associated with cyber-security**.** As speech-to-text systems are integrated into aviation operations, cyber-security becomes a paramount concern, as it was highlighted by the majority of the participants. Advancements in encryption technologies and secure network protocols are being developed to protect these systems from cyber-threats, ensuring the integrity and confidentiality of the communicated data, however, when security is tightened, the cyber-criminals, correspondingly, find more and more sophisticated ways to counter it. In their study, Dave et al. (2022), stated that the aviation industry is becoming increasingly attractive to cyber-criminals, especially terrorists, as the industry digitises and depends more on wireless technology. The researchers admitted that it is unlikely that attacks against aviation systems and all of their elements (such as, communication, navigation, and surveillance systems) will go away soon (Dave et al., 2022).

It is imperative, therefore, that robust cyber-security solutions be sought when implementing this new speech-to-text technology. The integration of advanced cyber-security measures, including sophisticated encryption and intrusion detection systems, could ensure the protection of sensitive aviation data processed through speech-to-text systems. This addresses the critical need for data integrity and confidentiality in aviation communications. Ishtiaq and Rahman (2021), researched cyber-security vulnerabilities and defence techniques in the aviation industry. Their research, not only addressed the - reasons behind aviation cyber-attacks, the technology that is usually targeted, and the vulnerabilities within the air transportation systems - but also recommended general security protocols to minimise these attacks (Ishtiaq & Rahman, 2021).

The Systemic Integration Theory and the Dynamic Organisational Capabilities Theory address accuracy challenges and cyber-security risks. General Systems Theory acknowledges the need for accuracy in all system components, from technology implementation to human interactions. Cyber-security is understood as an integral part of the system's health and integrity. The Dynamic Capabilities Theory reflects on the aviation sector's continual adaptation to emerging threats and challenges, such as the advancing cyber-security measures, and improving the accuracy of technological tools.

<u>Regulatory compliance</u>

Policy and Regulatory Compliance for rapid technological advancements necessitate the update of policies and regulations governing the use of such technology in aviation. Emerging policies are focusing on ensuring that these technologies meet safety and efficiency standards without compromising the established norms of aviation operations. For South African aviation, these changes would need to go through ICAO and, after that, the South African Civil Aviation Authority (SACAA); however, this is not a daunting task, as ICAO has already embarked on a digital transformation journey as part of its transformation strategies; this journey is outlined on their website under ICAO's transformational objective (Anderson, 2023). This proves that regulations can be amended, and the authorities are aware that the digital era is here, thus, there is a need to make changes to meet this new way of life. One of the challenges to this, is getting these new policies published and ready for implementation as they could take a few years, although, the technology is advancing in the meantime.

The adaptive policy frameworks for regulatory compliance with technology is evolving rapidly, as regulatory bodies are adopting more flexible and adaptive frameworks. These frameworks aim to accommodate emerging technologies, like speech-to-text while ensuring adherence to stringent aviation safety and efficiency standards. In their transformation strategy report, ICAO states that to stay current, it needs to adapt to the changing aviation industry, advancements in technology, and expanding obligations. This shows that ICAO will be prepared for the future by fostering an innovative culture (Anderson, 2023).

Training and Awareness

Innovative training approaches for workforce adaptation are crucial as technological advancements also extend to training methodologies. Augmented Reality (AR) and Virtual Reality (VR) are being used to simulate real-world scenarios, providing aviation professionals with hands-on experience in using speech-to-text technologies. This approach enhances understanding and eases the integration of new technologies into existing systems.

Gorbunov and Nechaev (2020), assert that they have been researching into AR and VR for air traffic controlling and have gathered 15 years’ worth of published work to support this area of research. They explicate that applications of VR/AR in the air traffic control domain include - controllers working at control towers, systems at remote towers, and systems for controller training (which provides for x-ray vision in LVO conditions), as well as, the linking of real aircraft and their flight settings for an improvement in situation awareness (Gorbunov & Nechaev, 2020). This technology can be applied to speech-to-text and used for training in the simulators, prior to its integration at the workstations.

The effective implementation of speech-to-text technology requires adequate training and awareness among aviation professionals. Advancements in educational technologies, such as simulation-based training modules, are being developed to help personnel understand and adapt to these new systems, ensuring smooth integration into existing workflows. A study done on speech and natural language processing - *Technologies for Pseudo-Pilot Simulator* - by Prasad (2022) demonstrated that the technology may open the door to creating a functional proof-of-concept pseudo-pilot system.

Air traffic controller training may be expedited while total costs are significantly decreased (Prasad, 2022). Pavlinovic, Boras, and Juricic (2016) proposed the development of a language technology system in air traffic controller training, in those spots that deviate from standard radio-telephony language. This system, which identifies the continuous speech of different speakers and transforms spoken messages into written text, could help reduce communication errors (Pavlinovic, Boras, & Juricic 2016).

Regulatory Compliance and training for effective adoption can be applied using the theories of Systemic Integration and Dynamic Organisational Capabilities. The systems perspective views regulatory compliance as a necessary framework within which all system elements must operate. Effective training is seen as a crucial component for system stability and efficiency, while, Dynamic Capabilities focus on the need for continuous learning and adaptation to meet regulatory requirements and successfully integrate new technologies.

<u>Proposition three - conclusion</u>

There are challenges in integrating speech-to-text technology in aviation, although, the rapid pace of technological advancement provides solutions to overcome these barriers, as proven by the extensive literature from various research studies. These studies testify to the fact that progress in technology in this area, is crucial since their findings are clearing the path for ensuring that speech-to-text technology can be effectively used to enhance safety and efficiency in South African aviation whilst the industry remains compliant with policies and regulations.

## 5.6 Conclusion

The potential of speech-to-text technology in enhancing efficiency in the aviation sector in South Africa is significant. This technology promises to improve operational efficiency, enhance safety margins, and increase customer satisfaction, if the system is running optimally. Its ability to provide accurate, real-time transcription can streamline communication, reduce air traffic controller workload, and mitigate risks associated with manual data processing. While challenges such as accuracy in diverse accents, cyber-security risks, and the need for policy and regulatory compliance exist, ongoing technological advancements and regulation changes are addressing these barriers. With proper implementation and continuous adaptation, speech-to-text technology stands to be a transformative tool in the aviation sector in South Africa, aligning with global trends towards digitalisation and automation in aviation.

When implemented using the General Systems Theory and Dynamic Capabilities Theory, the integration of speech-to-text technology in aviation reveals a multifaceted approach. This necessitates a systemic understanding of connected elements within the aviation sector and an adaptive, responsive approach to technological advancements. This holistic perspective would ensure that technological integration not only addresses current challenges but also positions the industry to navigate future developments and maintain its competitive edge, effectively.

# CHAPTER 6: CONCLUSION AND RECOMMENDATION

## 6.1 Introduction

This research was aimed at a thorough inquiry into the transformative potential of speech-to-text technology, within the aviation industry in South Africa. The research was structured around three pivotal questions, each designed to explore distinct issues of speech-to-text technology application in aviation and to explain the routes through which it could promote significant improvements in the sector.

Those questions are:

1. How can integrating speech-to-text technology in air traffic control systems influence operational and flight efficiency, in South Africa?

2. How can the use of speech-to-text technology impact customer-service efficiency, in the aviation sector, in South Africa?

3. What potential barriers can arise in successfully implementing speech-to-text technology, in the aviation sector, in South Africa?

In response to these questions, firstly, the research explored integrating speech-to-text technology within air traffic control systems to uncover how this integration can streamline operations and improve flight efficiency. This line of analysis was pivotal given the crucial role of air traffic controllers in maintaining the safety and regularity of flights; this suggested that even marginal enhancements in efficiency could have profound implications for the overall efficiency of aviation operations.

Secondly, the investigation focused on the impact of speech-to-text technology on customer service within the aviation sector. Understanding how speech-to-text can refine and expedite service delivery is essential in an industry where customer satisfaction is closely linked with operational success. This question explored the potential of speech-to-text to transform customer interactions, thereby enhancing the overall passenger experience.

Lastly, the research articulated any challenges and barriers that might delay the successful deployment of speech-to-text technology in aviation. This enabled a critical examination to identify technical and organisational hurdles, ranging from accuracy and reliability issues to integration with existing systems and resistance to change within the industry.

The research adopted a qualitative methodology to navigate the exploratory nature of these questions and achieve an understanding of speech-to-text technology's potential and challenges in the aviation industry. This approach allowed for an in-depth exploration of complex issues, drawing on various data sources, including expert interviews, case studies, and the utilisation of thematic analysis. By engaging directly with industry professionals and stakeholders, the study captured rich insights and perspectives, thereby providing a comprehensive overview of the role of speech-to-text technology in shaping the future of aviation in South Africa. Through this qualitative lens, the research endeavoured to answer the foundational questions and uncover developing themes and considerations that could guide a strategic implementation of speech-to-text technology, in the aviation sector.

## 6.2 Conclusion Regarding Research Question One

The integration of speech-to-text technology in South African air traffic controller systems, significantly, influences operational and flight efficiency. This technology can enhance communication accuracy, which is a critical factor in aviation operations. By converting spoken words into text, the technology would lead to reductions in misunderstandings and errors common in voice communications. This improvement in communication accuracy will directly impact flight safety and efficiency, as clear and accurate instructions are vital for effective air traffic management. In addition, speech-to-text systems streamline data processing, since manual methods of recording and transcribing air traffic communications are time-consuming and prone to errors.

Automating this process, hence, could lead to less delays in information distribution, allowing for quicker and more efficient flight plan adjustments and traffic management. This rapid processing is particularly crucial in high-traffic airspaces, where delays can have a cascading negative effects on flight schedules. Regarding safety, the precise transcription of communications ensures that pilots accurately receive and follow instructions from the air traffic controller. This accuracy is vital in avoiding navigational errors and ensuring adherence to flight paths, directly contributing to flight safety.

Another significant impact is the reduction of air traffic controllers' workload. By automating routine tasks, like data transcription, air traffic controller personnel can focus more on monitoring and decision-making aspects of air traffic management. This reduction in cognitive load is crucial in high-pressure environments like air traffic controller centres, as this leads to reducing the potential for human error, while enhancing operational safety. The integration of speech-to-text technology also offers long-term benefits, such as collecting and analysing vast amounts of data, which can be used to improve air traffic management strategies and training programs. This data can provide insights into common communication issues and operational inefficiencies, leading to more informed decision-making and policy development.

Research, however, shows that the technology still needs to be proven to be fully functional enough to be implemented in the South African aviation sector. This is because reports from countries outside of South Africa with better infrastructure and more advanced technology are still trying to prove that speech-to-text in air traffic controller systems is ready for implementation. Additionally, these reports also assert that more research work needs to be done before the technology can be fully implemented.

The research on speech-to-text by Badrinath and Balakrishnan (2021), proposed that more training data and improved ASR accuracy, would further increase the reliability of data extraction. Additionally, these authors determined that there were ways to increase the accuracy of ASR models for the air traffic controller domain, such as - using better language models, semi-supervised learning, better priors, or context, and training for the model with more air traffic speech data that had been transcribed (Badrinath & Balakrishnan, 2021). These improvements may increase the accuracy of transcription, opening valuable applications such as voice assistants for air traffic controllers and real-time safety monitoring.

## 6.3 Conclusion Regarding Research Question Two

The use of speech-to-text technology in the aviation sector could significantly impact on customer-service efficiency. This technology can enhance the accuracy and speed of communication between airline staff and passengers, leading to improved service delivery; for instance, real-time transcription of customer inquiries and rapid, accurate responses can significantly enhance the customer experience.

The technology will also allow for better handling of customer requests and complaints, as transcripts provide a clear record of interactions, aiding in more effective resolution of issues. It can be integrated into customer service channels like call centres to file flight plans, reduce waiting times, and improve the overall efficiency of customer-service operations. This will be especially beneficial during peak travel times or when dealing with flight disruptions.

The integration of speech-to-text technology in the aviation sector in South Africa, hence, can lead to significant improvements in customer service efficiency, enhancing the overall passenger experience and contributing to higher levels of customer satisfaction.

The technology, however, has yet to reach its potential, especially for an industry such as aviation that requires accuracy and precision. Research from Basak et al. (2023), concurs, as the findings show that Mel Frequency Cepstral Coefficient (MFCC) and deep-learning methods appear to be the foundation of the most accurate ASR systems, after comparisons of several techniques used in various stages of speech recognition systems. Yet, there is still a gap in speech signal analysis that must be fully addressed as there are plenty of areas to improve upon in the current state of speech signal processing integration in various systems, even though much progress has already been made (Basak et al., 2023).

## 6.4 Conclusion Regarding Research Question Three

The successful implementation of speech-to-text technology in the aviation sector in South Africa faces several potential barriers. The first and most crucial barrier is the accuracy and reliability of the system. Speech-to-text systems must be highly accurate to be effective in aviation, as this field cannot afford any errors, since any mistake could be catastrophic. Most challenges will arise in accurately transcribing diverse accents and dialects, and in noisy environments like airports and cockpits if the system is not integrated adequately. Research by Basak et al. (2023), supports this statement and further states that global Dig Data technology growth has expanded the potential for developing inventive and nearly-correct speech systems.

Furthermore, integrating this new technology with existing systems can be complex and costly, since its compatibility with current aviation software and hardware is another critical concern. If the systems are not incorporated correctly and the technology is introduced too early, it could add additional challenges, such as cyber-security risks. Since speech-to-text systems often involve processing sensitive data, ensuring robust cybersecurity measures is imperative to protect against data breaches and cyber-attacks.

An article by Ye et al. (2022), proved that backdoor attacks are quite popular with ASR systems; the article further showed the high percentage rate at which cyber-criminals successfully attacked the ASR system. Cyber-security defences, therefore, need to be exceptional, updated regularly and constantly measured for the system to be trusted and implemented.

Regulatory compliance, along with training and adaptation, can be implemented with an appropriate approach. Research has revealed that the aviation industry is heavily regulated, so ensuring that speech-to-text technology complies with all relevant safety and privacy regulations can be challenging but not entirely impossible. Research from Anderson (2023), has confirmed that digitalisation is being considered by the regulator, therefore, this challenge can be addressed. Effective implementation requires training staff to use and trust the technology whilst also alerting them of the regulations or policy amendments. Overcoming resistance to change and ensuring the workforce is skilled in using these new systems are essential steps that were not, however, fully explored during this research.

## 6.5 Recommendations

These recommendations need to be considered in addressing the shortcomings of the speech-to-text technology in enhancing efficiency in the aviation sector, in South Africa.

There is a necessity to invest in advanced AI such as APIs, Dig Data, and ML for improved accuracy, especially in complex language and noisy environments, such as in the aviation sector. This will require infrastructure upgrades, and once the technology is implemented, there must be regular system updates and maintenance. This will entail regular checks on the system to keep up with technological advancements and customer needs. There should also be a search for highly-skilled engineers and collaboration with technology developers for seamless integration with existing systems.

Additionally, robust security protocols should be implemented with stringent cyber-security measures and regular audits to safeguard the data. An engagement and collaboration with regulatory bodies are essential prior to implementation to ensure compliance and a constant update on any new safety standards and regulations.

It is necessary to customise speech-to-text systems to accurately recognise and transcribe diverse accents and dialects, as this is crucial for the aviation industry. Recommended also is to enhance user interface by developing a user-friendly interface system for customers interacting with speech-to-text enabled services; this will also ensure that the system is integrated with customer-service platforms for seamless use of the technology, for a unified approach.

Lastly, comprehensive training programs and change-management programs must be developed for staff to adapt to new technology. After that, there is the necessity for continuous training and feedback for ongoing engagement with advancements to regularly improve the system’s effectiveness.

By addressing these areas, the aviation sector can expand on the benefits of speech-to-text technology, which will, in turn, lead to an improved overall efficiency in the aviation sector in South Africa.

## 6.6 Suggestions for further research

A comparative study is required, hence, further researchers could do an investigation into the effectiveness of speech-to-text systems compared to traditional customer service methods, in different aviation contexts. There can also be research conducted on the technology adaptation and the user experience to explore how passengers from various demographic backgrounds adapt to and perceive speech-to-text technology in customer service.

Additionally, investigation in diverse locations should be undertaken on language and accent analysis. The effectiveness of speech-to-text systems in accurately recognising and transcribing diverse accents and dialects should be researched, as well as an impact study of speech-to-text technology on the roles, skills required, and job satisfaction of everyone involved in the aviation sector, from pilots all the way to ground staff. A long-term efficiency analysis should be conducted on the gains and return on the investment of implementing speech-to-text technology in the aviation sector in South Africa.

Cyber-security and data privacy should be prioritised. This would be in response to the articulated challenges around data privacy in relation to cyber-security when using the speech-to-text technology in the aviation sector. Results from such studies, their implications and solutions should be comprehensively detailed.

Lastly, research should be conducted into change-management strategies to facilitate the adoption of new technologies in the aviation sector. The results should observe the human-technology interaction and explore the impacts of speech-to-text technology on human roles and responsibilities in aviation, mainly focusing on air traffic controllers and pilots.

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# APPENDICES

## Appendix A: Interview Guide

**Interview Guide**

Good day. My name is Kagiso Mainganya, and I would like to thank you for participating in this interview. This interview is part of a research study that aims to explore the potential of Speech-to-text technology in enhancing efficiency in the aviation sector. The information you provide is valuable and will contribute to our understanding of the subject.

**Consent**

Before we begin, please confirm that you have given consent and that you agree to participate in this study. You have the right to withdraw at any time without any consequences.

**Demographic Information**

1. Can you please discuss your role in the aviation industry?
2. How many years of experience do you have in this industry?
3. Are you aware of the implementation of any Artificial Intelligence and Big Data initiatives in the aviation industry?

**Interview Questions**

**Understanding of AI and Big Data in Aviation**

4. Can you please describe your understanding of Artificial Intelligence and/or Big Data in the context of the aviation industry?

**Current Applications**

5. Are you aware of any current applications of Speech-To-Text technology, in the aviation sector?
6. How, in your opinion, can Speech-to-text technology be integrated into air traffic control and flight planning systems?

**Benefits and Challenges**

7. What do you believe are the potential benefits of integrating Speech-to-text technology in air traffic control and flight planning?
8. Can you describe any challenges or limitations that might arise with the integration of AI-driven Speech-to-text technology in the aviation industry?

**Safety and Efficiency**

9. How do you think speech-to-text technology can contribute to enhancing safety in the aviation industry?
10. In what ways do you believe speech-to-text technology can improve the efficiency of flight operations and planning?

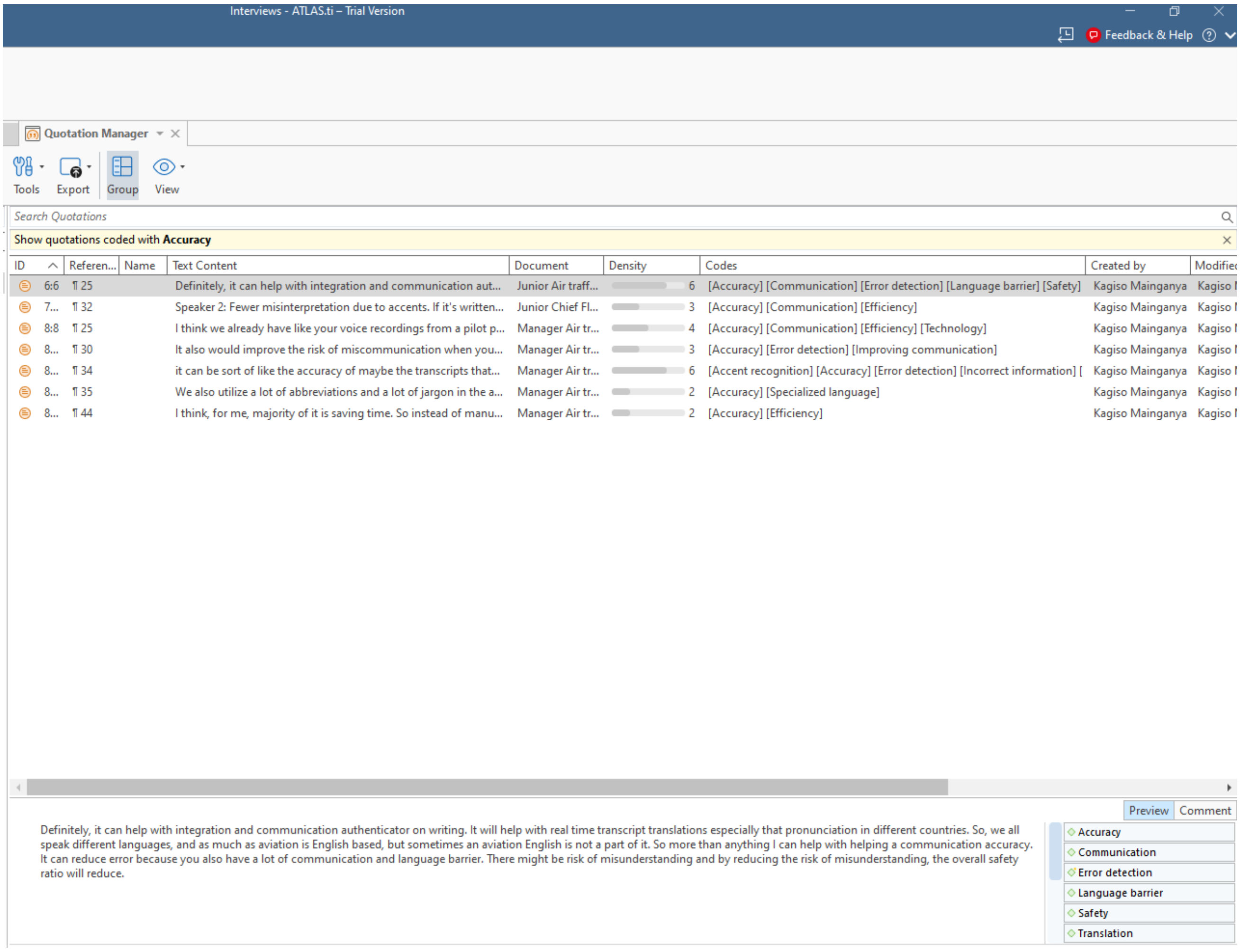
**Predictions**

11. What do you think the future holds for AI in the aviation industry, especially concerning speech-to-text technology?
12. Are there any policies, guidelines, or best practices that you think should be implemented to ensure the responsible and effective use of AI-driven speech-to-text technology in the aviation sector?

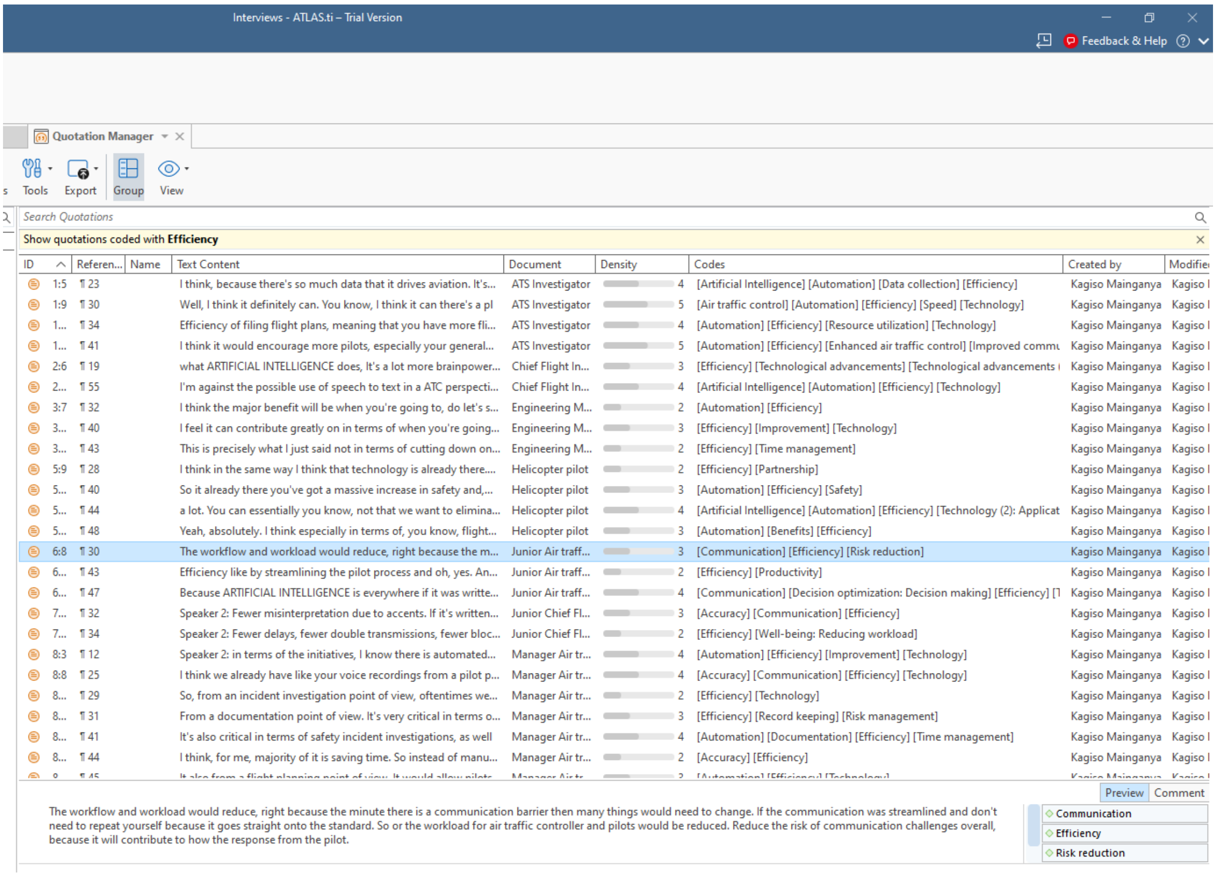
Conclusion

Thank you very much for your time and for sharing your insights. Your input is invaluable to this research. Do you have any final comments, or is there anything else you would like to add?

# Appendix B: Quotations Pertaining to Accuracy Codes



# Appendix C: Quotations Pertaining to Efficiency Interview Codes




| ID | Referen... | Name | Text Content | Document | Density | Codes | Created by | Modifie |
|---|---|---|---|---|---|---|---|---|
| 1:5 | ¶ 23 | | I think, because there's so much data that it drives aviation. It's... | ATS Investigator | 4 | [Artificial Intelligence] [Automation] [Data collection] [Efficiency] | Kagiso Mainganya | Kagiso I |
| 1:9 | ¶ 30 | | Well, I think it definitely can. You know, I think it can there's a pl | ATS Investigator | 5 | [Air traffic control] [Automation] [Efficiency] [Speed] [Technology] | Kagiso Mainganya | Kagiso I |
| 1... | ¶ 34 | | Efficiency of filing flight plans, meaning that you have more fli... | ATS Investigator | 4 | [Automation] [Efficiency] [Resource utilization] [Technology] | Kagiso Mainganya | Kagiso I |
| 1... | ¶ 41 | | I think it would encourage more pilots, especially your general... | ATS Investigator | 5 | [Automation] [Efficiency] [Enhanced air traffic control] [Improved commu | Kagiso Mainganya | Kagiso I |
| 2:6 | ¶ 19 | | what ARTIFICIAL INTELLIGENCE does, It's a lot more brainpower... | Chief Flight In... | 3 | [Efficiency] [Technological advancements] [Technological advancements ( | Kagiso Mainganya | Kagiso I |
| 2... | ¶ 55 | | I'm against the possible use of speech to text in a ATC perspecti... | Chief Flight In... | 4 | [Artificial Intelligence] [Automation] [Efficiency] [Technology] | Kagiso Mainganya | Kagiso I |
| 3:7 | ¶ 32 | | I think the major benefit will be when you're going to, do let's s... | Engineering M... | 2 | [Automation] [Efficiency] | Kagiso Mainganya | Kagiso I |
| 3... | ¶ 40 | | I feel it can contribute greatly on in terms of when you're going... | Engineering M... | 3 | [Efficiency] [Improvement] [Technology] | Kagiso Mainganya | Kagiso I |
| 3... | ¶ 43 | | This is precisely what I just said not in terms of cutting down on... | Engineering M... | 2 | [Efficiency] [Time management] | Kagiso Mainganya | Kagiso I |
| 5:9 | ¶ 28 | | I think in the same way I think that technology is already there.... | Helicopter pilot | 2 | [Efficiency] [Partnership] | Kagiso Mainganya | Kagiso I |
| 5... | ¶ 40 | | So it already there you've got a massive increase in safety and,... | Helicopter pilot | 3 | [Automation] [Efficiency] [Safety] | Kagiso Mainganya | Kagiso I |
| 5... | ¶ 44 | | a lot. You can essentially you know, not that we want to elimina... | Helicopter pilot | 4 | [Artificial Intelligence] [Automation] [Efficiency] [Technology (2): Applicat | Kagiso Mainganya | Kagiso I |
| 5... | ¶ 48 | | Yeah, absolutely. I think especially in terms of, you know, flight... | Helicopter pilot | 3 | [Automation] [Benefits] [Efficiency] | Kagiso Mainganya | Kagiso I |
| 6:8 | ¶ 30 | | The workflow and workload would reduce, right because the m... | Junior Air traff... | 3 | [Communication] [Efficiency] [Risk reduction] | Kagiso Mainganya | Kagiso I |
| 6... | ¶ 43 | | Efficiency like by streamlining the pilot process and oh, yes. An... | Junior Air traff... | 2 | [Efficiency] [Productivity] | Kagiso Mainganya | Kagiso I |
| 6... | ¶ 47 | | Because ARTIFICIAL INTELLIGENCE is everywhere if it was writte... | Junior Air traff... | 4 | [Communication] [Decision optimization: Decision making] [Efficiency] [T | Kagiso Mainganya | Kagiso I |
| 7... | ¶ 32 | | Speaker 2: Fewer misinterpretation due to accents. If it's written... | Junior Chief Fl... | 3 | [Accuracy] [Communication] [Efficiency] | Kagiso Mainganya | Kagiso I |
| 7... | ¶ 34 | | Speaker 2: Fewer delays, fewer double transmissions, fewer bloc... | Junior Chief Fl... | 2 | [Efficiency] [Well-being: Reducing workload] | Kagiso Mainganya | Kagiso I |
| 8:3 | ¶ 12 | | Speaker 2: in terms of the initiatives, I know there is automated... | Manager Air tr... | 4 | [Automation] [Efficiency] [Improvement] [Technology] | Kagiso Mainganya | Kagiso I |
| 8:8 | ¶ 25 | | I think we already have like your voice recordings from a pilot p... | Manager Air tr... | 4 | [Accuracy] [Communication] [Efficiency] [Technology] | Kagiso Mainganya | Kagiso I |
| 8... | ¶ 29 | | So, from an incident investigation point of view, oftentimes we... | Manager Air tr... | 2 | [Efficiency] [Technology] | Kagiso Mainganya | Kagiso I |
| 8... | ¶ 31 | | From a documentation point of view. It's very critical in terms o... | Manager Air tr... | 3 | [Efficiency] [Record keeping] [Risk management] | Kagiso Mainganya | Kagiso I |
| 8... | ¶ 41 | | It's also critical in terms of safety incident investigations, as well | Manager Air tr... | 4 | [Automation] [Documentation] [Efficiency] [Time management] | Kagiso Mainganya | Kagiso I |
| 8... | ¶ 44 | | I think, for me, majority of it is saving time. So instead of manu... | Manager Air tr... | 2 | [Accuracy] [Efficiency] | Kagiso Mainganya | Kagiso I |

The workflow and workload would reduce, right because the minute there is a communication barrier then many things would need to change. If the communication was streamlined and don't need to repeat yourself because it goes straight onto the standard. So or the workload for air traffic controller and pilots would be reduced. Reduce the risk of communication challenges overall, because it will contribute to how the response from the pilot.