DRONE INTEGRATION IN ADVANCING TECHNOLOGICAL, REGULATORY, AND AIR-GROUND INFRASTRUCTURE WITH CONSUMER PERSPECTIVES IN MALAYSIA

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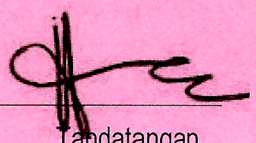

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ABSTRACT

The rapid development of drone technology has the potential to revolutionize various sectors in Malaysia, especially in the context of Industry 4.0. This research explores the feasibility and challenges of integrating drones into commercial applications, focusing on three critical factors: technological readiness, regulatory dynamics, and air-ground infrastructure. While drones hold promise for improving efficiency and reducing costs in industries such as logistics, agriculture, and infrastructure inspection, several barriers hinder their widespread adoption. These include limitations in battery life, AI integration, and the underdeveloped regulatory framework. Additionally, the lack of supporting air-ground infrastructure, such as 5G networks and droneports, further complicates large-scale drone deployment. This study also examines the role of collaborative initiatives between stakeholders, including government agencies, private industries, and regulatory bodies, in overcoming these obstacles and fostering smoother integration. By assessing these factors, the research aims to provide a comprehensive model for facilitating the growth of the drone industry in Malaysia, ultimately contributing to the nation's transition into a more efficient and technologically advanced economy. The findings will offer valuable insights for policymakers, industry leaders, and researchers aiming to unlock the full potential of drones in Malaysia's commercial landscape.

Keywords: Drone Technology, Commercial Applications, Technological Readiness, Air-Ground Infrastructure, Regulatory Dynamics, Stakeholder Collaboration

Abstrak

Perkembangan pesat teknologi dron berpotensi untuk merevolusikan pelbagai sektor di Malaysia, terutamanya dalam konteks Industri 4.0. Kajian ini meneroka kelayakan dan cabaran dalam mengintegrasikan dron ke dalam aplikasi komersial, dengan memberi tumpuan kepada tiga faktor kritikal: kesiapan teknologi, dinamik peraturan, dan infrastruktur udara-darat. Walaupun dron menjanjikan peningkatan kecekapan dan pengurangan kos dalam sektor-sektor seperti logistik, pertanian, dan pemeriksaan infrastruktur, beberapa halangan menghalang penerimaannya secara meluas. Ini termasuk kekangan dalam hayat bateri, integrasi kecerdasan buatan (AI), dan rangka kerja peraturan yang kurang berkembang. Selain itu, kekurangan infrastruktur udara-darat yang menyokong, seperti rangkaian 5G dan droneports, menambah kesukaran dalam melaksanakan dron pada skala besar. Kajian ini juga mengkaji peranan inisiatif kolaboratif antara pihak berkepentingan, termasuk agensi kerajaan, industri swasta, dan badan peraturan, dalam mengatasi halangan ini dan mempermudah integrasi yang lebih lancar. Dengan menilai faktor-faktor ini, kajian ini bertujuan untuk menyediakan modal yang komprehensif bagi memudahkan pertumbuhan industri dron di Malaysia, seterusnya menyumbang kepada peralihan negara ke arah ekonomi yang lebih cekap dan maju secara teknologi. Penemuan kajian ini akan memberikan pandangan yang berharga kepada pembuat dasar, pemimpin industri, dan penyelidik yang bertujuan untuk membuka potensi penuh dron dalam landskap komersial Malaysia.

Kata kunci: Teknologi Dron, Aplikasi Komersial, Kesiapan Teknologi, Infrastruktur Udara-Darat, Dinamik Peraturan, Kolaborasi Pihak Berkepentingan

DECLARATION

"I hereby declare that this report is the result of my own work and effort. Any information obtained from other sources has been properly acknowledged."

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CHAPTER ONE: INTRODUCTION

1.0 Introduction

1.1 Background of Study

The global industrial landscape has undergone multiple revolutions since 1780, and each driving transformative change in manufacturing and distribution processes. These revolutions have aimed to manage market complexities, enhance supply chain resilience, reduce costs, and improve operational speed. Throughout each revolution, industries have been able to offer more reliable and efficient value-added services to consumers.

China is the main player and contributes the most revenue in global market with US$1,526M in year 2024. In Southeast Asia, Drone market achieve revenue of US$40.4M in 2024, and the adoption volume trend is increase gradually and expected to grow 5.97% annually from year 2024 to 2029. Drone adoption rate in commercial usage for Singapore and Malaysia are rising especially in surveillance and aerial photography industries (Statista, 2024).

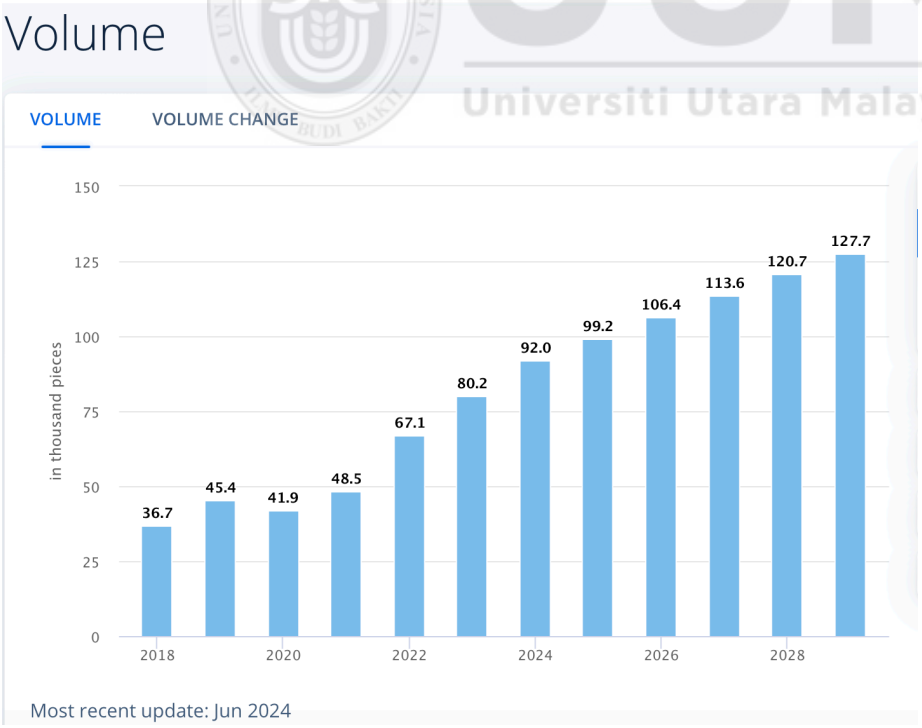

Figure 1.1 Volume by thousand piece for drone market in Southeast Asia

In Malaysia context, drone technology is increasingly recognized as a key component of Industry 4.0, particularly for its potential applications in logistics, agriculture, surveillance, and infrastructure inspection. Drones have the potential to revolutionize these industries by enabling faster, more efficient operations, reducing labor costs, and introducing advanced automation and data collection capabilities. For instance, in logistics, drones can offer cost-effective solutions for last-mile deliveries, especially in remote areas. Similarly, in agriculture, drones equipped with precision-mapping and crop-monitoring systems can significantly improve yield and resource efficiency. Moreover, their ability to provide real-time surveillance and assess infrastructure conditions has made them an attractive tool for urban planning and disaster management.

Hence, to support the growth of Malaysia drone ecosystem, it is important to study the challenges that hinder their widespread integration. This research will focus on few critical aspects ranging from technical, regulatory and air ground infrastructure. From a technological perspective, Malaysia faces hurdles in ensuring drone battery endurance, AI integration, and operational scalability, which are critical for commercial applications. Regulatory frameworks are still not fully equipped in Malaysia to address issues such as airspace management, safety, and privacy, creating uncertainty for businesses looking to adopt drone technology. Air-ground infrastructure is essential to enable seamless operations and communication. This includes droneports for charging and maintenance, air traffic management systems for safety, and advanced networks like 5G for real-time navigation and data transmission.

Asides, this research will also study on stakeholder collaboration efforts and role in improve consumer acceptance towards drone application as public perception of drones varies based on concerns around privacy, security, and the reliability of these systems.

Hence, this research "Drone Integration In Advancing Technological, Regulatory, And Air-ground Infrastructure With Consumer Perspectives In Malaysia" will focus on exploring the feasibility and challenges of drone applications in commercial use, aligning with the broader transformation in Industry 4.0.

1.1.2 Drones and Industry 4.0

Although the application of drones in commercial settings in Malaysia remains in its early stages, which still hindered by obstacles such as infrastructure, payload limitations, regulations, and battery life. However, drones are still expected to be a key future trend in logistics as drones promise to revolutionize the sector by bringing benefits such as increased efficiency,

productivity, and cost savings. As an emerging tool, drone hold the potential to streamline overall supply chains and become a key pillar of logistics operations.

Drone was initially used for military and recreational purposes, but drones are now evolving into important assets for various industries such as logistics, agriculture, transportation, construction and furthermore. Drones allow a better respond to market demand as it is a more flexible and provide faster and cost-effective solutions.

Drona had achieved and gained achievement in some of the area especially in healthcare in recent years by acting as valuable delivery tools in improving access to medical supplies and patient care, especially in remote or hard-to-reach areas. For instance, in 2019, the government of Ghana partnered with Zipline, a U.S.-based drone company to distribute medical supplies such as blood, vaccines, and medications across the country, particularly to rural areas. Drone services have been instrumental in reducing delivery times from hours to minutes, saving lives in emergencies. Asides, during the COVID-19 pandemic, drones had also contributed significantly and became essential delivery method for contactless deliveries of medical necessities, food, and groceries. Drones which equipped with temperature sensors played a crucial role during the pandemic in monitoring public health and safety in China and played significant role in combating the pandemic (Deng et al., 2021).

The use of drone applications was foreseen and expected to have the ability to cover the entire supply chain, from upstream till the downstream. For example, in the use of agricultural activities. Drone can be adopted and use to monitor crop health, map fields, and optimize irrigation. They can apply fertilizers, pesticides, and even monitor livestock, improving yield and reducing costs. Drones able to provide a promising solution in transforming traditional practices and able to improve agriculture productivity and efficiency in smart agriculture which can reduce the reliance of human intervention in farming which related to crop management (Gupta et al., 2022). For instance, drone able to provide precise monitoring of water stress, crop growth, pest detection, and yield estimation (Rejeb et al., 2022)

Asides, drone also expected to have great capabilities in smart manufacturing. Drone which equipped with cameras and sensors offer significant improvements in inventory tracking, visual inspection, and quality control. This "smart warehouse" approach, made possible by drone technology, allows for real-time data collection and better decision-making, contributing to cost savings and efficiency (Gago et al., 2021). Furthermore, the use of drone in manufacturing especially in oil and gas (O&G) industry able to aids in detect safety hazards such as leaking

in the manufacturing plant. Drones with optical gas imaging capabilities can be used for early detection of possible hazardous gas leakages (Nooralishahi et al., 2021).

Furthermore, drones expected to revolute especially in logistics industry and highly potential in replacing the use of trucks in last mile deliveries. The use of drone able to overcome barriers and shortage of current traditional logistics which mainly focus on trucks and land transports which contribute to noise and air pollution, traffic congestion, overcrowded parking areas, traffic incidents, increased delivery expenses, and other unexpected challenges associated with ground vehicles.

Logistics and e-commerce platform such as Amazon, Alphabet's Wing, Walmart, and UPS are exploring the possibilities to adopt drone technology as a sustainable transportation option in their delivery process, which mainly focus on last mile deliveries. Drone able to provide an eco-friendlier nature, faster delivery times, reduced operating costs, and minimal reliance on human labor. Additionally, companies such as Mercedes-Benz had also partnered with drone manufacturer, Matternet to explore on-demand e-commerce deliveries using electric vans in conjunction with drones. (Eskandaripour & Boldsaikhan, 2023).

Currently, there are few main players such as Parrot SA, DJI, and Autel Robotics in the consumer drone market. These companies are playing significant roles and gaining largest market share in the world. Parrot SA, a Paris-based company, focuses on consumer and commercial drones. Their consumer drones, like the mini, AR, and bebop models, cater to aerial photography, while their commercial line includes the ANAFI Ai and ANAFI USA. DJI, headquartered in Shenzhen, China tech hub, benefits from close proximity to suppliers and raw materials. As a private company, DJI is known for fostering creative, commercial, and humanitarian uses of its drones. Their technology supports a wide range of industries, from agriculture to search and rescue, by enabling safer and more efficient operations. Autel Robotics, also based in Shenzhen, has expanded its reach globally with R&D centers in the U.S., Germany, Italy, and Singapore. Known for its dedication to innovation, Autel has established a strong presence in the global drone industry through advanced technology development and autonomous solutions (Consumer Drones Market Trends: Size, Share, Forecast, 2029, 2024).

The growing popularity of aerial capturing and integration of artificial intelligence is anticipated to propel consumer drones market growth. However, despite the promising potential, drone usage in commercial applications in Malaysia is still early stage. Numerous

challenges must be addressed which include infrastructures, regulatory barriers and software and hardware technology integration. Hence, the collaboration among stakeholders such as governments, regulatory bodies, and private industries are critical in establish comprehensive planning and support for the sustainable growth of the drone industry. Clear guidelines, safety measures, and clarify responsibilities in drone usage need to be developed and discuss among stakeholders involved. Successful collaboration will enable a cohesive framework that ensures safe and efficient drone operations, paving the way for greater adoption in various sectors. Further studies are also required to create comprehensive implementation models, considering pre-launch, operational, and post-launch phases.

1.1.3 Drone market in Malaysia

Gohari et al. (2023) had conducted a studies of Malaysia academic research in drone areas in recent years. Following the guideline of Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA), out of 202 papers, only 54 drone research studies was published since 2018 to year 2023. This research studied about the drone application in areas such as agriculture, transportation, mapping flood management etc. The application of drone in agriculture and mapping gained the main focus among all the application areas. This data indicates a relatively small but growing interest in drone research within Malaysia. Further research, investment and focus may be needed to expand the scope and impact of drone technology across other sectors in Malaysia context as the current studies are heavily concentrated in agriculture and mapping. Expanding research to include sectors like healthcare, infrastructure inspection, and environmental monitoring could reveal additional benefits and applications for drones. Collaborative efforts between academia, industry, and government could also help address existing challenges and support the broader integration of drones in Malaysia economy and society.

According to Malaysia Drone Market Size, Share & Trends: Report, (2024), Malaysian drone industry is anticipated to expand at a compound annual growth rate (CAGR) of 21.44%, projected to reach approximately $7.27 billion by 2029, an increase from $2.75 billion in 2024. This growth is largely driven by rising popularity among younger users for recreational purposes, alongside growing commercial applications in sectors such as agriculture, construction, and defense.

Drones are utilized across various activities, including aerial photography, security surveillance, delivery, and agricultural monitoring. The Malaysian government has actively championed this

sector's growth through initiatives like the Malaysian Drone Technology Action Plan (MDTAP30), which aims to create 100,000 jobs and contribute RM 50 billion to the nation GDP by 2030.

Organizations such as Malaysia Digital Economy Corporation (MDEC) play a significant role in advancing drone technology across the country. Additionally, government bodies employ drones for public safety and in disaster relief efforts. With substantial support from both public and private sectors, Malaysia drone market is experiencing rapid growth and development.

Report Metric	Details
Market Size Value in 2024	US$2,752.224 million
Market Size Value in 2029	US$7,270.159 million
Growth Rate	CAGR of 21.44% from 2024 to 2029
Study Period	2019 to 2029
Historical Data	2019 to 2022
Base Year	2024
Forecast Period	2024 – 2029
Forecast Unit (Value)	USD Million
Segments Covered	• Component • Product Type • EU Classified Weight Class • Application • State
Companies Covered	• Alphaswift Industries Sdn. Bhd. • Aerodyne Group • Strat Aero Malaysia Sdn Bhd • Braintree Technologies • Vortex Edge Sdn Bhd

Figure 1.2: Expected market size value for drone from 2024 to 2029

1.2 Problem statement

The use of drone is under rapid development and having high potential in commercial use as it expected to benefit various stakeholders in supply chain from upstream to downstream starting from manufacturing sector till the distribution segment. Industry 4.0 trend and post- Covid had become the catalyst of drone adoption and accelerated the use of drone in various industries. However, the feasibility in implementation and obstacles for the widespread is still under investigation and it is still in crucial and infant stage. Hence, this research aims to investigate the implementation challenges and assess the feasibility of drone applications in multiple sectors to identify key obstacles that hinder drone application in commercial.

1.2.1 Lack of technological readiness

The successful implementation of drones highly rely on the ability in overcoming significant technological barriers, including insufficient battery life, operational scalability, and artificial intelligence (AI) integration. Current drone batteries struggle to meet the endurance demands of commercial operations, particularly in applications like last-mile delivery, agriculture, and industrial automation. Insufficient battery life often leads to delivery failures, operational disruptions, and reduced business scalability. Innovations such as "droneports" and modular battery systems are being explored to extend drone flight durations and improve reliability (Bláha et al., 2023).

Additionally, AI plays a pivotal role in advancing drone autonomy and adaptability. AI-driven systems enable drones to process real-time data, navigate complex environments, and dynamically respond to changing situations without operator intervention. However, the integration of advanced AI capabilities requires substantial computational power, which further strains already limited energy resources (Almalki et al., 2022). Without overcoming these technical challenges, drones will remain limited in their ability to perform sophisticated tasks effectively and at scale.

1.2.2 Regulatory Dynamics

While drone technology is advancing rapidly, Malaysia regulatory framework is underdeveloped, particularly in areas such as airspace management, safety protocols, and privacy standards. In countries like the United States, incidents such as near-misses between drones and manned aircraft of over 700 in 2015 underscore the importance for stringent regulatory oversight to ensure aviation safety (Whitlock, 2015). Malaysia must address similar

concerns by implementing robust policies for shared airspace management, particularly for drones operating in densely populated areas.

Additionally, the integration of air-ground infrastructure into the regulatory framework is essential for enabling safe and seamless drone operations. This includes establishing protocols for Beyond Visual Line of Sight (BVLOS) operations, real-time communication, and emergency responses. Regulatory bodies must also develop designated airspace corridors, standardized operational processes, and defined takeoff and landing zones to ensure the scalability and safety of drone applications (Tran & Nguyen, 2022). Without comprehensive regulations, businesses face uncertainty, which limits the potential for widespread drone adoption.

1.2.3 Supporting air-ground infrastructure readiness

The air-ground infrastructure required to support drones is currently inadequate to accomodate large-scale operations in Malaysia. Essential components like Ground Control Stations (GCS), Low-Earth Orbit (LEO) satellites, and cellular networks are critical for enabling reliable communication, navigation, and data transfer. These systems support crucial capabilities such as BVLOS operations and real-time data sharing, ensuring safe and efficient drone performance (Fan & Saadeghvaziri, 2019).

However, Malaysia 5G coverage remains limited with only 27% nationwide access as of late 2023 and limit advanced drone applications particularly in rural or remote areas (Johan, 2024). In contrast, countries like Singapore and Thailand have established extensive 5G networks, which facilitate seamless drone operations in industries like agriculture, logistics, and infrastructure inspection. Expanding Malaysia 5G coverage is crucial to enable widespread drone deployment, particularly in areas requiring real-time tracking and responsive adjustments.

Furthermore, existing airport infrastructure is optimized for manned aircraft, creating challenges for integrating drones into shared airspace. Technological advancements such as micro-airports and harmonized airspace management systems are essential for adapting current infrastructure to meet drone-specific requirements. Technologies like Global Positioning Systems (GPS), Real-Time Kinematic (RTK) positioning, and Unmanned Aircraft System Traffic Management (UTM) systems must be developed to ensure precise navigation and safe operations (Solomitckii et al., 2018).

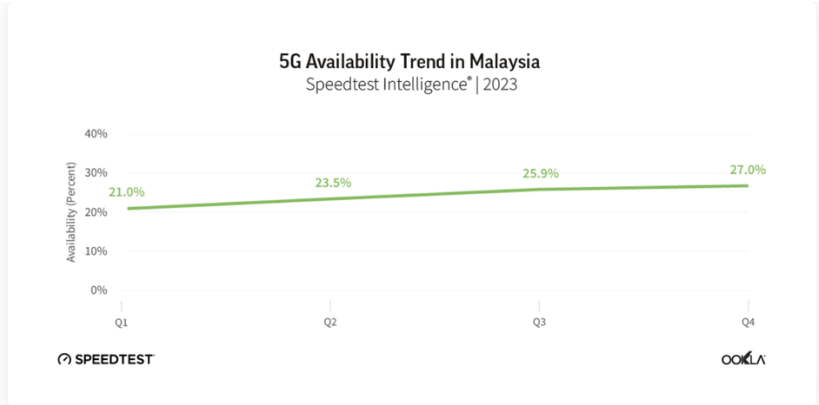

Figure 1.3: 5G availability trend in Malaysia in 2023

1.3 Research Question & Objectives

Research questions:

1. What are the key factors focus in technical, regulatory, and operational barriers that impact the adoption of drone technology in commercial applications in Malaysia?
2. How do collaborative initiatives between industry stakeholders influence the resolution of obstacles and promote smoother integration of drone technology in Malaysia?
3. What are the essential components of a model for collaborative initiatives that would effectively support the integration of drone technology in commercial sectors?

Research objectives:

1. To identify the key factors focus in technical, regulatory, and operational barriers that impact on the adoption of drone technology in commercial applications in Malaysia. To explore the collaborative initiatives between stakeholders in the industry due to overcome obstacles and facilitating a smoother integration of drone technology.
2. To develop a model of collaborative initiative on the integration of drone technology.

1.4 Significance of the research

Drone technology is poised to be a game changer for the logistics industry and has the potential to contribute significantly to various sectors once it achieves widespread adoption in commercial applications. In particular, its use in last-mile delivery can dramatically enhance overall logistics operational efficiency, reduce costs through streamlined business processes, and increase profitability. Moreover, drones can add value to consumers by enabling faster delivery times and improving business competitive advantages.

However, achieving widespread adoption requires addressing key obstacles and conducting comprehensive feasibility studies to ensure the successful implementation of drone technology in commercial industries. It is important to identify critical elements that drive drone adoption, such as cost efficiency and competitive advantages, while acknowledging the need to address obstacles like regulations and customer perceptions. Ali, Kaur, Gupta, & Ahmad, 2021) This research is vital in catalyzing the evolution of the drone industry, driving advancements, and broadening its applications across various commercial areas.

The research must emphasize its significance to four key stakeholder groups: industry, government, academia, and the community. For the industry, it identifies solutions to overcome technical, operational, and logistical challenges, enabling businesses to harness the efficiency and cost-reduction benefits of drones. For governments, it provides insights into the regulatory and infrastructural frameworks needed to support drone integration while ensuring public safety and compliance. For academic institutions, the research fosters innovation by exploring new technologies, systems, and applications that can drive the development of next-generation drones. Finally, for the community, it highlights how drone technology can improve everyday life, from faster deliveries to creating new job opportunities and fostering environmental sustainability.

By investigating collaborative initiatives among these stakeholders, the research can propose actionable strategies to mitigate obstacles and facilitate smoother integration of drone technology. This collective effort will ensure a holistic approach to implementing drone technology, ultimately enhancing its feasibility and transformative potential across diverse industries and society.

1.5 Scope of the Study

This research focuses on exploring the factors that influence the adoption of drone technology in commercial applications in Malaysia specifically in examines the role of technological readiness, regulatory dynamics, and air-ground infrastructure to shape the feasibility and implementation of drones in various industries. The research also investigates how collaborative initiatives among industry stakeholders contribute to overcoming challenges and fostering a smoother integration of drone technology. By analyzing these collaborations, the study aims to identify actionable strategies and propose a framework that addresses regulatory, technological, and infrastructural barriers. The findings will provide valuable recommendations for industry, government, and academia to enable the effective and sustainable integration of drone technology in Malaysia commercial landscape.

1.6 Definition of Key Terms

1.6.1 Drone (Unmanned Aerial Vehicle - UAV)

A drone, or unmanned aerial vehicle (UAV), refers to an aircraft that operates without a human pilot onboard. Drones are equipped with various technologies such as cameras, sensors, and GPS, enabling them to perform a range of tasks, including delivery, surveillance, and data collection.

1.6.2 Last-Mile Delivery

Last-mile delivery refers to the final step in the delivery process, where goods are transported from a transportation hub to the end consumer's location. This stage is often the most complex and costly part of the logistics chain, making efficient solutions critical for customer satisfaction.

1.6.3 Industry 4.0

Industry 4.0 represents the current trend of automation and data exchange in manufacturing technologies. It encompasses the Internet of Things (IoT), artificial intelligence (AI), robotics, and other innovations that enhance operational efficiency and productivity in various industries, including logistics.

1.6.4 Payload

Payload refers to the weight of the cargo that a drone able to carry during its operation. This specification is crucial for determining the drone’s capabilities and suitability for various applications, including commercial deliveries.

1.6.5 Regulatory Framework

The regulatory framework consists of the laws, guidelines, and policies established by governmental authorities to govern the operation of drones. This framework is essential for ensuring safety, privacy, and compliance in drone usage, particularly in airspace management.

1.6.6 Consumer Acceptance

Consumer acceptance refers to the willingness of consumers to adopt and use new technologies, including drones. This acceptance is influenced by factors such as awareness, perceived benefits, and concerns about privacy and security.

1.6.7 Technological Readiness

Technological readiness refers to the maturity and availability of technology for practical application. In the context of drones, it assesses the capabilities of drone systems, including battery life, AI integration, and navigation technologies, to meet commercial demands.

1.6.8 Operational Efficiency

Operational efficiency measures how effectively a company utilizes its resources to achieve optimal performance. In drone applications, it pertains to the ability to streamline delivery processes, reduce costs, and enhance service speed.

1.6.10 Air-Ground Infrastructure

The combined physical and digital frameworks that facilitate the operation of drones as they transition between aerial and terrestrial environments. This includes components like communication networks, control stations, and navigation systems.

1.7 Organization of the Study

The thesis is organized into five main chapters, each serving a distinct purpose in the exploration of drone applications in commercial use. Chapter 1 introduction, sets the stage by providing the background of the study, outlining the problem statement, and presenting the research questions and objectives. It also defines the scope and limitations of the research and clarifies key terms relevant to the study. Chapter 2, the Literature Review, critically evaluates existing literature and theories pertinent to the topic, serving as a foundation for the subsequent analytical sections by identifying gaps in current knowledge. Chapter 3 focuses on Methodology, detailing the research methods and techniques employed, including the research framework, hypotheses development, research design, and data collection procedures. This chapter also covers the measurement of variables and the techniques used for data analysis. In Chapter 4, Results and Discussion, the research findings are presented and analyzed, highlighting key results through figures and tables while connecting them to the research questions. Finally, Chapter 5, Conclusion and Recommendation, summarizes the key findings, emphasizes their theoretical and practical implications, and offers recommendations for future research. This structured approach ensures a logical flow of information while allowing for flexibility in content arrangement based on supervisory guidance.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter is organized into three main sections. Section 2.1 provides the background for the research, focusing on the history and context of the study. Section 2.2 presents a comprehensive literature review of the topic. Finally, Section 2.3 offers an overall summary of this chapter.

The literature review is critical for understanding the multifaceted aspects of drone implementation, including technological feasibility, regulatory landscapes, and consumer perceptions in commercial applications. This chapter provides a thorough understanding of the feasibility and obstacles related to drone technology in commercial use. Additionally, it serves as foundational knowledge to support the investigation of how drone technology can be effectively implement and to identify the barriers that may hinder its adoption across various industries.

2.1.1 The Global Emergence of Drone Technology

Drones, also known as Unmanned Aerial Vehicles (UAVs) or Unmanned Aircraft Systems (UAS), represent a transformative advancement in aviation technology. Designed to operate without an onboard pilot, these aircraft rely on either autonomous programming or remote control (Kale, 2021). The consistency in speed and altitude over extended periods has positioned drones as crucial tools across various sectors and applications span industries such as filmmaking, military surveillance, recreation, and increasingly, transformative commercial uses. The historical evolution of drones reflects their growing relevance. Emerging in the 19th century, unmanned balloons were initially deployed for military missions, including reconnaissance and air strikes. The innovation gained momentum during World War I with the development of UAVs like Britain's Aerial Target and the USA's Kettering Bug, though neither reached operational deployment (Kale, 2021).

The interwar period marked a critical phase, with Britain introducing the DH 82B Queen Bee, a radio-controlled drone designed for military target practice (Bálint, 2022). This innovation set the stage for more advanced applications. By the Vietnam War, drones had expanded into combat roles, engaging in missile launches and psychological operations, further demonstrating their utility in military strategy (Cyprian Aleksander, 2018). The technological trajectory continued into the late 20th century with the emergence of mini- and micro-UAVs in the 1990s, followed by the pivotal introduction of the Predator drone in 2000. The Predator

deployment in Afghanistan for surveillance and targeted strikes post-9/11 underscored its strategic importance and signaled the expanding scope of drone applications (Bálint, 2022).

2.1.2 Commercial Drone Applications and Global Milestones

The early 2000s marked the beginning of the commercial drone era, as businesses and professionals began recognizing the benefits of this technology. A significant milestone occurred in 2006 when the Federal Aviation Administration (FAA) issued its first commercial drone permit, paving the way for broader adoption (Weller, 2020). The commercial breakthrough came in 2013 with the release of DJI's Phantom series, a user-friendly drone by a Chinese manufacturer, which made drone operation accessible without specialized training. The accessibility fueled a surge in demand, and by 2015, the FAA had issued approximately 1,000 commercial drone permits. Small consumer drones equipped with cameras gained popularity for recreational use, aerial photography, and filmmaking.

In healthcare, drones demonstrated their life-saving potential. For example, in African nations like Rwanda and Ghana, drones have been instrumental in delivering medical supplies to rural and underserved areas. These deliveries have significantly reduced response times, lowered transportation costs, and improved healthcare accessibility (Emimi et al., 2023). During the COVID-19 pandemic, the relevance of drones grew as they facilitated critical deliveries during lockdowns. Companies such as Zipline delivered medical supplies and food, showcasing their effectiveness in last-mile delivery. Drones were also pivotal in curbing the pandemic's spread by transporting essential resources, including automated external defibrillators (AEDs) and personal protective equipment (PPE), to emergency scenes and healthcare facilities. Their capacity for expedited blood sample delivery further highlighted their role in overcoming logistical challenges in healthcare (Munawar et al., 2021).

Beyond healthcare, drones have made significant inroads into the commercial and logistics sectors. Amazon's Prime Air service exemplifies this trend, with its first official drone delivery in 2016 and subsequent federal approval in 2020 to expand operations. Similarly, Deutsche Post DHL's Parcelcopter project has targeted remote medical supply deliveries, while Alphabet's Project Wing is advancing drone capabilities for larger package deliveries. The food industry has also embraced drones, with companies like Domino's and McDonald's exploring meal delivery services in urban areas through partnerships with startups like Flytrex and Flirtey (Benarbia & Kyamakya, 2021).

Emerging technologies such as Blockchain, the Internet of Things (IoT), and Artificial Intelligence (AI) have further enhanced drone capabilities. Tang and Veelenturf (2019) highlight that market leaders like Alibaba and Amazon have integrated drones into their logistics functions, optimizing last-mile delivery and gaining a competitive edge in speed, reliability, and cost. These innovations underscore the strategic importance of drones in modern logistics.

The global drone industry is poised for exponential growth. According to the 2020 Drone Industry Insight Report, the sector is projected to achieve a Compound Annual Growth Rate (CAGR) of 13.8%, reaching a market value of $42.8 billion by 2025 (Mohanty et al., 2023). This growth is mirrored in specific regions, such as India, where the drone industry is expected to reach $1.5–$1.9 billion by 2026 (Edulakanti & Ganguly, 2023). The technology's versatility continues to expand its applications, from monitoring construction projects to crop spraying.

2.1.3 Drone Technology in Malaysia

In Malaysia, drones have proven it significant contribution in areas such as agriculture, logistics, and humanitarian operations. As per Soh et al. (2024) stated in research, DHL Express Malaysia has collaborated with Pen Aviation to demonstrate the practicality of drones for time-sensitive delivery tasks in port logistics. In November 2021, Pharmaniaga successfully completed the initial phase of its drone delivery concept, known as "Project Eagle," which involved transporting three kilograms of medicine to Pangkor Island. The project is set to continue with trials in other remote regions, such as Sabah and Sarawak. Asides, drone application for agriculture in Malaysia had also recorded in past research literature. Suhaizi et al. (2018) evaluated the effectiveness of drones for spraying in paddy fields, focusing on spray distribution and drift effects, and compared their performance with the traditional knapsack sprayer method. Man et al. (2019) investigated the adoption of drone technology for tasks such as paddy fertilization and oil palm mapping. Roslim et al. (2021) provided an overview of the potential applications of unmanned aerial vehicles (UAVs) and remote sensing in weed management, highlighting strategies to address future challenges. Nordin et al. (2021) examined the effectiveness of drones for chemical application in paddy fields. Nor and Hassan (2021) designed a conceptual framework for drones aimed at improving the efficiency of crop transportation within fields. Rahman et al. (2019) offered a general review of drone technology, discussing its advancements, current applications, challenges, and recommendations for effective implementation in Malaysia development and planning initiatives.

Malaysia government had also played significant role by promoted various initiatives and supports to catalyse the growth of drone ecosystem in Malaysia. Stakeholders collaborations among government and private industry players has been carried out to explore drone feasibility in term of technical, regulation and air-ground infrastructure supports perspective in Malaysia. According to Soh et al. (2024), the Malaysian Global Innovation and Creativity Centre (MaGIC) has partnered with AirAsia Digital to launch a pilot project aimed at evaluating the long-term feasibility of drone-based delivery services in urban settings. This six-month initiative, set in Cyberjaya which is the third national technology and innovation sandbox assessed on various factors, including drone operators capabilities, readiness for deployment, approval processes, operational experience, and potential service expansion.

According to Laman Khas Belanjawan 2024, (2024), in Budget 2024, Malaysia government had allocated RM76 million to strengthen drone ecosystem for research, development, commercialization, and innovation, with an additional RM10 million dedicated specifically to advancing the drone and robotics sector under Malaysian Research Accelerator for Technology & Innovation (MRANTI). MRANTI has also outlined an ambitious plan through the Malaysia Drone Technology Action Plan 2022-2030 (MDTAP30). Wahab et al., (2023) stated MDTAP30 is a strategic framework to advance drone technology across various sectors, including agriculture, logistics, public safety, and infrastructure in Malaysia and aims to position Malaysia as a regional leader in drone innovation by fostering technological development, regulatory enhancements, and public-private collaboration in global market. This plan emphasizes creating a supportive ecosystem for research and development, establishing clear regulatory guidelines to ensure safe and efficient drone operations, and promoting the integration of drones into commercial and public services. MDTAP30 also focuses on workforce upskilling and nurturing local drone-related industries to drive economic growth and sustainability. This comprehensive roadmap aims to accelerate the growth of the drone technology industry while promoting its responsible and efficient application across various sectors and projected to contribute RM50.71 billion to Malaysia's GDP and create 100,000 jobs by 2030.

The report stated by (The Edge Malaysia, 2024), MRANTI is leveraging drone technology for critical missions such as supporting security and rescue forces during emergencies and natural disasters. Through the Pasukan Tindakan Kecemasan Khas Drone initiative, MRANTI coordinates with local authorities, industry partners, and selected drone operators to assist flood victims and improve disaster response efforts.

As drones continue to evolve, ongoing research explores new frontiers, such as the Internet of Drones (IoD), flying ad-hoc networks, geofencing techniques, and signal-jamming technologies to enhance safety and security (Barka et al., 2018; Merkert & Bushell, 2020). These developments reflect the potential of drones to reshape industries and address critical challenges in both global and local contexts. Malaysia proactive approach underscores the importance of studying the feasibility of drone applications in technology, regulation, and air-ground infrastructure to support its ecosystem development.

2.2 Challenges for drone adoption: technology, regulation, and air-ground infrastructure

Drones is expected to have potential to revolutionize industries and reshape the way we interact with the world, but their widespread adoption faces significant challenges. Technological limitations, strict regulatory requirements, and the need for reliable air-ground infrastructure are the challenges that need to be addressed to unlock the full potential of drones and ensuring they can integrate safely and effectively into commercial application.

2.2.1 Drone Technological Readiness

The significance of emerging technologies has become increasingly evident, particularly in the aftermath of the COVID-19 pandemic, as highlighted by Zhou et al. (2020). The rapid advancement of technology has proven instrumental in facilitating essential logistics and transportation services, with tools such as geographic information systems (GIS) and Big Data analytics managing the delicate balance between supply and demand for critical resources, such as medical supplies. Innovations like digital supply chain twins have further enhanced decision-making processes, reshaping supply chain management in the era of Industry 4.0. According to Ivanov et al. (2019) and Hoffmann and Prause (2018), leveraging technologies such as the Internet of Things (IoT), Cyber-Physical Systems (CPS), and delivery robots like drones has become vital in driving digital transformation and smart logistics operations. These advancements underline the crucial role of technological readiness in improving logistics performance and achieving digital transformation goals.

Drone technology, as Vliet (2020) observed, has showcased promising applications across diverse fields, yet its journey to widespread adoption remains complex. Referring to the 2017 hype cycle analysis, drone technology was positioned in the 'Trough of Disillusionment,' with a projected 2-5 years to reach the 'Plateau of Productivity.' This highlights the uncertainty in the adoption of drones for commercial applications, necessitating feasibility studies to assess technological preparedness and navigate challenges effectively. The practical integration of drones requires evaluating key dimensions such as weight capacity, battery life, and operational reliability, which continue to constrain their feasibility in logistics.

Studies have explored innovative operational models to address these limitations. For instance, Murray and Chu (2015) proposed a coordinated delivery model integrating trucks and drones, optimizing delivery routes through heuristic approaches based on the Traveling Salesman Problem (TSP). Similarly, Es Yurek and Ozmutlu (2018) developed a two-stage iterative solution combining truck routing with mixed-integer linear programming (MILP) for drone

tours. These models underscore the potential of algorithm-driven strategies in enhancing efficiency. Benders' decomposition, as demonstrated by Vasquez et al. (2021), further exemplifies modular problem-solving approaches by separating truck routing and drone optimization tasks.

The evolution of drone technology also reflects ongoing efforts to enhance efficiency and operational flexibility. Agatz et al. (2018) introduced a dynamic programming approach allowing stationary trucks to enhance delivery speed. Liu et al. (2022) employed reinforcement learning to address stochastic travel times, achieving significant delivery time reductions. Marinelli et al. (2018) and Masone et al. (2022) extended operational capabilities by proposing methods to optimize battery efficiency and enable drones to carry multiple packages. Collectively, these studies emphasize the transformative potential of drones while acknowledging the technological challenges that remain.

Moreover, frameworks like the Technology Readiness Level (TRL), as noted by Vliet (2020), offer a structured approach to assessing the maturity of drone technology, spanning basic principles to full operational capability. Hanson and Olsson (2020) highlighted the relevance of Innovation Diffusion Theory in understanding how drone technologies spread across market segments, influenced by factors such as complexity, compatibility, and supporting infrastructure. Lewis (2019) emphasized the Resource-Based View (RBV), focusing on how strategic investments, intellectual property, and partnerships contribute to advancing drone readiness.

In the context of user adoption, the Technology Acceptance Model (TAM) has proven effective in exploring attitudes toward drones. Kuo, Hsu, and Chiu (2023) identified perceived usefulness and ease of use as pivotal factors in shaping acceptance, particularly for users unfamiliar with drones. The application of TAM and its extensions offers valuable insights into understanding the readiness and potential adoption of drone technologies in logistics and beyond.

This body of research reflects a multifaceted exploration of drone technological readiness, highlighting both the advances and the persistent hurdles in integrating drones into commercial and industrial applications. The continuous refinement of hardware, software, and operational models holds the promise of transformative changes in logistics and supply chain management, provided these challenges are systematically addressed.

2.2.2 Drone Regulatory Dynamics

Emerging technologies, such as drones and artificial intelligence, are reshaping industries with their dual-use capabilities and transformative potential. However, the rapid commercialization of drones has brought forth critical challenges, including concerns over safety, privacy, and security, which necessitate the development of comprehensive and adaptive regulatory frameworks. Historically, drone regulations evolved slowly, primarily derived from broader aviation laws, such as the Chicago Convention of 1944, which were designed for manned aircraft. Over time, as drone applications diversified, this reactive approach proved insufficient to address the unique risks posed by unmanned aerial vehicles (UAVs).

The International Civil Aviation Organization (ICAO) has been criticized for its delayed response in establishing a cohesive framework for UAVs. This contrasts with more proactive efforts, such as those by the European Union Aviation Safety Agency (EASA), whose 2018 regulations emphasize public safety, accountability, and social acceptance. Despite advancements in some regions, fragmented national policies and the accelerating pace of technological innovation continue to challenge the harmonization of global regulatory standards (Lynch, 2022).

Lee et al. (2022) highlight the heightened regulatory awareness spurred by the growth of recreational and commercial drone markets in countries like the United States, Germany, and Japan. Their findings emphasize the necessity for robust regulations to address data protection and privacy concerns effectively. Similarly, Shenoy and Tyagi (2022) argue that outdated regulatory frameworks struggle to keep pace with technological evolution, advocating for stakeholder collaboration to ensure the ethical and responsible use of drones.

The balance between fostering innovation and ensuring public safety is a recurring theme in the regulatory discourse. Portuese (2024) discusses this tension, particularly as AI-embedded drones emerge. While fostering innovation is critical, regulations must also address safety, competition, and privacy. The U.S. Federal Aviation Administration (FAA) Modernization and Reform Act exemplifies this balance by permitting civil drone operations while maintaining safety standards. Notably, the legal disputes between DJI and Autel underscore the complexities of ensuring fair competition in the drone market.

Accidents involving drones further highlight the urgent need for robust regulatory frameworks. Tran and Nguyen (2022) report a significant rise in near-miss incidents between drones and aircraft, posing threats to civil aviation security. Similar patterns emerge in Australia, where

Ghasri and Maghrebi (2021) categorize drone-related incidents into equipment failures and poor coordination among aerial activities. These findings underscore the necessity for regulations tailored specifically to the unique risks posed by UAVs, including battery limitations, airworthiness, and pilot licensing.

From an international perspective, regulatory approaches vary significantly. Clarke (2014) and Huang et al. (2021) examine the implications of drone use on behavioral privacy, while Chen and Huang (2021) explore integration into airspace systems. Countries such as Canada and Singapore distinguish between commercial and recreational use, imposing specific operational requirements for each category (Transport Canada, 2020; CAAS, 2020). In New Zealand, Henderson (2022) identifies gaps in pilot qualification standards, highlighting areas for improvement in safety regulations.

Global standardization of UAV regulations remains a critical challenge. Khan et al. (2024) emphasize the importance of harmonized regulatory frameworks to facilitate the safe and efficient adoption of drones across sectors. Their research explores the role of advanced technologies, such as LiDAR and collision avoidance systems, in enhancing UAV safety and autonomy, underscoring the interconnectedness of technological readiness and regulatory evolution.

The literature collectively reveals the complexities of crafting regulations that balance innovation with safety and ethical considerations. While national policies reflect varying priorities, the need for global collaboration and standardized practices is evident in achieving the safe and sustainable integration of drones into modern society.

2.2.3 Air-Ground Connection Infrastructure

The development of air-ground integrated networks has emerged as a critical focus in network architecture research, driven by the need for global coverage, high reliability, and low-latency communication. Zhang et al. (2024) highlight that such networks merge satellite systems with high-altitude platform networks to bridge the coverage gaps of traditional terrestrial communication systems. This approach ensures continuous connectivity for users in remote regions and during natural disasters, addressing a critical gap in existing infrastructure. The redundancy provided by multiple communication nodes—including satellites, high-altitude platforms, and ground base stations—ensures stable operations even under conditions of failure or interference. Such robustness is vital for maintaining communication services during

emergencies, underscoring the infrastructure's role in facilitating seamless data flow between aircraft and ground-based networks.

Strohmeier et al. (2020) emphasize the infrastructure's transformative role in enabling in-flight connectivity services. Cellular towers transmit signals to aircraft antennas, delivering high-speed internet to passengers and significantly enhancing the travel experience. Two primary technologies underpin these services: air-to-ground (ATG) networks and satellite communication systems. ATG systems, operating within the 3.5 GHz frequency range, offer faster transmission rates and cost efficiencies, making them suitable for domestic flights where proximity to ground-based infrastructure is feasible. Conversely, satellite communication systems are indispensable for long-haul flights over oceans and remote areas, ensuring global connectivity (Liu et al., 2023).

Ojo and Akinyemi (2022) further elaborate on the versatility of satellite communication systems, noting their adoption across telecommunications, broadcasting, military operations, and emergency response. These systems enable reliable data transmission and voice communication over vast distances, particularly in regions where traditional infrastructure is absent. As aviation moves toward the Aviation 4.0 paradigm, Sekera and Novák (2021) argue that high-bandwidth satellite systems, such as Low Earth Orbit (LEO) satellites, are essential for addressing safety services and rising data demands. The push for high-quality connectivity also presents significant revenue opportunities for airlines, further highlighting the importance of advanced air-ground communication systems in the evolving aviation landscape.

The role of air-ground connection infrastructure extends to drones, forming the backbone of an integrated ecosystem essential for UAV operations. Edelman et al. (2023) note that this ecosystem encompasses both physical and digital components, supporting near-ground activities like payload handling, charging, refueling, and terminal functions analogous to those in manned aviation. Zhang and Zhao (2022) explore the concept of micro-airports as autonomous infrastructures that facilitate air-ground connections, enhancing operational safety and efficiency. These infrastructures connect various stakeholders in the UAV ecosystem, supporting applications in logistics, surveillance, and emergency response (Ojo & Akinyemi, 2022).

The evolution of drone air-ground infrastructure parallels that of airports, transitioning from basic functionality to sophisticated systems enabling seamless service access. Similar to airports, these infrastructures are critical for integrating drones into existing aviation

frameworks. They play a pivotal role in early adoption within controlled environments such as seaports and industrial zones, setting the stage for broader regulatory frameworks and systemic growth (McKinsey, 2021).

Despite progress, Edelman et al. (2023) identify two primary gaps in current air-ground solutions for autonomous drones. First, existing standards often overlook the role of ground infrastructure in payload handling and data offloading, relying instead on cloud-based services. Second, while systems prioritize drone landing accuracy—using GNSS or local sensors—broader servicing needs remain underaddressed. Autonomous ground robots, akin to those used in manned aviation, could bridge this gap by supporting drones without requiring high-precision repositioning, thereby linking drones to a comprehensive ground service ecosystem.

The literature underscores the growing importance of air-ground connection infrastructure in advancing both manned and unmanned aviation. As technologies mature, their ability to support seamless operations across diverse environments will be instrumental in shaping the future of connectivity and mobility.

2.3 A Competitive Edge: The Strategic Importance of Drone Integration

In the dynamic environment of Industry 4.0, businesses must strategically adopt advanced technologies to maintain a competitive edge. This era, characterized by automation and data exchange, presents unparalleled opportunities for enhancing operational efficiency, cost-effectiveness, and environmental sustainability. Drone technology epitomizes these possibilities, emerging as a cornerstone for innovation in logistics and beyond.

2.3.1 Industry 4.0 and Logistics 4.0 Context

The transition to Industry 4.0 is reshaping traditional business models by leveraging cyber-physical systems, the Internet of Things (IoT), and data-driven decision-making. Logistics 4.0, an offshoot of Industry 4.0, underscores the integration of IoT and automation in logistics processes, fostering increased standardization and labor-saving practices. These technological advancements enable seamless communication between humans and objects, allowing organizations to streamline workflows, optimize resources, and improve responsiveness to market demands (Khofiyah et al., 2020).

The incorporation of drone technology into Logistics 4.0 exemplifies this transformation. Drones represent a convergence of innovation and practicality, capable of revolutionizing

supply chains through improved speed, accessibility, and operational flexibility. By automating previously labor-intensive tasks and enabling real-time data communication, drones align with the core objectives of Industry 4.0, providing companies with the tools to thrive in an increasingly competitive global market.

2.3.2 Applications of Drone Technology in Logistics

The practical applications of drones extend across diverse industries and sectors. In logistics, drones are becoming indispensable for tasks such as e-commerce deliveries, medical transport, fleet management, spare parts logistics, and even same-day food delivery. Their unique ability to traverse challenging terrains, bypass urban congestion, and operate autonomously allows for faster, more reliable delivery services.

Moreover, the use of drones promotes environmental sustainability. Unlike traditional vehicles powered by fossil fuels, drones rely on electricity, significantly reducing carbon emissions. This shift aligns with global sustainability goals, enabling companies to contribute to environmental preservation while enhancing their operational capabilities (Hwang, Kim, & Kim, 2019).

2.3.3 Real-World Case Studies

Empirical evidence demonstrates the transformative impact of drones on logistics and operational efficiency. Düzgün (2021) highlighted the advantages of drones in traffic control in Istanbul, including reduced maintenance costs, broader area coverage, and effective performance during natural disasters. This case study underscores drones' ability to enhance service delivery while addressing critical challenges such as disaster response and urban congestion.

In the pharmaceutical sector, Vlahovic et al. (2017) explored the integration of drones into delivery operations. Their findings revealed that drones not only improve cost efficiency but also enhance service responsiveness and operational flexibility. These attributes are particularly valuable in time-sensitive industries where delays can have significant consequences.

Niu et al. (2024) emphasized the competitive advantage of drones in last-mile delivery, a critical component of modern logistics. Unlike traditional vehicles, drones can bypass obstacles such as traffic jams, road accidents, and construction sites, ensuring faster and more reliable

deliveries. Hanifee (2023) highlighted another critical advantage: drones are not constrained by human labor limitations, allowing for continuous operation and greater flexibility.

A practical example of this efficiency is demonstrated by Meituan-Dianping, a leading food delivery company in China. The company reported that its drone delivery services averaged 12 minutes per delivery, representing a 150% increase in efficiency compared to conventional methods. This success showcases the potential of drones to transform last-mile logistics, setting new benchmarks for speed, service quality, and customer satisfaction (Pandaily, 2023).

2.3.4 Economic and Environmental Benefits

Drone technology offers significant cost and environmental benefits over traditional delivery methods. Nurgaliev et al. (2023) conducted a comparative study of drone and vehicle-based deliveries for a five-mile trip. The results showed that drones were marginally more cost-effective, with delivery costs of $1.80 per package compared to $1.90 for internal combustion engine (ICE) vans. More importantly, drones produced substantially lower CO2 emissions than both electric and fossil fuel-powered vehicles. These findings highlight the dual benefits of drones: reduced operational costs and a smaller environmental footprint.

By consuming less energy and operating on electricity, drones support sustainable development goals while enhancing logistics efficiency. Their adoption allows companies to align with environmental regulations and consumer expectations, further strengthening their market position.

2.3.5 Strategic Implications for Businesses

The integration of drone technology into logistics and other industries represents a strategic opportunity for businesses to gain a competitive edge. By providing faster, more cost-efficient, and environmentally sustainable solutions, drones enable companies to address critical challenges such as last-mile delivery and urban congestion. Additionally, the flexibility and autonomy of drones open new possibilities for innovation, allowing businesses to develop tailored solutions that meet the unique demands of their markets.

As technological advancements continue to refine drone capabilities, their role in the global economy is expected to grow. Companies that invest in drone integration today are positioning

themselves at the forefront of industry innovation, ensuring long-term competitiveness in an increasingly digital and environmentally conscious world.

2.4 The Need for Feasibility Studies: Understanding Drone Ecosystem Readiness

The growing enthusiasm for drone technology in various industries underscores the transformative potential of these innovations, but as Vosniakos & Maltezos (2022) stated, it is crucial to conduct thorough feasibility studies to understand not just the benefits, but also the limitations and challenges of deploying drones. These studies are foundational in determining whether drones are viable solutions for specific applications, ensuring that their integration into industries such as logistics, healthcare, and manufacturing is both effective and sustainable.

Irizarry & Johnson (2014) offer a comprehensive definition of feasibility in the context of drones, describing it as an assessment that spans five core dimensions: technical, economic, operational, legal, and environmental. Each of these factors plays a pivotal role in understanding the potential of drone applications in real-world settings. For instance, technical feasibility examines whether drones have the necessary performance attributes—such as payload capacity, endurance, and manoeuvrability—to perform tasks in specific environments. Economic feasibility assesses whether the costs associated with drone deployment, including maintenance and infrastructure requirements, are outweighed by the potential benefits such as reduced labour costs or faster delivery times. Operational feasibility looks at how well drones integrate into existing workflows and systems, while legal feasibility considers regulatory requirements such as airspace control and privacy laws. Lastly, environmental feasibility evaluates the impact of drones on the surrounding environment, including potential disruptions to wildlife and emissions.

Weller (2020) highlights the critical importance of feasibility studies in industries like logistics, where drones are increasingly seen as potential solutions for last-mile delivery. With the rapid rise of e-commerce, the demand for faster and more cost-efficient delivery systems is only intensifying. Drones offer a promising alternative by reducing human labor requirements and improving delivery times, but their successful integration into logistics operations depends on a clear understanding of their feasibility in terms of cost-effectiveness, scalability, and regulatory compliance. This makes feasibility studies not only a necessary precursor to drone deployment but also a key tool for informing decision-making processes at both strategic and operational levels.

Beyond logistics, the role of feasibility studies extends to the broader economic context, as noted by Dobysheva & Gidaspova (2020). Their research underscores how investments—both macro and microeconomic—are shaped by ongoing technological developments. The

feasibility of drone projects is therefore intrinsically tied to broader economic dynamics, including the allocation of resources, the impact of technological advancements on labor markets, and the long-term sustainability of drone-based systems. In essence, a well-conducted feasibility study forms the bedrock of an investment project, ensuring that financial and operational risks are minimized while maximizing potential returns.

Benarbia and Kyamakya (2021) offer a specific example of the challenges and opportunities in the e-commerce sector. In 2019, China distributed over 63.5 billion parcels, and last-mile delivery remains one of the most expensive and complex components of the logistics chain. Drone technology, as they argue, can provide a cost-effective solution to these challenges by reducing delivery times, lowering operational costs, and cutting down CO2 emissions. However, the feasibility of such systems hinges on overcoming several critical barriers, including fleet management, the optimization of delivery routes, and the coordination between drones and traditional ground-based vehicles. These factors must be carefully studied and tested to create a robust and efficient drone delivery model, one that can be scaled while maintaining economic viability.

Further reinforcing the importance of feasibility studies, Haus et al. (2019), Cheskes et al. (2020), and Vosniakos & Maltezos (2022) emphasize the need for such studies across various sectors. Cheskes et al. (2020) focus on the potential use of drones to deliver Automated External Defibrillators (AEDs) to rural and remote areas, where access to healthcare services is limited. Their research compares the response times of drone deliveries with traditional ambulance services, highlighting that drones could significantly improve emergency response times in areas with limited access to medical resources. This work highlights a crucial aspect of feasibility: the need to evaluate not just the technical capabilities of drones, but also their impact on human lives, especially in critical situations like medical emergencies.

Similarly, Vosniakos & Maltezos (2022) examine the integration of drones into manufacturing systems, focusing on the mechanical integration of drones with machinery and their collaboration with the Internet of Things (IoT). This study underscores that drones must be able to seamlessly work with other technologies to optimize production processes and improve safety. The challenges in this area involve understanding how drones can be safely integrated into environments where they work alongside humans and robots, and ensuring that systems are properly aligned and synchronized to avoid accidents or inefficiencies. These challenges

highlight the complex nature of feasibility studies and the multifaceted approach needed to assess drone applications in such industries.

2.4.1 Challenges in Constructing a Drone Feasibility Study

While the concept of a drone feasibility study is widely recognized as essential, conducting one is far from straightforward. Zubin et al. (2020) identify several key challenges that researchers and practitioners face when constructing a feasibility study for drone technology. Among these challenges are the need to account for a variety of operational factors, such as the number of stops, routing sequences, service times, and the costs associated with implementing drone systems. Each of these variables must be carefully modeled and tested to understand the practical implications of drone deployment.

The economic and environmental impacts of drone technology are particularly complex to assess. As drones are integrated into existing logistical or operational frameworks, their benefits must be weighed against the costs of infrastructure development, regulatory compliance, and potential environmental disruptions. Zubin et al. (2020) suggest that a comparative analysis, grounded in simulation models, can offer insights into how drones perform in various conditions, allowing for a clearer understanding of their feasibility across different industries. Vosniakos & Maltezos (2022) further elaborate on this point, explaining that simulations of drone operations must incorporate nonlinear models that account for variables such as the effects of ground conditions, propeller flow, and airflow disturbances. These simulations are vital to assessing the true potential of drones in real-world environments, helping to refine designs and optimize performance.

2.4.2 Assessing Feasibility and Overcoming Challenges in Drone Technology for Commercial Last-Mile Delivery

As Fehling & Saraceni (2023) note, the logistics industry is under significant pressure to meet the growing demands of e-commerce, with workforce shortages exacerbating the challenges of last-mile delivery. The global logistics sector faced a shortage of 150,000 drivers in 2020, highlighting the need for innovative solutions that can reduce dependency on human labor. Drone technology is seen as a potential answer to this crisis, offering a way to maintain delivery speed while reducing the strain on human workers. However, for drones to be truly effective in last-mile delivery, their technological feasibility must be carefully assessed, particularly in terms of their ability to handle diverse delivery environments, payload capacities, and endurance.

Maghazei et al. (2022) build on this idea by exploring how advancements in drone technology influence the feasibility of various drone applications. They argue that understanding the technological readiness of drones requires evaluating multiple factors, including payload capacity, endurance, maneuverability, and sensor capabilities. Feasibility studies, they emphasize, must look beyond technical specifications and assess the broader economic, operational, legal, and environmental factors that impact the deployment of drones in commercial applications. Only through such comprehensive evaluations can decision-makers ensure that drone technology can be seamlessly integrated into existing systems and workflows, providing both short-term solutions and long-term sustainability.

2.5 Summary

For the 2.1 parts, this sub-chapter explores the global development and commercial applications of drone technology, tracing its historical evolution from military use to its growing role in various industries like healthcare, logistics, and agriculture. It examines key milestones in drone commercialization, technological advancements, and their expanding market potential. Additionally, it highlights the specific use and growth of drone technology in Malaysia, focusing on government initiatives, research, and its impact on sectors like logistics, agriculture, and emergency response.

As for 2.2, this sub-chapter explores the challenges associated with the widespread adoption of drones, focusing on technological limitations, regulatory hurdles, and the need for reliable air-ground infrastructure. It examines how technological readiness, including factors like battery life, weight capacity, and operational reliability, affects the integration of drones into

commercial applications. The sub-chapter also delves into the evolving regulatory landscape, highlighting the complexities of crafting global standards that ensure safety, privacy, and ethical use while fostering innovation. Lastly, it discusses the crucial role of air-ground connection infrastructure in supporting seamless drone operations, emphasizing the need for integrated systems that enhance connectivity and operational efficiency.

For sub- chapter 2.3, it explores the strategic importance of drone integration in the context of Industry 4.0 and Logistics 4.0. It highlights how drone technology can enhance operational efficiency, cost-effectiveness, and environmental sustainability. The adoption of drones in logistics, including applications such as e-commerce delivery, medical transport, and fleet management, is presented as a transformative force. Real-world case studies demonstrate how drones improve service delivery, flexibility, and competitive advantage. The sub-chapter also emphasizes the economic and environmental benefits of drones, particularly their lower costs and reduced carbon emissions compared to traditional delivery methods. Finally, it discusses the strategic implications for businesses, stressing that early adoption of drones can provide a competitive edge in the global marketplace.

In Sub chapter 2.5, it underscores the importance of conducting comprehensive feasibility studies before deploying drone technology in various industries. It highlights how these studies assess the viability of drones across five core dimensions: technical, economic, operational, legal, and environmental. The need for feasibility studies is especially critical in sectors like logistics, where drones are considered for tasks such as last-mile delivery, due to the increasing demand for faster, cost-efficient solutions.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Research Framework

The research framework for this study on the implementation feasibility and obstacles of drone technology in commercial applications is designed to provide a comprehensive understanding of the subject by combining both descriptive and exploratory elements. The theoretical foundation is based on Diffusion of Innovations Theory, which will guide the analysis of how drone technology is adopted across various sectors. This theory will help identify the factors that influence the adoption of drones and how different stakeholders perceive and engage with the technology. A critical component of the framework is stakeholder analysis, which includes insights from a variety of key factors such as industry experts and consumers. Industry experts, including drone technical specialists and procurement specialists, will provide insights into the technical capabilities and challenges of drones in commercial operations. Consumer feedback will be gathered to understand market perceptions, attitudes, and concerns regarding drone adoption, particularly in industries like logistics and e-commerce.

Data collection will primarily involve qualitative methods, with a focus on semi-structured interviews. These interviews will be conducted with a wide range of stakeholders, including drone technology experts, supply chain managers, logistics professionals and consumers. The interviews will explore participants experiences and insights into the challenges and opportunities related to drone technology adoption. Key themes to be addressed in the interviews include technological feasibility, which will assess current drone capabilities and limitations; regulatory challenges, focusing on legal frameworks, airspace management, and privacy concerns; operational efficiency, looking at how drones can enhance logistics processes and cost savings and public perception, which will explore consumers attitudes toward drones and their willingness to embrace drone-based services.

Once the data has been collected, thematic analysis will be applied to identify patterns and trends within the data. This analysis will involve coding the interview responses to identify key themes, such as technological limitations, regulatory hurdles, consumer resistance, and operational challenges. These themes will then be grouped into broader categories that align with the research questions. Through this process, the study will uncover critical insights into the barriers and opportunities for drone adoption.

The research aims to produce several key outcomes. First, it will identify the barriers preventing wider adoption of drone technology, including technical, regulatory, and societal

obstacles. Second, it will offer insights into potential collaborative efforts that could facilitate smoother integration of drones into commercial applications, such as partnerships between businesses, regulatory authorities, and educational institutions. Lastly, the study will provide practical recommendations for stakeholders, including policymakers, business leaders, and educators, to enhance the implementation and acceptance of drone technology in various industries. By addressing both theoretical and practical dimensions, this research will contribute valuable insights into the complex process of integrating drones into commercial use, especially in logistics, healthcare, and supply chain management.

3.2 Research design

This research adopts a qualitative approach using semi-structured interviews to explore the feasibility and obstacles of implementing drone technology in commercial use. Interview protocol is attached and can be refer to appendix 1.1. The study aims to provide in-depth insights into the practical, operational, and regulatory challenges that affect the integration of drones across various industries in commercial. By focusing on the perspectives of industry experts and consumers which are the main stakeholders in the drone ecosystem, this research seeks to gather diverse viewpoints that highlight both the potential and limitations of drone technology (Busetto et al., 2020).

Semi-structured interviews allow flexibility in responses, enabling participants to share their expertise, experiences, and perceptions in detail. This design explores several key areas, including technological feasibility, which examines current advancements in drones and their readiness for large-scale commercial deployment. It also delves into operational efficiency, understanding the practical challenges involved in integrating drones into logistics and other business operations. Additionally, it addresses regulatory challenges by investigating the legal and policy barriers that may impact the widespread adoption of drone technology.

Asides, this research also focuses on public perception and acceptance by gathering consumer feedback to assess how drones are viewed in logistics and other commercial sectors. Furthermore, educational and skill barriers are examined to understand how drone academies are preparing personnel and addressing skill gaps in the industry.

Through this qualitative research design, this study seeks to provide comprehensive insights and potential solutions to mitigate obstacles to drone implementation. The semi-structured interviews with key stakeholders are intended to identify critical factors that influence the feasibility and success of drone applications in commercial use (Tomaszewski et al., 2020).

3.3 Operational Definition

In this research, several key concepts are defined to ensure clarity and consistency in the analysis of drone technology implementation in commercial applications.

Concepts	Definition
Drone technology	Defined as unmanned aerial vehicles (UAVs) equipped with various sensors, cameras, and navigation systems used for tasks such as delivery, inspection, and data collection in commercial contexts. (Siju et al., 2022)
Technical capabilities	Refer to the specific characteristics of drones, including payload capacity (the maximum weight a drone can carry), battery life (the duration a drone can operate on a single charge), and navigation systems (technologies enabling autonomous positioning and navigation).
Operational efficiency	Characterized as the effectiveness of an organization in utilizing its resources to achieve maximum output with minimal waste, particularly in relation to time, cost, and productivity improvements that result from integrating drone technology.
Public perception	Includes the collective beliefs, attitudes, and evaluations held by consumers regarding drone technology, addressing aspects such as safety, reliability, environmental impact, and overall acceptance of drone services within the logistics sector.
Consumer acceptance	Described as the willingness of individuals or businesses to adopt and utilize drone technology, influenced by their perceptions, experiences, and understanding of its benefits and drawbacks.

Table 3.1: Key concepts operational definitions

These operational definitions will guide the qualitative interviews and analyses conducted in this research, ensuring that key concepts are consistently applied and comprehensively understood.

3.4 Measurement of Variables/Instrumentation

In this research, variables will be assessed through qualitative interviews designed to gather detailed insights from key stakeholders regarding the implementation of drone technology in commercial applications. The primary variables of interest include technical feasibility, operational efficiency, public perception, and consumer acceptance.

Technical feasibility will measure by exploring the specific capabilities of drones, such as payload capacity, battery life, and navigation systems. Interview questions directed at industry experts and personnel from drone academies will aim to evaluate how these technical aspects influence the adoption of drone technology.

Operational efficiency will examine by interview stakeholders about the perceived impact of drone technology on logistics and delivery services. Industry experts will be prompted to share their experiences regarding efficiency improvements.

As for public perception, the interviews will focus on understanding consumer attitudes toward drone technology, especially regarding safety, reliability, and environmental impact. Feedback will be collected from consumers who have interacted with drone services, as well as those who have yet to adopt these technologies, providing a comprehensive view of societal attitudes.

Lastly, consumer acceptance will measure by assessing the willingness of consumers to adopt drone services. Interview questions will explore barriers to acceptance, such as a lack of awareness or understanding of drone technology, as well as factors that could enhance acceptance, like perceived benefits and positive experiences with drone services.

The data collection instrument will consist of semi-structured interview guides tailored to each stakeholder group, ensuring that key themes are explored while allowing flexibility in responses. This qualitative approach will provide a rich dataset that captures the different perspectives of participants which aim to facilitate a deeper understanding of the feasibility and obstacles associated with drone technology in commercial use.

3.5 Data Collection

In qualitative research, the process of data collection is essential for obtaining in-depth insights and a deeper understanding for the research. For this research, qualitative interviews will be the primary method for gathering data, focusing on stakeholders experiences, perceptions, and challenges related to the integration of drone technology in various industries.

Primary data will be collected through semi-structured interviews with key stakeholders, including industry experts and consumers. Industry experts will provide insights into technical, regulatory, and operational aspects of drone technology. These interviews will be designed to be open-ended, allowing participants to discuss their experiences and opinions in detail, while also addressing specific research objectives related to the feasibility and challenges of implementing drone technology.

After selecting the interview participants for this research, a structured set of interview questions was developed to explore the challenges associated with implementing drone technology in commercial sectors. These interviews targeted essential stakeholders, including drone industry experts and consumers, each providing unique perspectives on drone usage in logistics and other commercial applications. The questions aimed to investigate the feasibility of drone adoption, the barriers faced by various stakeholders, and the potential benefits drones could offer across different industries.

The interview guide was organized into six main sections: participant background, current feasibility of drone adoption in commercial, the impact on operational efficiency after drone adoption and participants outlook and recommendations for better integration of drones into commercial settings.

Each interview lasted approximately one hour, with responses recorded either via audio or in written format. This approach was designed to obtain detailed and comprehensive information from participants to understand more about the challenges and opportunities related to drone technology adoption especially in the context of its commercial application. The conversational nature of the interviews allowed for a rich, participant-centered exploration of the topic, while still maintaining a structured approach to ensure consistency in data collection.

3.6 Sampling

In this research, a qualitative approach will be employed to gather in-depth insights from a purposeful sample of stakeholders which involved in the implementation of drone technology in commercial applications. This sample include industry experts and consumers. The purposive sampling method ensures that participants are selected based on their relevant knowledge and experience, allowing for a richer understanding of the perceptions, challenges, and opportunities related to drone technology.

The main informant in this research is from Respondent 1 which is specialist in drone technology and had adopted drone into business application. Asides, Respondent 4 which currently pursuing P.H.D in supply chain management also provide details and rich insights from academic perspectives in drone implementation in logistics. Furthermore, Respondent 7 who work as 3PL specialist involved in last-mile delivery management aids in offer practical, operational insights into drone optimization delivery processes, particularly in e-commerce logistics.

Whereas, for Respondent 2 and 3, aids in provide insights from consumer and business application user perspectives. They offer insights into the consumer-facing aspects of drone technology, particularly in terms of product positioning, market demand, and consumer perception of drone-based solutions. It also focuses on product development and market fit. Their perspective is valuable for understanding how drone technologies can be integrated into new products and solutions in logistics and beyond.

As for Respondent 5 as finance specialist, it helps to evaluates the economic feasibility of drone integration, analyzing costs, budgeting, and financial implications for businesses considering drone adoption. Whiles Respondent 6 as procurement specialist able to provide insights in manages the sourcing and purchasing of drone technologies and related components, providing practical insights into the logistical and financial aspects of drone acquisition.

By focusing on these key stakeholders, the research aims to capture diverse perspectives that highlight both the potential and limitations of drone applications. This qualitative approach facilitates detailed discussions, enabling participants to share their experiences and opinions, which will enhance the depth and richness of the data collected. This method will provide opinions in different perspectives which allows for a more analysis of the feasibility and obstacles associated with drone technology in commercial use by reflecting the complexities of stakeholder perspectives in this emerging field.

3.7 Techniques of Data Analysis

In this research, qualitative data analysis will be employed to interpret and derive insights from the data collected during interviews with industry experts and consumers. The qualitative approach focuses on identifying themes, patterns, and key insights that emerge from participants experiences, opinions, and knowledge.

The main analysis technique will be thematic analysis as the primary method to analyze interviews data which involves coding the qualitative data to identify recurring themes, patterns, or feasibility of drone technology implementation, its challenges, and potential solutions. The process begins with familiarization with the data, which involves transcribing interviews and thoroughly which recording in words or audio. Next, coding is needed to label specific segments of data that relevance to the research objectives. These codes may address various aspects, such as technical, regulatory, and operational challenges, as well as public perceptions and collaborative efforts.

Once coding is complete, similar codes are grouped together to form broader themes. The identified themes are then reviewed and refined by cross-checking them against the raw data to ensure they accurately reflect the dataset and align with the research questions. After each theme is clearly defined and named for reporting purposes, it will facilitate a structured presentation of the findings.

Content analysis will complement thematic analysis by systematically organizing the data into categories based on predefined or emergent codes. This method involves quantifying the frequency of specific words, phrases, or ideas within the interview responses. By combining thematic and content analysis, the research can provide a richer understanding of the data, highlighting both the qualitative themes and the quantitative trends present in the respondents feedback. Chapter 4: Data analysis and findings

CHAPTER 4: DATA ANALYSIS AND FINDINGS

4.0 Introduction

This chapter includes the analysis of the data collected from interviews with various stakeholders and the insights gained regarding the feasibility and obstacles of implementing drone technology in commercial use. The analysis addresses the primary research objectives by examining the technical, regulatory, and operational challenges faced in drone integration within commercial sectors. This chapter also discusses the role of collaborative initiatives among stakeholders in the drone ecosystem to overcome these barriers. The highlighted key findings offer a comprehensive understanding of the current state of drone adoption in commercial sectors, along with future possibilities and potential for broader adoption. Additionally, this chapter provides a detailed breakdown of the findings, organized directly in response to the research objectives, ensuring clarity and alignment with the study's goals.

4.1 Profile of Respondents

The primary data was collected using interviews method for quantitative methodology to gather information and insights for this research paper. Total of 8 interviewees from various industries was involved to gather insights for this topic. Interview questions was distributed to interviewees before the interview session to allow participants to prepare and gather any necessary information to contribute effectively to the discussions. The interviews sessions were conducted from 23 Oct 2024 to 3 Nov 2024, around one hour for each session to cover three main sessions.

Table 4.1 illustrates the profile and background of each respondent. These individuals were selected based on their relevant work experience to ensure their insights would be highly pertinent to the study objectives. All the respondents play significant roles within the drone and commercial ecosystem, and their insights provide a well-rounded understanding of drone application in Malaysia. The diverse backgrounds of these respondents played different role in supply chain which include individuals from finance and procurement departments, who offer a perspective on cost control and organizational preferences regarding drone adoption. Marketing and product managers contribute insights on the potential benefits of drone technology and consumer preferences. Logistics specialists provide valuable information on how drones could enhance last-mile delivery processes. Technical experts in the drone field offer insights into technical capabilities and solutions to overcome current barriers.

Additionally, a respondent with a Ph.D. in supply chain management offers an academic perspective, adding depth from an educational and knowledge-based standpoint.

The information gathered from these interviews provides a comprehensive view of the current state, challenges, and potential for drone technology in commercial applications. Insights from finance and procurement professionals highlight the economic considerations involved in adopting drones, including cost-benefit analyses, budgeting, and financial implications. These insights help in understanding organizational preferences and investment decisions. Marketing and product managers have provided perspectives on consumer demand and market needs, illustrating how drones could enhance customer experiences and increase competitiveness, while also identifying potential benefits valued by businesses and consumers alike. Specialists from logistics have contributed valuable insights on the operational impact of drones, especially in last-mile delivery, outlining potential efficiency gains, logistical challenges, and necessary adjustments for incorporating drones within existing supply chains. Technical experts have shared details on the current capabilities of drones, covering aspects such as battery life, navigation, payload capacity, and safety features, while also identifying key technical barriers and potential solutions to improve reliability and functionality. Additionally, the academic perspective from a Ph.D. in supply chain management brings a broad understanding of both theoretical and practical implications, supporting strategic insights essential for creating a model that leverages drone technology effectively within the supply chain. Together, these perspectives offer a holistic understanding of drone application in commercial sectors and the steps needed for successful integration.

Table 4.1 provides a summary and overviews of respondents including their age group, role and responsibilities in their working positions. The various stakeholders in supply chain will be able to provide deeper insights and ensure the data collected reflect the current state of drone ecosystem in Malaysia. To maintain confidentiality and anonymity, the respondents were assigned codes (R1, R2, R3, R4, R5, R6, R7, R8) in place of their names.

Respondents	Age group	Role	Responsibilities
Respondent 1 (R1)	30-40	Drone technical experts	Specialist in drone technology and operations.
Respondent 2 (R2)	20-30	Marketing manager	Develops marketing strategies for products.
Respondent 3 (R3)	20-30	Product manager	Oversees product development and market fit.
Respondent 4 (R4)	30-40	Product manager	Oversees product development and market fit.
Respondent 5 (R5)	20-30	Finance specialist	Analyses financial viability and budgeting control
Respondent 6 (R6)	30-40	Procurement specialist	Manages sourcing and purchasing.
Respondent 7 (R7)	20-30	3PL specialist	Last mile deliveries management
Respondent 8 (R8)	30-40	P.H.D students in supply chain management	Researcher exploring new technologies impact on supply chains.

Table 4.1 Profile of Respondents

4.2 Data Analysis and Findings

The interviews questions were divided into three main sessions to further drill down the information according to research objectives. The sessions include the examinations of obstacles that hinder the widespread adoption of drone technology in commercial applications in Malaysia, the collaborative initiatives between stakeholders in the industry and the impact of the collaboration in overcome and develop a model of collaborative initiative on the integration of drone technology. The sessions and sub-questions involved will showcase by using Thematic analysis by defining themes and sub-themes.

4.2.1 To identify the key factors focus in technical, regulatory, and operational barriers that impact on the adoption of drone technology in commercial applications in Malaysia.

The first objective of this paper is to investigate the key technical, regulatory, and operational barriers that impede the widespread implementation of drone technology in commercial applications within Malaysia. The respondents and stakeholders from various industries insights provided valuable perspectives on the challenges faced in the adoption of drone technology. Their collective experiences and viewpoints provided valuable perspectives on the multifaceted challenges faced in the adoption of drone technology.

Sub-questions of the sessions as below: -

1. What do you see as the biggest barriers to the widespread adoption of drones for commercial use in Malaysia?
2. How do you think current regulations affect the use of drones in commercial sectors? Are there any specific policies that create challenges?
3. From your perspective, what technical challenges (such as battery life, signal interference, etc.) limit the commercial use of drones?
4. What operational issues (e.g., safety, training, logistics) do you think hinder businesses or individuals from adopting drone technology?
5. How do you believe these obstacles could be overcome to promote more widespread drone use in Malaysia?

This analysis examines the current challenges facing the widespread adoption of drones for commercial use in Malaysia as identified by eight key respondents. In this sub chapter, the insights gathered focus on several key barriers such as regulatory and technical limitations, as

well as operational and integration issues between relevant departments. This analysis will delve into the obstacles mentioned by the respondents and explore the implications for the future adoption and integration of drone technology in commercial sectors.

For Objective one, a thematic analysis of the interview responses reveals the following themes related to the barriers to the widespread adoption of drone technology in Malaysia for commercial use. Most respondents had highlighted regulatory barriers as the main barriers for drone adoption in commercial application. R1, R2, R3, R4, R5 & R6 responses highlighted regulatory barriers which include unclear and complex regulations, as a significant obstacle. Concerns about safety, public acceptance, and potential risks associated with drone use in commercial sectors were also mentioned as key barriers.

Respondents expressed concern over the regulatory environment governing drone operations in Malaysia. They highlighted that current laws lack comprehensive regulations and policies, including licensing requirements, flight zone restrictions, and privacy considerations. The absence of clear guidelines creates uncertainties and complicates the safe and lawful integration of drones into commercial sectors. For instance, without well-defined licensing requirements, businesses may face difficulties in certifying operators, while uncertain flight zone restrictions can lead to operational constraints, especially in urban or sensitive areas. Privacy concerns was also highlighted by respondents as they felt that without stringent data protection policies, drone usage could lead to potential privacy breaches, impacting public acceptance and trust.

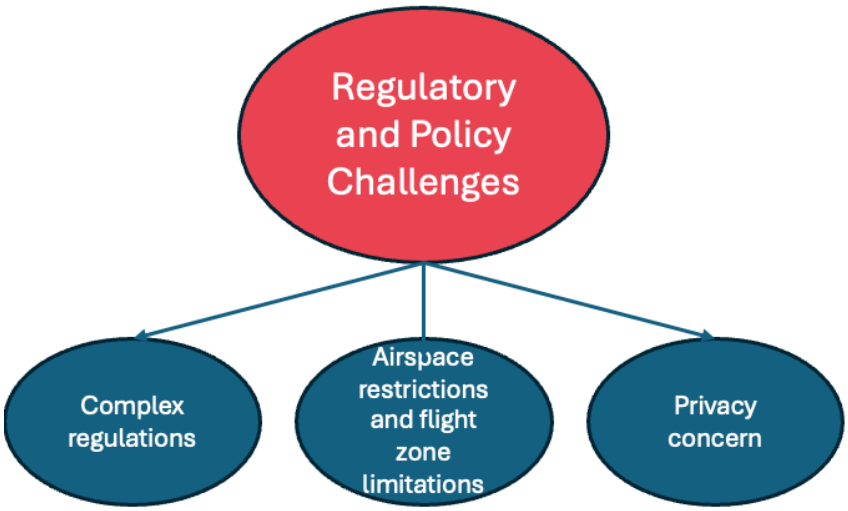

Figure 4.1: Regulatory and Policy Challenge of drone commercial applications in Malaysia

Theme	Sub-theme	Quote
Complex Regulations	Licensing Requirements and Regulatory Gaps	"The biggest barriers to the widespread adoption of drones for commercial use in Malaysia include regulatory restrictions, safety concerns, and maintenance costs." (R1)
		"Current laws and regulations significantly impact the use of drones, imposing stringent standards that may hinder adoption and restrict flexibility." (R2)
Airspace Restrictions	Flight Zone Limitations	"Drone operations are restricted by regulations, particularly in metropolitan areas, close to airports, and other restricted regions." (R3)
		"Specific policies, such as restrictions on flying overpopulated areas and the need for approval from multiple agencies, create challenges to widespread adaptation." (R4)
Privacy Concerns	Data Collection and Public Trust	"The commercial use of drones involves privacy considerations, especially when it comes to data collection, adding compliance requirements for businesses." (R5)
		"Public concerns around privacy and safety remain high, and raising awareness through campaigns could help address these issues." (R6)

Table 4.2: Thematic analysis of Regulatory and Policy Challenge of drone commercial applications in Malaysia

Asides, technical limitation was also highlighted as the key concerns by respondents. This section discusses about the specific technical challenges identified by the respondents such as battery life, signal interference, weather conditions, and the lack of automation in drone

operations. These highlighted factors will restrict drones performance, reliability, and scalability in various industries.

Battery life is a significant limitation for drones, especially in commercial applications where longer flight durations are often required. R1 & R3 mentioned that the current battery technology limits drones operational time will restricts on drone capacity to perform tasks over larger distances or prolonged periods. Additionally, the payload capacity, influenced by battery limitation, drones ability to carry essential equipment or cargo for commercial use will be affected.

Furthermore, Malaysia tropical climate which characterized by frequent rain, high humidity, and fluctuating temperatures. These specific weather-related challenges directly impacted on drone operations. R4 & R6 mentioned that drones are particularly vulnerable to adverse weather. This factor can lead to decreased stability, sensor malfunction, and even equipment damage for drone. Rain and high winds can significantly reduce a drone ability to operate safely, limiting the feasibility of outdoor applications.

Besides that, signal interference which include GPS disruptions and connectivity issues was also highlighted as a major operational challenge. In densely populated areas, or regions with high levels of electromagnetic interference, drones often face difficulties maintaining stable connections. This affects their ability to navigate accurately and could lead to disruptions or loss of control, which is particularly concerning for commercial applications requiring high reliability. R3, R5, R6 mentioned that the lack of comprehensive air-ground connection infrastructure such as signal towers and dedicated networks for drones was identified as a primary cause of signal interference in Malaysia. Without these structures, maintaining stable connections becomes difficult, especially in areas where existing networks are oversaturated or inadequate for drone operations.

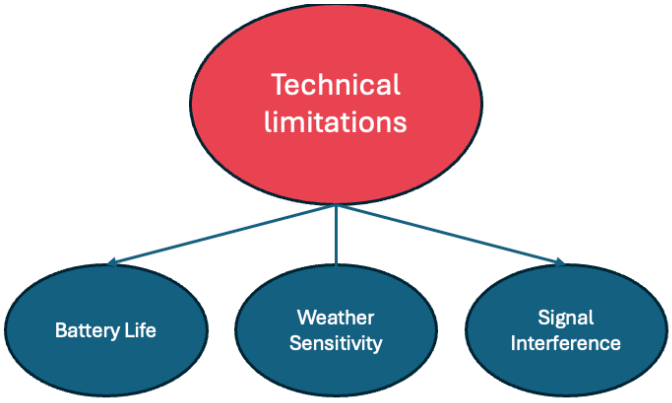

Figure 4.2: Technical limitations of drone commercial applications in Malaysia

Theme	Sub-theme	Quote
Technical Limitations	Battery Life	"The current battery technology limits drones' operational time, restricting their capacity to perform tasks over larger distances or prolonged periods." (R1, R3)
	Payload Capacity	"With limited battery capacity, drones struggle to carry essential equipment or cargo, impacting their effectiveness for commercial use." (R1, R3)
	Weather Conditions	"Malaysia's tropical climate, with frequent rain and high humidity, affects drone stability and can lead to sensor malfunctions and equipment damage." (R4, R6)
		"Drones are particularly vulnerable to adverse weather; rain and high winds significantly reduce their ability to operate safely, which limits their feasibility for outdoor applications." (R4, R6)
	Signal Interference	"In densely populated areas or regions with high electromagnetic interference, drones struggle to maintain stable connections, affecting navigation accuracy and potentially leading to loss of control." (R3, R5, R6)

Theme	Sub-theme	Quote
Infrastructure Challenges	Lack of Air-Ground Connectivity	"The lack of air-ground infrastructure, like signal towers and dedicated networks, leads to GPS disruptions and connectivity issues, especially in urban environments." (R3, R5, R6)
		"Malaysia currently lacks comprehensive infrastructure for stable drone connectivity, which limits commercial applications that demand high reliability." (R3, R6)

Table 4.3: Thematic analysis of technical limitations of drone commercial applications in Malaysia

Besides that, in this data analysis, impact of technological, regulatory, and air-ground infrastructure barriers on operational barriers were also identified as significant barrier for drone widespread. These interrelated barriers influence the smooth integration of drones into existing business systems and logistics networks, leading to significant operational hurdles.

The respondents emphasized the need for skilled operators and the associated training costs. The complexity of integrating drones into existing logistics and business systems such as inventory management and delivery networks are also seen as a challenge. Safety concerns particularly the risk of malfunctions and collisions, further complicate the adoption of drone technology. Additionally, the high initial investment and maintenance costs of drone fleets make it difficult for many businesses to justify widespread adoption.

R2, R4, & R6 emphasized that the process of integrating drones into existing logistics, inventory management, and business systems posed significant challenges. They mentioned that without tailored solutions, drones could disrupt the current workflows rather than enhance efficiency. This feedback highlights the importance of a thorough operational analysis prior to drone implementation. Businesses may need customized solutions to bridge the gap between traditional logistics processes and drone-enabled workflows. In the absence of such adjustments, businesses could face disruption rather than enhancement, a risk that is particularly pronounced in sectors with tightly controlled inventory and logistics operations.

On the other hand, R1, R3, & R5 had also pointed to safety issues as a major hurdle, specifically noting concerns around potential malfunctions and the risk of collisions. These concerns were

heightened in environments where drones would operate in close proximity to people or sensitive infrastructure, which necessitates stringent risk management. The emphasis on safety from these respondents illustrated in commercial applications, risk management and technological reliability is the most important part that cannot be avoided. Businesses may need to invest in more advanced drones with enhanced safety features or create rigorous training programs to mitigate risks. Additionally, compliance with regulatory standards regarding drone safety may introduce further complexity and require firms to implement detailed safety protocols.

One of the primary barriers noted by respondents R2, R4, and R5 is the high financial burden associated with drone adoption. The significant initial investment in acquiring drone fleets and the continuous costs for maintenance make it challenging for businesses to justify the ROI, particularly if the drones are not expected to generate immediate or substantial cost savings. Given that drone technology is still evolving, businesses may also need to upgrade their fleets periodically, further adding to the financial strain. These financial concerns underline the need for a detailed cost-benefit analysis before investment. For businesses considering drone adoption, it may be beneficial to adopt a phased implementation approach, starting with pilot programs that allow them to assess the ROI before committing to a large-scale investment. Alternatively, leasing drones or collaborating with third-party drone service providers could reduce the financial burden and allow businesses to benefit from the latest technology without the high upfront costs.

Figure 4.3: Operational challenges of drone commercial applications in Malaysia

Theme	Sub-theme	Quote
Operational Challenges	Need for Skilled Operators	"The need for skilled operators and the cost of training are significant barriers to drone adoption in commercial settings." (R1, R4)
	Integration with Business Systems	"Integrating drones into current logistics and business systems, such as inventory management and delivery networks, presents substantial challenges." (R2, R5)
	Safety Concerns (Malfunctions & Collisions)	"Safety is a major concern, especially the risk of drone malfunctions and potential collisions, which complicates the adoption process." (R3, R6)
	High Initial Investment and Maintenance Costs	"The high initial investment required for drone fleets, along with ongoing maintenance expenses, makes it difficult for many businesses to justify their widespread adoption." (R1, R3)

Table 4.4: Thematic analysis of operational challenges of drone commercial applications in Malaysia

4.2.2 To explore the collaborative initiatives between stakeholders in the industry due to overcome obstacles and facilitating a smoother integration of drone technology.

The second section of this study focuses on evaluating the impact of collaborative initiatives between stakeholders aimed at overcoming barriers and enabling the seamless integration of drone technology into various industries. By identifying and analyzing these collaborative efforts, this section seeks to understand their effectiveness in addressing challenges and promoting widespread adoption of drones. Case studies from other countries are included to

provide comparative insights and demonstrate successful examples of overcoming industry-specific barriers.

The discussion is framed by the following sub-questions:

1. Have you seen any examples of collaboration between businesses, government, or technology providers to improve the integration of drones in commercial activities?
2. How effective do you think these collaborations have been in overcoming the challenges faced by the drone industry?
3. In what ways do you believe partnerships between stakeholders can make drone technology more accessible and beneficial for businesses and consumers alike?
4. What role do you think collaborative efforts should play in improving the regulations, technology, or operational around drone usage?
5. How could further collaboration between industry stakeholders help accelerate the adoption of drone technology in commercial applications?

This section analyzes and examines how collaborative efforts among industry stakeholders such as government, private companies, and technology providers influence drone industry in Malaysia, particularly in overcoming regulatory, operational, and technological challenges. Based on respondent feedback, the analysis focus on key collaborative initiatives, their effectiveness, and the potential for accelerating drone adoption through enhanced partnerships.

R1 & R2 respondent had highlighted the efforts of stakeholder analysis that carried out in Malaysia to improve the development of drone system such as National Technology and Innovation Sandbox (NTIS). NTIS is forum for public-private collaboration where drone technology is tested, addressing regulatory and operational challenges specific to Malaysia. This is an initiative that carried out by AirAsia and Malaysian Global Innovation & Creativity (MaGIC) supported by Civil Aviation Authority of Malaysia (CAAM) which aim to encourage the overall drone ecosystem development in Malaysia. Drone demonstration and delivery flight test was carried out in Cyberjaya during the event organized by NTIS in 2021. R2 believed that NTIS will helps drone system to overcome logistical and regulatory obstacles by allowing them to test ideas in a controlled setting, which usually prevents commercial deployment.

Asides, respondents highlighted partnerships between drone companies and logistics providers is also playing crucial roles in enhance overall drone ecosystem development in Malaysia. R1, R2 & R3 believe that collaborative initiative from drone key players for safety and testing initiatives such as designated test sites and collision avoidance systems are crucial for building

public trust and promoting safety. For instance, Singapore UAS framework has set a standard that could influence Malaysia and nearby nations by creating safety norms that might enhance public acceptance. For instance, R3 had top up on successful case study in China and referenced this as an international example where collaboration in logistics could serve as a model for Malaysia. They highlighted how Fengyi UAV operates logistics networks in rural regions, providing insights on partnerships potential impact on agriculture and logistics. Respondents recognized that resource-sharing partnerships among manufacturers, service providers, and logistics companies reduce costs and make drone technology more accessible for businesses, especially SMEs.

Other than that, current drone systems in highly applicable and common use in specific industries. R2, R3, R5 &R6 noted that collaborations have been particularly successful in industries such as agriculture and disaster relief. In worldwide, drones are commonly used for precision farming, flood monitoring, and post-disaster assessments. Partnerships in these sectors show the operational efficiency drones can bring but suggest a need for broader application, such as in logistics and construction.

R5 highlighted the effectiveness of drones in disaster-prone regions, especially for monitoring floods and assessing damage. During flooding, drones can quickly survey large areas, providing real-time data to emergency responders, who can then allocate resources more efficiently. R3 noted that partnerships between government agencies and drone operators have facilitated quicker response times and improved coordination in emergency response efforts. Collaborative efforts with organizations like the Red Cross, as R3 noted, have been instrumental in integrating drones into emergency response strategies. These partnerships illustrate the practical benefits of drones in humanitarian work, reinforcing public trust and highlighting their value in critical, life-saving applications. In farming, R2 & R3 mentioned the use of drones in agriculture, especially for precision farming, has proven to be highly efficient. Drones equipped with multispectral and thermal sensors can capture detailed images of crop health, soil conditions, and pest infestations. R5 observed that partnerships with agricultural research organizations have allowed farmers to gather critical data, leading to better decision-making and crop management practices. Respondents noted that drones contribute to cost reduction by minimizing the need for extensive labour and enabling targeted applications of water, fertilizers, and pesticides. R6 emphasized that these collaborations allow for a more sustainable approach to agriculture by optimizing resources, reducing environmental impact, and increasing yields.

R2, R3, and R6 acknowledged that while drone use in logistics is still in its early stages, there is strong potential for expansion. Last-mile delivery, especially in rural or difficult-to-access areas, has seen some success through pilot programs in collaboration with logistics companies and government agencies. R3 suggested that broader adoption of drones for delivery could significantly reduce costs, emissions, and delivery times. Despite the potential, R5 observed that deploying drones in densely populated areas presents challenges, including regulatory hurdles, noise concerns, and safety issues. Hence, the collaborations with urban planners and regulators could help develop drone traffic management systems and address community concerns. Respondents noted that collaborative efforts could streamline regulatory approvals, especially for commercial use, which could accelerate the deployment of drone in commercial application. There was a consensus that partnerships between companies, regulatory bodies, and legal experts are essential in creating sector-specific regulations and streamlined approval processes. This can reduce time to market, making drones more accessible for industries. However, respondents emphasized that regulatory challenges remain a major obstacle, requiring more structured and flexible policies to support rapid technological growth.

Other than that, thematic analysis of the respondent feedback reveals a strong consensus on the importance of collaboration and standardization within the drone industry. Respondents emphasized that establishing industry-wide standards is essential for ensuring the safety and reliability of drone operations, which in turn can help build public trust and streamline regulatory approvals. This view was notably shared by R2 and R4, who pointed out that standardization would promote consistent safety practices, thereby mitigating the risks associated with drone usage across various sectors. Additionally, resource-sharing partnerships were identified by respondents R4 and R6 as a strategic way to lower costs, particularly for small and medium-sized enterprises (SMEs) that may find the cost of entry to drone technology prohibitive. By pooling resources, SMEs could access shared drone fleets and infrastructure, enabling a broader range of industries to adopt drones without the burden of high initial investments.

Knowledge-sharing also emerged as a pivotal theme, with respondents like R2 and R5 noting that collaborative learning across companies can accelerate the adoption of best practices, thereby strengthening the entire ecosystem. Knowledge-sharing initiatives allow businesses to better understand the operational nuances of drones, reducing the learning curve and enhancing service consistency, which ultimately improves consumer satisfaction. Furthermore, bridging the gap between technical capabilities and operational requirements was seen as an area where

collaboration could have a significant impact. R3 and R6 expressed that while drones possess impressive technological capabilities, their effectiveness can be limited if they do not meet specific industry needs. A coordinated approach involving government, industry, and technology providers could help align drone functionalities with operational requirements, fostering a more tailored and effective application of drones across sectors. R6 highlighted that shared resources would allow smaller businesses to participate in drone applications without needing to own or maintain expensive equipment, making drones a viable option for a wider range of industries. This accessibility could lead to greater experimentation and innovation in drone applications across diverse sectors, accelerating the overall industry growth and adoption.

R5 mentioned that the standardization is interconnected with the streamline of regulatory processes by demonstrating a proactive industry commitment to safety. With clear standards, government agencies and regulatory bodies would be more inclined to grant operational permissions, knowing that drones are operated under strict, consistent guidelines. R6 added that regulatory bodies might even consider developing incentives or "fast-track" approvals for companies adhering to these standards, encouraging wider adoption across industries.

Theme	Sub-theme	Quote
Collaboration	Public-private partnerships	"NTIS is a forum for public-private collaboration where drone technology is tested, addressing regulatory and operational challenges specific to Malaysia." (R1, R2)
	Industry partnerships	"Partnerships between drone companies and logistics providers play crucial roles in enhancing the overall drone ecosystem development in Malaysia." (R1, R2, R3)
	Knowledge-sharing and resource-sharing	"Knowledge-sharing initiatives across companies can accelerate the adoption of best practices." (R2, R5)

Theme	Sub-theme	Quote
	Collaborative learning	"Collaborative learning across companies can strengthen the entire ecosystem." (R2, R5)
Technology and Innovation	Technological advancements	"Drone systems have been effective in precision farming and disaster relief, bringing operational efficiency." (R2, R3, R5, R6)
	Bridging technical and operational gaps	"A coordinated approach involving government, industry, and technology providers could help align drone functionalities with operational requirements." (R3, R6)
Regulation and Standardization	Regulatory challenges and solutions	"Regulatory challenges remain a major obstacle, requiring more structured and flexible policies to support rapid technological growth." (R5)
	Standardization and safety	"Establishing industry-wide standards is essential for ensuring the safety and reliability of drone operations." (R2, R4)
	Streamlined regulatory approval	"Partnerships between companies, regulatory bodies, and legal experts are essential in creating sector-specific regulations and streamlined approval processes." (R3)
Cost and Accessibility	Cost reduction and resource sharing	"Resource-sharing partnerships reduce costs, making drone technology more accessible for SMEs." (R4, R6)
	Lowering barriers for SMEs	"SMEs could access shared drone fleets and infrastructure, enabling a broader range of industries to adopt drones without high initial investments." (R4, R6)

Theme	Sub-theme	Quote
Operational Efficiency	Drone applications in agriculture and logistics	"Drones have proven to be efficient in precision farming, flood monitoring, and post-disaster assessments." (R2, R3, R5, R6)
Operational Efficiency	Disaster response and humanitarian work	"Collaborations with organizations like the Red Cross have been instrumental in integrating drones into emergency response strategies." (R3)
	Last-mile delivery and logistics	"Last-mile delivery in rural areas has seen success through pilot programs with logistics companies and government agencies." (R2, R3, R6)
Public Trust and Safety	Building public trust	"Collaborative initiatives for safety and testing, such as designated test sites and collision avoidance systems, are crucial for building public trust." (R1, R2, R3)
	Addressing community concerns	"Collaborations with urban planners and regulators could help develop drone traffic management systems and address community concerns." (R5)

Table 4.5: Thematic analysis of the impact of collaborative initiatives between stakeholders in the industry due to overcome obstacles and facilitating a smoother integration of drone technology

4.2.3 To develop a model of collaborative initiative on the integration of drone technology.

The third session of the interview is to develop a model for collaborative initiatives aimed at the integration of drone technology. This section of the interview focuses on understanding the various components necessary for successful collaboration among stakeholders in the drone industry. This session covered the essential elements which need to be included in model development.

1. What key components do you believe should be included in a model that supports the integration of drones into commercial industries?
2. How can various stakeholders (e.g., government, businesses, consumers) collaborate more effectively to ensure the successful integration of drone technology?
3. What are the most important factors to consider when building a system that encourages collaboration and facilitates the smooth adoption of drones in commercial settings?
4. How should consumer concerns or feedback be integrated into a model for drone technology development and usage?
5. What kind of industry standards or best practices would you recommend as part of a collaborative model for integrating drone technology into commercial sectors?
6. What future strategies or initiatives do you believe are necessary to ensure long-term collaboration and successful scaling of drone technology across various commercial sectors in Malaysia?

Stakeholder roles and responsibilities emerged as a main theme in this session. Respondents had emphasized the need for clear definitions of each party role in the whole ecosystem, from regulatory bodies and industry leaders to technology developers and operators. Clear role definitions are seen as essential for ensuring smooth operation and accountability among all parties involved.

R1 emphasized that clarity in defining roles is crucial for maintaining accountability within the ecosystem. According to R1, without a well-structured model outlining the responsibilities of each party, it would be difficult to track performance or assign responsibility in case of issues. This could lead to confusion or inefficiency in operations, particularly in complex applications like logistics or agriculture, where multiple stakeholders are involved. R3 expanded on this by highlighting the importance of role clarity in preventing operational overlap. In cross-sector applications, such as logistics and agriculture, different stakeholders ranging from regulatory bodies to technology developers may be involved in various capacities. R3 pointed out that without clearly defined roles, there is a risk of duplicating efforts or having gaps in responsibility, leading to inefficiencies and even safety concerns.

Respondents reinforced the need for proper role assignment as absence of clear roles definitions, stakeholders may vaguely assume overlapping tasks or responsibilities, which will hinder the collaborative nature of drone applications. They stressed that defining each role precisely

ensures smoother workflows and minimizes friction in multi-stakeholder environments. R5 and R6 further elaborated on the point by suggesting that the complexity of drone applications necessitates clear role allocation to ensure that each party understands its scope of work, especially as technologies and real case study evolve. Respondents mentioned that this clarity should be reflected not only in technical and operational roles but also in legal and regulatory frameworks. As drone technology continues to advance, they emphasized that clear definitions help ensure compliance with laws and regulations, reduce disputes, and foster a sense of trust among stakeholders.

Asides, R2 and R5 emphasized that interoperability and technology standards are fundamental to creating a model for effective drone technology integration. R2 highlighted the importance of shared technical standards for seamless integration will allow various systems and drones to operate compatibly. For instance, in practical situation, drones from different manufacturers, operating under diverse conditions will still be able to coordinate smoothly in shared airspaces or within cross-industry operations like logistics, emergency response, or agriculture. R2 underscored that without these shared standards, integrating drone technology would be chaotic, as varying technologies would struggle to communicate or align with one another.

R5 added that standardization is not just about compatibility, it will also impact to overall drone efficiency and reliability performance. By setting consistent data protocols, communication systems and airspace management technologies, model would minimize technical incompatibility issues, streamlining operations and reducing the likelihood of errors or disruptions. For instance, standardized data protocols mean that data collected and shared between drones and ground systems would be in a uniform format, making it easier to analyze. Communication system standards ensure that drones can reliably interact with control stations or other drones, which is crucial for safe and efficient airspace navigation.

Both respondents highlighted that technology standardization is deeply interlinked with regulatory compliance and approval. Since the drone industry in Malaysia is still evolving, regulatory bodies are working to keep pace with technological developments. By establishing interoperability standards, the model would not only support technological integration but also ease the regulatory approval process. Standardized protocols and systems allow regulators to define and enforce clear compliance benchmarks, which in turn streamlines the certification process for new drones or operational models. R2 and R5 suggested that collaborative efforts

to define and align these standards early on could significantly facilitate regulatory compliance and expedite approvals and accelerate adoption of drone technology in commercial application.

Moreover, R2 and R5 noted that establishing common standards would promote knowledge sharing among stakeholders. As best practices and technological insights are exchanged, the industry can collectively improve on and innovate around these standards, creating a continuous cycle of improvement. They emphasized that interoperability would not only solve immediate operational challenges but would also support long-term scalability and sustainability in drone operations across different industries.

Furthermore, resource allocation and funding mechanisms were also discussed by respondents. Respondents emphasize the need for a sustainable and balanced approach to distributing resources across collaborative drone projects. As drone technology continues to evolve, the allocation of resources becomes increasingly critical in ensuring that initiatives are not only financially viable but also equitable and sustainable in the long term.

For instance, respondents pointed out that network infrastructure development, especially for air-ground connectivity which require huge investment from various stakeholders especially from government. R1 and R2 noted that this development involves a significant amount of capital, which might be beyond the capacity of any single entity. Hence, they highlighted the importance of public-private partnerships (PPPs) to share the financial burden. The government would need to allocate appropriate funding for infrastructure projects, especially considering the large-scale investments required for building networks that can support seamless air-ground connections, which are fundamental for the success of drone technology in sectors like logistics, agriculture, and urban planning. R3 elaborated on the challenges faced by governments in funding such projects as the costs involved are often high due to the complex infrastructure required, such as communication networks, maintenance systems, and regulatory frameworks. As these networks play a pivotal role in ensuring reliable drone operations, consistent financial considerations are necessary from both the public and private sectors to keep pace with the rapid development of drone technology. Without such sustainable funding, the infrastructure might fail to meet the growing demands of drone applications, potentially stalling progress. For example, Malaysia stakeholders which include government and network players such as Maxis had collaborated with Huawei in the construction of Malaysia 5G network. This 5G network will be a critical part of Malaysia communications infrastructure and development

plan as it will help meet the growing demand for broadband and attract more investments to make Malaysia a competitive digital economy.

Besides that, respondents consistently emphasized that safety protocols as the most important elements to include in the model to ensure the safe operation of drones, particularly as the technology continues to scale for commercial and industrial use. They underscored the importance of pre-flight checks, height restrictions, and clearly defined operational guidelines to minimize the risks associated with drone flights. These protocols are seen as crucial to maintain operational integrity across various drone applications, from logistics to agriculture, and particularly in urban settings where drone traffic may increase.

A key concern raised by respondents was the safety of small drones, which are often constrained by flight permissions that limit their altitude and operational range. R2 pointed out that despite their smaller size, these drones still face potential risks, especially in densely populated areas. Therefore, establishing clear safety standards for their operation is critical to ensure that these devices don't pose hazards to public safety or existing air traffic systems.

For larger commercial drones, the necessity of risk management protocols was highlighted as particularly crucial. These drones typically carry heavier payloads and operate at higher altitudes, which could lead to more severe consequences in the event of malfunctions or accidents. Respondents stated that as commercial drone usage expands, risk management must evolve to address both operational risks and external factors, such as weather conditions and technical failures.

Respondents emphasized the critical role of regulatory bodies in promoting effective drone safety protocols. R3 referenced a significant incident in September 2024 at Tianjin Binhai International Airport in China, where drone interference disrupted airport operations. The intrusion of drones into flight paths and unauthorized entry into restricted airport areas led to the delay of 29 flights, eight cancellations, and the rerouting of 32 planes to other airports. As a result, more than 3,000 passengers were affected by this security breach, highlighting the urgent need for strict regulations to prevent such occurrences and ensure the safe integration of drones into airspace. Unauthorized drone flights near airports or restricted areas have already led to disruptions in critical services. These disruptions not only jeopardize public safety but also undermine trust in the technology. These incidents stressing the need for stringent safety and security protocols.

Furthermore, respondents underscored the critical role of education and training initiatives in developing a capable workforce that can effectively manage and operate drone technologies. As the drone industry evolve, the complexity of drone systems and the diversity of their applications require for more specialized knowledge and expertise.

R1 stressed the need for joint training programs and certification courses, particularly those that focus on the technical skills required for drone operation. These programs should not only address the mechanical and technological aspects of drones but also the safety protocols and compliance standards necessary for safe and lawful operations. According to R1, these programs will ensure that personnel are well-equipped to navigate the evolving landscape of drone technology and can perform their roles effectively across different sectors.

In addition to technical skills, R6 emphasized the importance of promoting cross-sector understanding. By offering training that bridges gaps between different industries such as logistics, agriculture, and emergency services, it is possible to establish uniform operational standards across these sectors. R6 stated that a consistent set of standards will facilitate smoother collaboration and ensure that drone technologies are used efficiently and safely across various domains. For example, a drone operator in agriculture may encounter similar safety guidelines and operational procedures as those working in logistics. R6 mentioned that cross-sector training, will help to standardize safety and regulatory practices and foster a harmonized approach to drone technology across industries.

Lastly, public engagement and communication were highlighted as crucial elements in fostering societal acceptance of drone technologies. As drones become more integrated into daily life, it is important for the public to understand both the benefits and safety measures associated with their use to minimize concerns and build trust.

R7 suggested that efforts should be made to educate the public about the positive impacts of drone technology, such as its potential to improve efficiency in sectors like logistics, agriculture, and emergency response. R7 emphasized that education about the safety measures such as drone regulation and operational restrictions will help to alleviate public concerns and create a more informed and supportive public.

On the other hand, R8 recommended that proactive communication strategies be employed to address potential concerns around privacy and airspace safety. As drones often operate in shared spaces, concerns about their potential for invasion of privacy or interference with manned aircraft are common. By being transparent and proactive in discussing how drones

operate within established safety guidelines, publics concerns will be able to overcome. This would not only reassure the public but also contribute to widespread acceptance of drones as a legitimate technology with clearly defined safety protocols.

Theme	Sub-theme	Quote
Stakeholder Roles and Responsibilities	Role clarity and accountability	"Without a well-structured framework outlining the responsibilities of each party, it would be difficult to track performance or assign responsibility in case of issues." — R1
		"In cross-sector applications, different stakeholders may be involved in various capacities. Without clearly defined roles, there is a risk of duplicating efforts or having gaps in responsibility, leading to inefficiencies." — R3
		"Defining each role precisely ensures smoother workflows and minimizes friction in multi-stakeholder environments." — R5, R6
Interoperability and Technology Standards	Shared technical standards	"Without shared technical standards, integrating drone technology would be chaotic, as varying technologies would struggle to communicate or align with one another." (R2)
		"Standardization will also impact overall drone efficiency and reliability performance, streamlining operations and reducing the likelihood of errors or disruptions." (R5)
		"By establishing interoperability standards, we can significantly facilitate regulatory compliance and expedite approvals." (R2, R5)

Theme	Sub-theme	Quote
Resource Allocation and Funding Mechanisms	Sustainable resource distribution	"Public-private partnerships (PPPs) are important to share the financial burden, especially for large-scale infrastructure projects like air-ground connectivity." (R1, R2)
		"Governments face challenges in funding infrastructure projects due to high costs, including communication networks and maintenance systems, which are necessary for reliable drone operations." (R3)
Safety Protocols and Risk Management	Safety protocols and regulations	"Pre-flight checks, height restrictions, and operational guidelines are crucial to minimize the risks associated with drone flights." (R2, R4, R5, R6, R8)
		"Clear safety standards for small drones are critical to ensure that these devices don't pose hazards to public safety or existing air traffic systems." (R2)
		"The incident at Tianjin Binhai International Airport highlights the urgent need for strict regulations to prevent drone interference and ensure safe integration into airspace." (R3)
Education and Training Initiatives	Technical skills and certification	"Joint training programs and certification courses will ensure personnel are well-equipped to navigate the evolving landscape of drone technology and can perform their roles effectively." (R1)
	Cross-sector understanding	"Cross-sector training will help to standardize safety and regulatory practices and foster a harmonized

Theme	Sub-theme	Quote
		approach to drone technology across industries." (R6)
Public Engagement and Communication	Societal acceptance of drones	"Efforts should be made to educate the public about the positive impacts of drone technology, such as its potential to improve efficiency in sectors like logistics, agriculture, and emergency response." (R7)
		"Proactive communication addressing concerns about privacy and airspace safety will help overcome public skepticism and promote the widespread acceptance of drones." (R8)

Table 4.6: Thematic analysis of develop a model of collaborative initiative on the integration of drone technology

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.0 Introduction

This chapter will conclude the Feasibility Study on "Drone Integration In Advancing Technological, Regulatory, And Air-ground Infrastructure with Consumer Perspectives in Malaysia" by summarizing the main findings, discussing their broader implications, and providing practical recommendations for stakeholders involved in drone technologies. As the drone industry continues to evolve and scale, understanding the feasibility of widespread commercial adoption, alongside the barriers that hinder this process, is crucial for informed decision-making. The insights gained through this research offer valuable direction for addressing challenges and ensuring sustainable, efficient, and safe drone applications across various sectors. This chapter also serves to encourage and provide a foundation for the commercial application of drones in Malaysia.

5.1 Overview of the Study

This research explores the feasibility and challenges associated with the commercial use of drone technology in Malaysia, with a focus on advancing technological, regulatory, and air-ground infrastructure. As drones gain traction in industries such as logistics, agriculture, urban planning, and emergency response, this research delves into the opportunities and obstacles faced in their integration into these sectors.

A qualitative research methodology was utilized, primarily involving in-depth interviews with key stakeholders, including government regulators, technology experts, and industry leaders. This approach aims to capture a multifaceted understanding of the barriers to widespread drone adoption, considering technical, operational, regulatory, and societal perspectives.

The research investigates several critical area such as the integration of drone technologies into existing commercial infrastructures, the development of regulatory frameworks for safe and efficient drone operations, and the technological and financial challenges impeding progress. In addition, the research addresses the social acceptance of drones, emphasizing the importance of public engagement strategies to overcome concerns related to privacy, safety, and airspace management.

By examining these aspects, the study seeks to provide a comprehensive assessment of the current status of drone adoption in Malaysia. It aims to identify actionable insights and offer practical recommendations to overcome the barriers identified, thereby supporting the growth

and expansion of drone technology for commercial applications. Ultimately, the research aspires to contribute to shaping a conducive environment for drone integration, benefiting various industries and enhancing operational efficiency.

5.2 Discussion of the Study

The findings of this research reveal critical technical, regulatory, and operational challenges that hinder the widespread adoption of drone technology for commercial applications in Malaysia.

5.2.1.RO1: To identify the key factors focus in technical, regulatory, and operational barriers that impact on the adoption of drone technology in commercial applications in Malaysia.

The main and most concentrated theme across the feedback received from respondent and the analysis of thematic analysis is the complexity and lack of clarity in Malaysia regulatory framework for drone operations. Respondents identified vague and inconsistent regulations as the most significant barrier to drone adoption in commercial sectors. Without clear regulations on licensing, flight zone restrictions, and data privacy, businesses face uncertainty when incorporating drones into their operations. For instance, unclear licensing requirements create difficulties in certifying drone operators, which not only impedes operational efficiency but also raises concerns over safety and legal compliance. Additionally, without specific flight zone restrictions, drone operators may face challenges in navigating urban and sensitive areas, further restricting their commercial use. Privacy concerns also emerge as a major issue, with respondents pointing out that the absence of stringent data protection policies could lead to breaches of privacy, undermining public trust in drone technology.

The regulatory environment must be updated and standardized to align with global best practices. To overcome these barriers, Malaysia could draw on the experiences of leading countries like the United States, which have established more comprehensive and clear drone regulations. Establishing a robust regulatory framework that balances innovation with public safety will be essential for creating a conducive environment for drone use in commercial applications.

Another critical barrier identified by respondents is the technical limitations of drones, which include issues related to battery life, signal interference, and weather-related challenges. The current limitations in battery technology restrict drones flight duration, preventing them from performing tasks over extended distances or for prolonged periods. This becomes particularly

problematic in industries that require long-duration flights, such as agricultural monitoring or logistics.

Weather conditions in Malaysia, particularly the frequent rainfall, high humidity, and fluctuating temperatures, pose additional challenges for drone operations. The vulnerability of drones to adverse weather conditions can cause equipment malfunction, reduced stability, and even damage to the drone, making outdoor operations less reliable and safe. As Malaysia tropical climate can be unpredictable, this limits the practicality of using drones for certain tasks such as environmental monitoring or logistics, without additional safeguards and improvements in drone design.

Furthermore, signal interference was highlighted as a critical issue, especially in densely populated urban areas where electromagnetic interference can disrupt drone navigation systems. The lack of dedicated infrastructure for air-ground connections, such as signal towers or network support for drone operations, exacerbates this challenge. Without stable connectivity, drones are prone to losing control, which is particularly problematic for commercial applications that require high levels of reliability and safety. Enhancing the country communications infrastructure and developing dedicated networks for drone operations are essential steps in mitigating these technical limitations.

The lack of regulatory technical challenges and air ground infrastructure will directly raise operational concerns and hinder the widespread adoption of drones in Malaysia. One of the most prominent operational barriers is the need for skilled drone operators. Several respondents emphasized that a shortage of qualified drone operators, coupled with the high costs of training, poses a significant obstacle for businesses looking to implement drone technology. Moreover, integrating drones into existing logistics, inventory management, and business systems is another operational challenge. This research highlighted the need for customized solutions that bridge the gap between traditional processes and drone-enabled systems. Businesses must carefully assess how drones will fit into their existing operations and ensure that any changes to their processes are well-managed to prevent disruptions.

Safety concerns, particularly the risk of drone malfunctions and collisions also remain a major barrier to widespread drone adoption. Drones operating in commercial sectors must be equipped with advanced safety features to minimize these risks. However, businesses may find it financially prohibitive to invest in high-end safety technology, especially given the high initial investment and maintenance costs associated with drone fleets. Several respondents

pointed out that, in the absence of substantial immediate cost savings, businesses might be reluctant to make large-scale investments in drone fleets. This financial burden calls for a careful cost-benefit analysis and possibly a phased approach to implementation, where businesses can begin with pilot programs before committing to full-scale adoption.

The high initial investment required for drone fleets and the ongoing costs of maintenance and upgrades is serve as one of the main barriers. These financial concerns coupled with the uncertainty regarding ROI, make it difficult for many businesses to justify the adoption of drones, especially in industries that are not yet fully familiar with the technology. As drone technology continues to evolve rapidly, businesses must also account for the need to upgrade their fleets regularly, which can add additional financial pressure.

5.2.2 RO2: To explore the collaborative initiatives between stakeholders in the industry due to overcome obstacles and facilitating a smoother integration of drone technology.

Another key area of this study is to explores the collaborative efforts among key stakeholders such as government bodies, private companies, and technology providers to overcome regulatory, operational, and technological challenges in the Malaysia drone industry. Respondent feedback highlights several initiatives, including the National Technology and Innovation Sandbox (NTIS), which provides a platform for testing drone technology in a controlled environment. These partnerships aim to address barriers such as regulatory uncertainty, logistical obstacles, and technical limitations, accelerating drone adoption across various sectors.

Key collaborations in worldwide such as partnerships between drone companies and logistics providers have fostered innovation and safety standards. This serve as a great examples of the successful integration of drones in agriculture and disaster relief efforts, where drones have proven effective for precision farming and emergency response. Despite challenges in logistics, especially in densely populated areas, respondents emphasize the potential for drones to improve efficiency, reduce costs, and enhance sustainability, particularly in rural areas.

The study also stresses the importance of standardization and knowledge-sharing across industries to promote safety, consistency, and faster regulatory approvals. Respondents recognize that resource-sharing initiatives can make drone technology more accessible to small and medium-sized enterprises (SMEs) and able to aids SMEs to reduce the financial burden of adopting new technology. By collaborating on safety norms, operational procedures, and

regulatory frameworks, stakeholders can facilitate the broader deployment of drones across commercial sectors.

5.2.3 RO3: To develop a model of collaborative initiative on the integration of drone technology.

The last part of this research focuses on the importance of clearly defined stakeholder roles, interoperability standards, resource allocation, and safety protocols in the development of the drone industry in Malaysia as these serves as the key elements in developing model of this research. Respondents emphasized the need for clear role definitions to ensure accountability and avoid operational overlaps in complex drone applications such as logistics and agriculture. Clear roles are seen as essential for smooth collaboration, reducing inefficiencies, and ensuring safety.

Stakeholders also stressed the importance of interoperability standards for technology integration. Shared technical standards allow drones from different manufacturers to operate seamlessly in cross-industry applications, enhancing efficiency and reducing errors. Additionally, standardization supports regulatory compliance, facilitating faster approvals and broader adoption of drone technology.

Resource allocation, particularly for air-ground connectivity infrastructure, is another key consideration. Respondents highlighted the need for public-private partnerships (PPPs) to share financial burdens and ensure sustainable infrastructure development. The government role in funding large-scale projects, like network infrastructure, is critical for the success of drone applications in sectors like logistics, agriculture, and urban planning.

Safety protocols were identified as crucial for the safe operation of drones. Respondents stressed the need for comprehensive risk management, particularly for larger commercial drones operating in crowded areas. Additionally, regulatory bodies were seen as essential in promoting effective safety protocols to prevent incidents, such as those involving drone interference with airport operations.

Education and training programs were also highlighted, with a focus on developing specialized skills for drone operations, safety, and compliance. Cross-sector training would help standardize practices and foster smoother collaboration between industries. Finally, public engagement and communication were deemed essential to build societal trust and understanding of drone technologies. Addressing concerns about privacy and airspace safety

through transparent communication would facilitate public acceptance and the broader integration of drones into daily life.

Objective	Findings
Regulatory Challenges	- Complex and unclear regulations on licensing, flight zone restrictions, and data privacy.
	- Lack of clear guidelines impedes drone adoption in commercial sectors.
	- Privacy concerns due to insufficient data protection policies.
	Recommendation: Update and standardize regulations to align with global best practices.
Technical Limitations	- Limited battery life restricts flight duration for extended tasks.
	- Malaysia's tropical climate (rain, humidity, temperature fluctuations) causes operational challenges.
	- Signal interference in urban areas disrupts drone navigation systems.
	Recommendation: Enhance air-ground communication infrastructure and improve drone design.
Operational Concerns	- Shortage of qualified drone operators and high training costs.
	- Difficulty integrating drones into existing logistics and business systems.
	- High investment costs in drones and safety technology are prohibitive for many businesses.
	Recommendation: Adopt phased implementation with pilot programs and focus on cost-benefit analysis.

Objective	Findings
Collaborative Efforts	- Initiatives like NTIS provide controlled environments for testing drone technology.
	- International partnerships in agriculture and disaster relief serve as models for Malaysia.
	- Resource-sharing initiatives help SMEs reduce financial burdens.
	Recommendation: Foster collaboration among stakeholders to address regulatory and technological barriers.
Stakeholder Roles and Safety Protocols	- Clear stakeholder roles are essential for accountability and avoiding overlaps.
	- Development of interoperability standards for seamless drone operation.
	- Strong safety protocols to minimize risks, especially in urban areas.
	Recommendation: Establish clear roles, safety standards, and cross-industry training programs.
Education and Public Engagement	- Specialized training programs for drone operations and safety are needed.
	- Public engagement and transparent communication are crucial to building trust in drone technology.
	Recommendation: Promote public awareness and develop training programs for safe and compliant drone operations.

5.2.4 Proposed research model

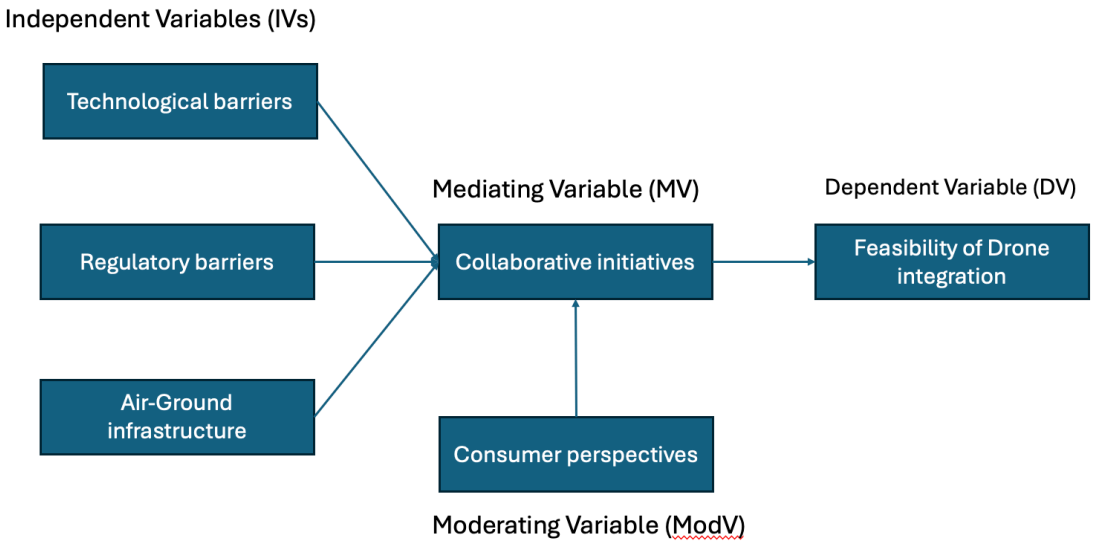

Figure 5.2 Proposed research model

5.3 Contribution of the Study

This research provides valuable insights into the key obstacles hindering the widespread adoption of drone technology in Malaysia's commercial sector, focusing on technical, regulatory, and air ground infrastructure challenges. By identifying barriers such as unclear regulations, technical limitations, and the lack of air ground infrastructure connectivity, the research underscores the complexity of integrating drone technology into various industries. The study also proposes practical solutions, including clearer regulatory frameworks, enhanced safety protocols, and strengthened public-private partnerships to address resource allocation challenges. Ultimately, this study contributes to the development of a more comprehensive model for drone adoption, offering actionable recommendations for stakeholders across industries to ensure smoother integration and long-term sustainability. Furthermore, it serves as a foundation for future research on the commercial application of drones in Malaysia, providing valuable insights for further technological advancements and policymaking.

5.3.1 Theoretical Contribution

This research makes a significant theoretical contribution to the field of drone technology adoption, particularly in commercial sectors within emerging markets like Malaysia. It presents a detailed model that identifies, categorizes, and analyses the critical technical, regulatory, and operational barriers that hinder widespread drone adoption. By focusing on Malaysia's unique context, the research offers insights into region-specific challenges, such as ambiguous regulations, limited infrastructure, and operational complexities, which have not been comprehensively explored in prior literature.

The research also enriches existing theoretical models of technology adoption by applying them to the novel and complex innovation of drones, while incorporating local nuances specific to Malaysia’s commercial landscape. The research highlights how regulatory frameworks, infrastructure limitations, and workforce skills are integral to the successful integration of drone technology in business operations.

Furthermore, by linking these challenges to practical solutions such as clearer regulatory standards, dedicated infrastructure for drone operations, and enhanced training programs, the research bridges the gap between theoretical models of technology adoption and real-world applications. This research extends beyond identifying obstacles, providing potential pathways to overcome them, thus offering a dynamic and forward-looking perspective on drone integration in commercial industries.

Additionally, this research presents a unique approach to understanding the intersection of technology adoption theories and industry-specific needs. It suggests that theoretical models must be adaptable to the specific regulatory, economic, and infrastructural contexts of different countries. As such, this research introduces a new theoretical lens for understanding drone adoption in emerging economies, contributing to the broader literature on technology adoption in under-explored regions.

5.3.2 Practical Contribution

From a practical perspective, this research provides valuable contributions to the successful adoption and integration of drone technology in Malaysia's commercial sectors. By identifying and analyzing the key technical, regulatory, and operational challenges, the study offers actionable insights for various stakeholders, including industry specialist, private companies, and technology providers.

A key practical contribution of this study is the emphasis on the need for a clear and standardized regulatory framework. The research suggests that businesses and drone operators require clear guidelines on licensing, flight zone restrictions, and data privacy policies to confidently integrate drones into their operations. For policymakers, this finding emphasizes the need to establish comprehensive regulations that align with global standards, fostering innovation while ensuring public safety.

The study also highlights the necessity of improved infrastructure, particularly air-ground connectivity, to mitigate technical challenges such as signal interference and limited battery life. For industry players, this highlights the need for investment in specialized networks and infrastructure to support drone operations, especially in urban and densely populated areas.

Operationally, the research underscores the need for skilled drone operators. It identifies the demand for specialized training programs to address the shortage of qualified personnel. For businesses, this offers practical guidance on how to integrate drones into existing processes, ensuring that staff are well-prepared to manage the technology. The study also suggests that businesses could benefit from phased implementation, starting with pilot programs before committing to full-scale drone adoption. This approach reduces both risk and financial burden.

Additionally, the research addresses financial concerns, particularly the high initial investment required for drone fleets. For companies contemplating drone technology, the study advocates

conducting cost-benefit analyses and exploring partnerships or collaborative efforts to share resources, making the technology more accessible, especially for smaller businesses.

Lastly, the research emphasizes the importance of collaboration among various stakeholders, such as government bodies, industry leaders, and technology developers, to create synergies that can resolve operational and technological barriers. This approach fosters innovation and ensures that solutions to challenges are both practical and aligned with industry needs. By fostering such collaboration, the study provides a roadmap for creating an ecosystem conducive to the successful and sustainable integration of drone technology in Malaysia's commercial sectors.

5.4 Limitation of the Study

While conducting this research, several limitations hindered the research scope and depth. The primary limitation was time constraint as this research was conducted within a three-month window and had restrict the number of stakeholders surveyed and limiting the variety of feedback gathered across the drone ecosystem in Malaysia. With more time, the research will be able to engage with wider participants to provide a more comprehensive overview of perspectives.

Asides, this research only rely on qualitative methods in collecting data. Although qualitative insights are valuable for understanding complex, subjective experiences, however this approach not able to fully capture quantitative aspects such as statistical trends, larger sample sizes or measurable outcomes, which could enhance the generalizability and precision of the findings.

Furthermore, the availability of resources and primary data specific to Malaysia drone industry is limited as drone technology is a evolving and new and field in Malaysia, hence local studies and resources is deficit. Although some information can be taken from more advanced market such as China and United State. But it often lacked direct applicability due to Malaysia unique regulatory environment, climate, and societal perspectives.

5.5 Recommendation for Future Research

5.5.1 Addressing the Deficit in Drone Knowledge, Studies, and Research in Malaysia

One of the significant barriers identified in this study is the lack of comprehensive knowledge and research surrounding drone technologies in Malaysia. Despite the growing interest in drones, there remains a significant gap in both technical expertise and academic research that can guide the development of policies, safety standards, and operational model in Malaysia.

Compared to leading nations in drone technology such as China, Singapore, and the United States, Malaysia's development in drone systems lags. These countries have invested heavily in research and development (R&D), establishing advanced drone infrastructures, and pioneering innovative solutions across sectors such as logistics, agriculture, emergency services, and urban planning. As a result, Malaysia faces several challenges in competing with these nations in terms of technological advancement, operational efficiency, and regulatory frameworks.

The lack of studies directly impacts the data collection required for the successful integration of drones in commercial applications. Before introducing new technologies, especially in industries like logistics, agriculture, and urban planning, it is essential to collect large datasets from multiple scenarios and case studies. These datasets will help in understanding the degree of how drones function in various real-world environments and are critical in developing a comprehensive and accurate picture of the feasibility of drone applications. Without sufficient data, stakeholders including government agencies, research institutions, and private companies will lack the foundational insights needed to assess operational challenges, safety concerns, and efficiency factors. Large-scale data collection can guide the development of drone safety standards, operational protocols, and regulatory frameworks, ensuring that drones operate efficiently and safely in commercial settings.

For instance, gathering data from pilot programs and real-life drone operations in various environments such as urban, rural, industrial, and agricultural settings would allow researchers to identify patterns of drone performance, weather conditions impact, battery life limitations, payload capacity, and flight time. By collecting data from different operational conditions, it will be possible to identify potential risks, operational bottlenecks, and areas for improvement.

To address the deficit in drone knowledge and research in Malaysia, government initiatives must play a central role in promoting and supporting research and development (R&D) efforts.

A crucial step in bridging this knowledge gap is the establishment of dedicated drone R&D hubs, which would serve as collaborative spaces for researchers, engineers, and policymakers to drive technological innovation, enhance safety standards, and foster advancements in areas such as autonomous navigation, artificial intelligence (AI)-based analytics, and advanced communication systems. These hubs would provide state-of-the-art facilities to test and develop cutting-edge drone technologies, ensuring that Malaysia's drone industry can evolve with globally competitive solutions tailored to local needs.

Focusing on key technologies such as autonomous navigation systems, AI-based analytics, and advanced communication systems will be vital for Malaysia drone industry. Autonomous systems would reduce human intervention and improve safety by allowing drones to navigate complex environments, while AI-powered analytics would enable real-time decision-making and predictive maintenance. Furthermore, advanced communication systems including 5G and Wi-Fi 6 would ensure seamless coordination between drones and ground stations, facilitating safer operations, particularly in urban or high-traffic areas.

Collaboration between the government, academic institutions, and private companies will be essential in creating these R&D hubs. The government can provide policy guidance, regulation, and funding, while academic institutions can lead fundamental research and training programs. Private companies can contribute by commercializing innovations and bringing market-driven solutions to fruition. This tri-sector partnership would not only expedite drone technology development but also foster locally relevant solutions, addressing Malaysia's unique challenges such as its tropical climate and specific regulatory needs.

By developing these hubs, Malaysia can ensure that its drone industry benefits from both cutting-edge research and practical, context-specific applications. This approach will empower Malaysia to overcome existing barriers and establish itself as a leader in the global drone market, with technologies and operational model that are safe, sustainable, and tailored to its national context. Ultimately, creating dedicated drone R&D hubs will help Malaysia close the knowledge gap, foster innovation, and ensure the safe, efficient, and widespread adoption of drone.

On the other hand, Malaysia regulatory authorities can collaborate with drone academies and manufacturers, such as AirAsia drone academy and DJI to establish drone certification programs. These certifications would set safety and operational limits for different drone classes, addressing public safety concerns. Drone academies can also offer more functional and

specialized courses that tailored to commercial applications for industries such as agriculture, logistics, and construction. All the centralized flying data will then serve as a national database and contribute to further research, analytics, and development of safety standards.

Another important initiative is to involve the implementation of real-name registration system for drone purchases. By requiring individuals to register their drones under their legal identities, this policy able to aids and establish a secure record of ownership by adding a layer of accountability. This measure would be effective in safeguarding public security by deterring unauthorized surveillance and preventing misuse of drones in restricted or sensitive areas. In addition, a real-name registration system would simplify tracking and regulating drone operations and help authorities to ensure compliance with safety and operational standards.

5.5.2 Collaboration and technologies sharing with key players worldwide

Another essential recommendation to enhance Malaysia drone industry is fostering international collaboration and technology sharing with key global players. In order to stay competitive and adopt the best practices, Malaysia needs to engage with leading countries and companies in drone technology such as China, the United States, and Singapore, which have already made significant contribution in advancing drone systems. By participating in global drone initiatives, research, and joint ventures, Malaysia can access cutting-edge innovations and adapt them to meet local requirements. This kind of collaboration is crucial in accelerating Malaysia entry into the global drone market and ensuring the commercial viability of drone applications across various sectors.

A critical aspect of international collaboration would be the sharing of technologies and best practices in areas such as autonomous flight systems, airspace management, and regulatory frameworks. For instance, the United States has experience in developing drone regulations and airspace management protocols which could serve as a valuable guideline for Malaysia in shaping its own regulatory framework. By learning from the experiences of other countries, Malaysia can streamline its regulatory processes, ensuring that drones can be safely integrated into national airspace while meeting international standards.

Such collaborations among countries also contribute to the international harmonization of drone regulations, which is crucial for the seamless operation of drones across borders. As drone technologies continue to advance, the global nature of their applications means that standardized safety protocols, operational guidelines, and certification processes will be essential for minimizing risks and ensuring operational consistency. Malaysia involvement in international regulatory discussions and partnerships will not only help align its drone policies with global standards but also position the country as a proactive participant in the global drone ecosystem. This collective effort can ultimately foster a more integrated, efficient, and safe global airspace for drones.

Furthermore, China is known as the top players that having most patents and technologies for drone in worldwide. China continues to lead the world in drone innovation, with Chinese companies responsible for 82% of global drone patent filings since 2015. In 2023, this share increased to 87%, totaling 17,285 patent applications. DJI, the leading drone manufacturer based in China, was the most prolific filer, submitting 88 patents that year (Peet, 2024). China

dominance in the drone industry presents a unique opportunity for Malaysia to establish strategic partnerships with Chinese drone manufacturers and technology developers.

Such collaborations could significantly enhance Malaysia drone manufacturing capabilities by providing access to cutting-edge technologies and innovations. Partnering with China advanced drone industry could enable Malaysia to import high-quality drone systems but also support local production and assembly and boost local economy. This collaboration would foster knowledge transfer, allowing Malaysia to build its own capacity for drone technology development, as well as offer workforce training and development in advanced manufacturing processes.

Malaysia as an island country presents a unique and favorable environment for testing drone technology due to its diverse geographical features and strategic positioning. The combination of urban, rural, and coastal areas, along with its varied landscapes such as forests, mountains, and waterways, makes it an ideal testing ground for a wide range of drone applications, including agriculture, logistics, environmental monitoring, and disaster response. Malaysia rural areas and agricultural sectors provide an excellent opportunity to test agricultural drones, especially for crop monitoring, spraying, and precision farming. Additionally, its coastal regions make it suitable for testing drones designed for maritime operations, such as search and rescue missions, environmental monitoring, and marine surveillance.

By leveraging China leadership in drone technology, Malaysia could accelerate the growth of its domestic drone industry, establishing itself as a competitive player in the global market. Moreover, such partnerships could stimulate innovation and create opportunities for Malaysia involvement in global supply chains, making it an attractive hub for drone technology research, development, and manufacturing in the region. Take Vanuatu as an example, the collaboration between China and Vanuatu has proven transformative particularly in improving logistics. China involvement in enhancing Vanuatu infrastructure including the introduction of water-based aircraft for transportation, demonstrates the impact international partnerships and positive transformation on a country economic and logistical capabilities (Times, 2022). Similarly, Malaysia might be able to see significant improvements in its logistics and transportation sectors through similar collaborations with Chinese technology leaders, particularly in enhancing connectivity between urban and rural areas, and streamlining supply chains. This would not only support the country growing demand for drone technologies but also position Malaysia as a leader in the rapidly evolving global drone ecosystem.

On the other hand, some companies such as Google, Microsoft, and Nvidia had made billions of dollars investment to set up data centre in Malaysia. Southern Malaysian city, Johor Bharu is projected to become the AI superhub of Southeast Asia. It has 1.6 gigawatts of total data centre supply and is expected to overtake Singapore as the largest market in Southeast Asia. This growing infrastructure for data storage and processing is a key enabler for the expansion of drone technology in Malaysia. Drones generate vast amounts of data, from real-time navigation to environmental monitoring and payload management. With the rapid development of AI technologies and cloud computing, data centres in Malaysia will play a crucial role in supporting the data-heavy demands of drone applications. These centres will facilitate faster data processing, storage, and analytics, making it easier to deploy drones for various commercial uses such as logistics, agriculture, urban planning, and surveillance.

Furthermore, the development of Johor Bahru as an AI superhub will also create a conducive environment for collaborations between drone technology companies and AI research institutions. This will foster innovation in areas like autonomous drone systems, machine learning, and data-driven decision-making. With AI and data center infrastructure in place, Malaysia could become a regional leader in the integration of AI-powered drones, attracting global players and reinforcing its position in the fast-growing drone and tech industries.

Malaysia growing investments in data infrastructure, strategic positioning for drone testing, and potential collaborations with leading global drone manufacturers such as China, the United States, and Singapore will significantly contribute to the country emergence as a competitive player in the global drone market. By leveraging international partnerships, technological advancements, and local testing environments, Malaysia can accelerate the growth of its drone industry, enhance its logistical and transportation systems, and strengthen its position as a key player in the rapidly evolving global drone ecosystem.

5.5.3 Way forward

For the widespread of drone applications in Malaysia especially in commercial use, stakeholders in drone ecosystem such as regulator, public and private sector, academic researchers need to collaborate and work together towards the outcome. This multi-stakeholder approach will ensure that the challenges and opportunities associated with drone technology are addressed comprehensively.

Regulators must work closely with private industry players and academic researchers to develop clear, standardized, and globally aligned regulations. This includes creating a

transparent licensing system, defining restricted airspaces, and implementing data protection laws. Ongoing consultations with the public and industry experts are essential to ensure that regulations are practical and adaptive to emerging drone technologies.

Asides, public agencies, including government bodies and local authorities, should collaborate with private companies to build the necessary infrastructure for drone operations. This includes developing air-ground connectivity, signal towers, and 5G networks tailored to drone needs. Government incentives and subsidies for drone technology adoption can also help reduce the financial burden on businesses, particularly SMEs.

Furthermore, continuous investment in R&D is necessary to overcome technical barriers such as battery life, weather-related challenges, and signal interference. Collaboration between academic institutions, private companies, and government bodies can drive innovation in drone technology, ensuring that it meets the diverse needs of industries like agriculture, logistics, and disaster responds.

To mitigate risks, stakeholders should work together to develop comprehensive safety protocols for drone operations. This includes standardized safety features for drones, such as collision avoidance systems, and risk management frameworks for operations in urban areas and near critical infrastructure like airports. Establishing insurance frameworks for drone operations will also help manage financial risks.

By fostering collaboration among these stakeholders, Malaysia can overcome the regulatory, technical, and operational challenges to unlock the full potential of drone technology in commercial applications.

5.6 Summary

In conclusion, this research explores the potential for integrating drones into commercial operations across Malaysia which focus on the barriers and feasibility of widespread adoption. This research assesses opportunities and challenges in key focus sectors in current world which include logistics, agriculture, urban planning, and emergency response. Further studies and applications in other industries should also be identify and justify ensuring that new technology able to provide more advantages and convenient to publics.

A qualitative approach was adopted in this research by conducted interviews with personnel from industry leaders, technology experts and publics to gain more valuable insights of technical, operational, regulatory, and societal obstacles that hinder drone use.

The study covers critical areas such as the integration of drone technology into existing commercial infrastructures, the regulatory requirements for safe drone operations, and financial and technological challenges that could impact further development. Additionally, it also addresses the public acceptance of drones and proposes strategies to manage concerns related to privacy, safety, and airspace. The findings of this research aim to guide stakeholders in Malaysia in addressing these challenges and support the sustainable, efficient, and safe adoption of drones in Malaysia commercial sectors.

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Appendix 1.1: Interview Questions

Topic: Drone Integration In Advancing Technological, Regulatory, And Air-ground Infrastructure With Consumer Perspectives In Malaysia

Background for this study: -

In recent years, drone technology has emerged as a revolutionary tool with vast potential for transforming various industries, including logistics, delivery services, agriculture, surveillance, and even healthcare. Drones offer the promise of enhancing operational efficiency by reducing costs, increasing delivery speed, and providing access to hard-to-reach areas. Countries worldwide are exploring the adoption of drones in their commercial sectors, with the goal of optimizing performance and achieving greater scalability.

However, despite these advantages, there are significant obstacles that slow down the widespread adoption of drones in commercial applications. Key challenges include technological limitations (such as battery life, payload capacity, and navigation systems), regulatory hurdles (airspace management, safety standards, and licensing), and the readiness of businesses to incorporate drones into their operations. Additionally, consumer acceptance of drones is a critical factor, as concerns about safety, privacy, and the environmental impact must be addressed for broader adoption.

In Malaysia, the potential for drone technology in commercial industries is promising, but the implementation feasibility faces many obstacles. There is a need for greater collaboration between stakeholders—government agencies, businesses, technology providers, and consumers—to overcome these barriers and create a smooth integration pathway for drone technology.

This research aims to explore the technical, regulatory, and operational challenges surrounding the use of drones in commercial applications in Malaysia. Furthermore, it seeks to investigate how collaborative initiatives among stakeholders can facilitate a more successful integration of drone technology. By developing a framework for collaborative efforts, this study will provide insights into the best ways to harness the potential of drones and unlock their full benefits for various industries.

Interview questions

Background Information

Briefly introduce yourself.

Name:

Gender:

Role and responsibilities:

Questions: -

Objectives 1: To examine the primary technical, regulatory, and operational obstacles that hinder the widespread adoption of drone technology in commercial applications in Malaysia.

1. What do you see as the biggest barriers to the widespread adoption of drones for commercial use in Malaysia?
2. How do you think current regulations affect the use of drones in commercial sectors? Are there any specific policies that create challenges?
3. From your perspective, what technical challenges (such as battery life, signal interference, etc.) limit the commercial use of drones?
4. What operational issues (e.g., safety, training, logistics) do you think hinder businesses or individuals from adopting drone technology?
5. How do you believe these obstacles could be overcome to promote more widespread drone use in Malaysia?

Objectives 2: To measure the impact of collaborative initiatives between stakeholders in the industry due to overcome obstacles and facilitating a smoother integration of drone technology.

1. Have you seen any examples of collaboration between businesses, government, or technology providers to improve the integration of drones in commercial activities?
2. How effective do you think these collaborations have been in overcoming the challenges faced by the drone industry?
3. In what ways do you believe partnerships between stakeholders can make drone technology more accessible and beneficial for businesses and consumers alike?
4. What role do you think collaborative efforts should play in improving the regulations, technology, or operational around drone usage?
5. How could further collaboration between industry stakeholders help accelerate the adoption of drone technology in commercial applications?

Objectives 3: To develop a model of collaborative initiative on the integration of drone technology.

1. What key components do you believe should be included in a model that supports the integration of drones into commercial industries?
2. How can various stakeholders (e.g., government, businesses, consumers) collaborate more effectively to ensure the successful integration of drone technology?
3. What are the most important factors to consider when building a system that encourages collaboration and facilitates the smooth adoption of drones in commercial settings?
4. How should consumer concerns or feedback be integrated into a model for drone technology development and usage?
5. What kind of industry standards or best practices would you recommend as part of a collaborative model for integrating drone technology into commercial sectors?
6. What future strategies or initiatives do you believe are necessary to ensure long-term collaboration and successful scaling of drone technology across various commercial sectors in Malaysia?