Economic feasibility analysis of small-unmanned aircraft Systems (sUAS) commercial package delivery: Improvement of FAA pilot-to-sUAS and visual line of sight (VLOS) regulation

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Abstract

This study evaluates the economic feasibility of small Unmanned Aircraft Systems (sUAS) commercial package delivery under evolving Federal Aviation Administration (FAA) regulatory frameworks. The analysis focuses on the impact of pilot-to-sUAS ratio relaxation, specifically 1:1, 1:10, and 1:20 scenarios, on operational cost efficiency and profitability. Using comparative cost modeling and simulation analysis, the study integrates real-world data from FAA waivers, FAA BVLOS ARC recommendation, and Matternet trials, and verified industry cost benchmarks to construct a reproducible financial model for multirotor and fixed-wing platforms.

Results demonstrate that under the current 1:1 FAA restriction (Part 107), commercial sUAS delivery operations remain economically unviable due to high labor costs. However, when the pilot-to-sUAS ratio is relaxed to 1:10, profit margins improve significantly, and at a 1:20 ratio, operations transition into sustainable profitability. For example, profitability in San Francisco increases from −5.82 percent under the 1:10 scenario to 16.3 percent under 1:20, while New York City improves from −13.43 percent to 10.29 percent, despite weather-related constraints.

These findings confirm that regulatory flexibility in pilot-to-sUAS ratios is a primary driver of cost reduction and operational scalability in drone logistics. The results also support the FAA's BVLOS ARC recommendations emphasizing performance-based regulation and automation thresholds (AFR Levels 2–3) as key enablers of scalable, safe, and economically feasible one-to-many operations.

The study contributes an analytical framework that links regulatory conditions to economic outcomes, providing quantitative evidence for policy design and industry adoption. By integrating cost modeling, simulation, and regulatory analysis, it offers a standardized

approach for evaluating future multi-drone logistics operations and supports broader integration of sUAS within the advanced air mobility (AAM) ecosystem.

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Dedication

This work is dedicated to my beloved wife, Su Yin Gan, and my children, Yeji, Hajun, and Yeeun, whose love, patience, and sacrifices allowed me to dedicate my time fully to this thesis. Your unwavering support gave me the strength to persevere through every challenge along the way.

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Chapter 1 - Introduction and General Overview

1.1 General Overview

The use of Small Unmanned Aircraft Systems (sUAS), or sUASs, for commercial package delivery operations presents a revolutionary opportunity to significantly enhance the efficiency, scalability, and environmental sustainability of delivery services. A pivotal area of potential advancement for efficiency and cost reduction is the simultaneous operation of multiple sUASs by a single remote pilot referred to as multi-sUAS operations. The aviation regulatory framework was not designed with the ability for a single pilot to operate multiple aircraft in mind. Accordingly, the framework to enable such operations is complex. Currently, major commercial package delivery operators, such as Amazon and Zipline, pursue regulatory waivers, exemptions, or operational certification pathways to facilitate simultaneous multi-sUAS operations, which is important for operational scalability, customer reach, and the practicality of multi-sUAS operations. This paper examines the economic feasibility of multi-sUAS package delivery operations, specifically comparing varying pilot to sUAS ratios (e.g., 1, 10, and 20), to highlighting the importance of regulatory pathways that permit multi-UAS operations and inform what those frameworks should aim to enable.

1.2 Identification – Defining sUAS vs. Drones

Definitions for sUAS and drones vary by civil aviation regulatory authority. In the US, for example, sUAS are defined by the U.S. Federal Aviation Administration (FAA) as unmanned aircraft systems weighing less than 55 pounds (25kg), including their payloads. FAA 14 CFR Part 107 provides guidelines for conducting civil sUAS operations without an airworthiness certificate, mandating operational limitations such as VLOS and altitude restrictions (FAA, 2020).

In contrast to sUAS, the term “drone” is a broad and colloquial term that refers to any Unmanned Aerial Vehicle (UAV), regardless of size or weight. The FAA defines “Unmanned Aircraft Systems (UAS)” as aircraft formerly referred to as “Unmanned Aeiral Vehicles (UAVs)” or “drones,” highlighting their increasing operational presence in the National Airspace System (FAA, 2024). It can describe anything from a tiny hobby quadcopter to a large military UAV. In short, all sUAS are drones, but not all drones can be officially categorized as sUAS under FAA regulations.

Globally, definitions of unmanned aircraft systems are further shaped by international and regional aviation bodies. The International Civil Aviation Organization (ICAO) defines a Remotely Piloted Aircraft System (RPAS) as a remotely piloted aircraft along with its control station, communication links, and other essential components (ICAO,n.d). In Europe, the European Union Aviation Safety Agency (EASA) defines “Unmanned Aircraft” as any aircraft without a pilot onboard, while “UAS” refers to the drone plus its control, communication links, and support equipment (EASA,n.d). Similarly, in the United States, the FAA distinguishes between an ‘unmanned aircraft,’ defined as an aircraft operated without the possibility of direct human intervention from within or on the aircraft, and a ‘UAS,’ which includes the unmanned aircraft and all associated elements such as communication links and control components required for safe operation (14 CFR 107.3, FAA, 2024).

In Africa, both Rwanda and Ghana have implemented regulatory frameworks consistent with this structure. The Rwanda Civil Aviation Regulations Part 27 (2024) define an Unmanned Aircraft System (UAS) as an aircraft operated without a pilot onboard, together with the control and communication components required to ensure safe and effective operation (Rwanda Civil Aviation Authority, 2024). Similarly, the Ghana Civil Aviation (Remotely Piloted Aircraft Systems) Directives Part 28 (2018) differentiate between a Remotely Piloted Aircraft (RPA), the physical aircraft, and a Remotely Piloted Aircraft System (RPAS), encompassing the aircraft, the remote pilot station, and the associated command-and-control links (Ghana Civil Aviation Authority, 2018).

These definitions reflect the growing harmonization of terminology across civil aviation authorities, reinforcing the global consensus that effective regulation of unmanned aviation requires a clear distinction between the vehicle itself and the integrated system that enables its command, control, and communication functions.

1.3 Identification – Defining Multirotor vs. Fixed-Wing sUAS

For the purposes of this paper, sUAS are divided into two major platform categories: multirotor and fixed-wing platforms, each optimized for different operational needs in commercial package delivery. There are also hybrid drones with both vertical and wing-borne flight capabilities that will not be discussed here.

Multirotor drones are typically equipped with four or more rotors, enabling vertical take-off and landing (VTOL), precise hovering, and stable maneuverability. These features make them highly suitable for last-mile delivery operations in urban areas, where spatial constraints and the need for pinpoint drop-offs are common (DJI, 2021) (Terra Drone, 2022). However, their relatively limited battery life and flight range restrict their effectiveness in longer-distance missions.

In contrast, fixed-wing drones operate more like traditional aircraft, relying on forward motion to generate aerodynamic lift. They typically provide greater energy efficiency, longer flight times, and higher cruising speeds, making them ideal for middle-mile commercial package delivery and rural area delivery where long distances must be covered (Boon et al., 2017) (DJI, 2021). However, fixed-wing systems cannot take off vertically or hover, and therefore often require dedicated launch and recovery infrastructure and are less maneuverable in constrained urban airspace.

1.4 FAA Regulatory Frameworks to Simultaneous Multi-sUAS Commercial Package Delivery Operations

sUAS operations under 14 CFR Part 107 are limited to VLOS (107.31) and to the operation of only one aircraft at a time (107.35), unless granted specific waivers by the FAA. Operators applying for waivers must provide detailed operational justifications that address key safety considerations outlined by the FAA. Currently, FAA 14 CFR Part 107.35 restricts UAS operating under Part 107 to a single pilot to operating only one sUAS at a time. This restriction, however, is expressly waivable14 CFR 107.205. Companies like Zipline have obtained waivers from the FAA, allowing them to operate multiple sUASs simultaneously (FAA, 2025). To obtain such waiver, operators are required to undergo a comprehensive approval process and even after approval, they must comply with the waiver's operational constraints for safety. To obtain a waiver under 14 CFR Part 107, companies are typically required to submit detailed operational information based on the complexity of proposed operation. While all waiver requests must address core safety criteria such as operational risk mitigation, pilot qualifications, and command/control procedures, additional elements like Safety Management Systems (SMS), flight planning documentation, and backup systems may be necessitated by the specific risk profile or scale of the operation.

For BVLOS waivers, the FAA evaluates considerations including whether the applicant's remote pilot in command (RPIC) can maintain awareness of the aircraft's position, ensure surveillance of the surrounding airspace, provide visual conspicuity, and respond to system malfunctions or failures. Applicants must also demonstrate reliable command and control (C2) link performance and justify their detect-and-avoid (DAA) capabilities (FAA, n.d.). In the case of multi-sUAS waivers, FAA reviewers assess whether the proposed operating environment poses minimal inherent risk, if appropriate mitigation strategies are in place for system failures, and how the RPIC will effectively manage multiple aircraft trajectories to avoid conflicts. The use of visual observers (VOs) is also examined to ensure safe monitoring across all units. The FAA notes that approvals are typically limited to low-risk scenarios, such as flights on predefined routes with visual observers making them unsuitable for routine or scalable commercial applications (FAA, n.d.).

For regular, large-scale commercial applications such as highly automated or autonomous package delivery involving BVLOS and one-to-many (1: N) pilot-to-sUAS operations, the FAA requires the operator to be certified under 14 CFR Part 135. In addition, Part 135 requires that the aircraft have a Type Certificate (TC) or seek exemption from FAA design approval under 44807. However, despite ongoing efforts to integrate advanced drone operations, the FAA has yet to grant type certificates (TCs) to leading commercial operators such as Zipline and Wing. Instead, these firms have been operating under exemptions and proposed airworthiness criteria issued the "special class" category for small UAS. This situation underscores the broader regulatory challenges the FAA encounters in developing formal certificate pathways for small, unmanned aircraft systems, where the technical and safety complexities have significantly slowed progress toward full type certification (Federal Aviation Administration, 2020; FAA, n.d).

The FAA reviews these applications and grants approval only if sufficient evidence demonstrates that multi-sUAS operations will not compromise the safety of the National Airspace System (NAS). This evaluative process underscores that regulatory flexibility under Part 107 is conditional upon an operator's ability to prove verifiable safety data and robust risk mitigation strategies. However, even after receiving approval, operators are typically subject to a range of operational restrictions. For instance, FAA Waiver 107W-2024-04627, granted to Zipline, outlines specific operational limitations. First, the operational environment requires that sUASs maintain a minimum visibility of two miles and adhere to specific cloud clearance regulations. Second, the number of sUASs a pilot can simultaneously operate is capped at a maximum of six. Third, flights are only permitted in pre-approved areas, with restrictions on operations near public events and densely populated regions. Fourth, sUASs must be equipped with collision avoidance systems, emergency landing procedures, and real-time communication monitoring, all of which are subject to regular FAA inspections. Lastly, companies must submit operational data and flight logs upon FAA request, and failure to comply may result in waiver revocation.

In 2021, the FAA established an advisory committee, the UAS BVLOS ARC, to provide the FAA with recommendations for performance-based regulatory requirements to normalize safe, scalable, economically viable, and environmentally advantageous UAS BVLOS operations that are not under positive air traffic control. The FAA's BVLOS ARC's Final Report (2022) provides specific safety justification for expanded pilot-to-sUAS ratios. The report proposes threshold ratios of 1:5 for operations under AFR Level 2 automation, and up to 1:20 for AFR Level 3, assuming validated autonomous systems and low-risk operating environments. Crucially, the ARC does not treat 1:N operations as inherently unsafe, but rather emphasizes the need to match scale with automation and risk mitigation. In highly automated scenarios, the report recommends assigning legal and operational responsibility not to individual remote pilots, but to a newly defined supervisory role, the Remote Flight Operations Supervisor (RFOS). This shift reflects a systems-based safety logic in which scalable operations are feasible when oversight is restructured and automation is trusted. These detailed ARC recommendations provide a regulatory framework to model pilot-to-sUAS ratios of 10 or 20 for future BVLOS deployment.

1.5 Significance of the Study

This research holds significance across multiple dimensions, spanning policy development, industrial applications, and academic contributions. By investigating the economic feasibility of multi-sUAS operations under different regulatory scenarios, this study aims to provide data-driven insights that can influence decision-making at various levels. By investigating the economic feasibility of multi-sUAS operations under varying regulatory conditions ranging, this study identifies how regulatory flexibility can impact unit economics, scalability, and labor productivity in commercial drone logistics.

As outlined in the FAA's BVLOS ARC Final Report (2022), practical constraints on pilot-to-sUAS ratios arise not only from regulation but also from operational realities such as delivery area size, airspace complexity, and human workload. This study will provide empirical evidence on what a regulatory framework needs to achieve for cost reductions, efficiency improvements, and the overall feasibility of safe multi-sUAS operations. The findings will be valuable for policymakers by providing empirical evidence on the economic impact of current FAA regulatory constraints, highlighting how relaxing pilot-to-sUAS ratio restrictions could reduce operational costs, enhance profitability, and ultimately support broader adoption of sUAS commercial package delivery solutions.

For commercial package delivery companies, sUAS service providers, and technology developers, the results of this research can have potential to inform the development of optimized business models and support the adoption of more scalable operational strategies. Sectors such as e-commerce, healthcare and emergency response, may benefit from regulatory flexibility that reduces cost and improves efficiency in sUAS-based logistics.

Academically, existing studies such as Sudbury and Hutchinson (2016) have primarily emphasized general cost-saving advantages of replacing delivery trucks with sUAS technology. However, this research does not explicitly examine the economic implications of FAA pilot to UAS ratio regulatory constraints on labor costs and scalability. Therefore, a clear research gap remains regarding the economic and operational feasibility of scaling multi sUAS operation systems under relaxed regulatory scenarios (Sudbury & Hutchinson, 2016). This study extends the framework by assessing multi-sUAS scenarios, offering a new perspective on sUAS-based commercial package delivery. Furthermore, this research introduces a multidisciplinary analytical approach that integrates economic modeling, operational cost assessments, and regulatory impact analysis, contributing a more comprehensive methodology for future studies on autonomous aerial commercial package delivery.

Ultimately, this study aims to provide policymakers and industry stakeholders with empirical evidence on the economic implications of what revisions to the FAA regulatory need to achieve.

1.6 Research Objectives

This research seeks to address the gap in understanding the economic implications of relaxing FAA pilot-to-sUAS ratio regulations through the adoption of a standardized, performance-based approval framework.

Although the current framework permits 1:many operations through waivers under Part 107.35, these approvals typically require highly customized safety cases and time-intensive FAA reviews, introducing regulatory friction that delays implementation and elevates operational costs and are limited to VLOS operations. More fundamentally, such waivers do not override the broader Part 107 requirement for VLOS operation under section 107.31. Hence, even approved multi-sUAS operations remain confined to VLOS environments, which severely limits their scalability for commercial package delivery.

Rather than advocating for deregulation, this study proposes the development of a more standardized, performance-based approval pathway either through a reformed waiver process or a dedicated rulemaking mechanism such as the anticipated Part 108. By establishing risk-based tiers and automation thresholds (AFR Level 2 or 3 as recommended in the BVLOS ARC Final Report), the FAA could streamline authorization for routine 1:many operations while maintaining safety integrity. Such a structure would enable operators to follow consistent and predictable procedures for designing Concepts of Operations (CONOPS) and developing scalable commercial models. By addressing these aspects holistically, this research will provide valuable insights into how sUAS commercial package delivery can evolve into a sustainable and economically viable alternative within the broader commercial package delivery ecosystem. By investigating the economic feasibility of multi-sUAS operations under different regulatory scenarios, this study aims to provide data-driven insights that can influence decision-making at various levels.

By systematically evaluating regulatory scenarios transitioning from the current restriction of one pilot per sUAS (1:1) to more relaxed scenarios (1:10 and 1:20), the study aims to quantify potential cost savings, operational efficiencies, and increased profitability associated with multi-sUAS operations. These constraints of the current regulatory options for 1:many operations underscore the need for a more flexible, performance-based regulatory framework that can accommodate scalable multi-sUAS operations without compromising safety. Insights derived from this research are intended to inform policymakers, facilitate industry adoption of scalable sUAS commercial package delivery solutions, and contribute to academic literature through comprehensive economic modeling and operational analysis.

Chapter 2 - Literature Review

2.1 Introduction

This literature review explores the current research and global practices related to the commercial package delivery of simultaneous operation of multiple small unmanned aircraft systems (multi-sUAS) by one remote pilot. It critically examines regulatory frameworks, industrial case studies, and academic research with particular emphasis on how regulatory constraints influence the economic feasibility, scalability, and labor efficiency of commercial sUAS operations.

2.2 Economic Implications of Global Regulatory Context

2.2.1 FAA Regulation

The FAA's regulatory framework influences the economic feasibility of multi-sUAS commercial package delivery operations. The FAA provided two primary regulatory frameworks for operating sUAS to conduct 1:many, each with varying implications for commercial package delivery.

Under Part 107 of the Federal Aviation Regulations, specifically 14 CFR 107.35, it explicitly states: "A person may not operate or act as a remote pilot in command or visual observer in the operation of more than one unmanned aircraft at the same time." This regulation significantly limits operational scalability under Part 107, resulting in increased labor costs for sUAS-based commercial package delivery. Part 107 waivers under 107.35 allow operators to exceed 1:1 pilot-to-sUAS ratio, but only on a case-by-case basis with rigorous justification. For instance, Zipline became one of the first operators to secure a waiver (FAA 107W-2024-04627), authorizing a single remote pilot to operate up to six drones in rural, low density BVLOS medical delivery corridors, subject to safety mitigations such as fleet telemetry, automated deconfliction, and detect -and -avoid protocols (FAA, 2021). Similarly, Matternet received a waiver to oversee up to 20 drones at a California test site, provided a visual observer ensured airspace clearance (DroneDJ, 2023). However, Part 107 waivers are inherently limited in scope and duration, constraining long term- scalability.

Alternatively, Part 135 certification has been employed by companies like Zipline, Amazon, Wing, and UPS FF to conduct BVLOS package deliveries. For example, in June 2022, Zipline received its Part 135 air carrier certification, enabling it to operate long-range, on-demand commercial drone deliveries in the U.S. Amazon obtained Part 135 certification in 2020, allowing it to deploy its MK30 drone for one-hour deliveries up to 7.4 miles, demonstrating technological and economic viability beyond what Part 107 permits (Amazon,2024; BBC,2023). Likewise, Wing Aviation operated under Part 135 authority in Christiansburg, Virginia, where an FAA Environmental Assessment authorized up to nine concurrent drones managed from a centralized operation hub- an early regulatory precedent for 1:many BVLOS (FAA,2019).

Part 135 requires the aircraft to either have a type certification (FAA design approval) or the operator to obtain an exemption from this requirement, called 44807, which commonly known as a “Section 44807 exemption”. This provision allows the FAA to determine that certain statutory requirements for airworthiness certification are not necessary for safe operations, provided the applicant demonstrates an equivalent level of safety. For example, Matternet received Type Certification under Part 21 for its M2 delivery sUAS in September 2022, making the first non-military sUAS to achieve this status in the U.S. Type certification validates the airworthiness of the sUAS design, enabling it to operate like traditional aircraft.

Recognizing the limitations of existing frameworks, the FAA's BVLOS ARC Final Report (2022) recommends a shift towards performance-based regulations to accommodate scalable 1:many operations. The report suggests establishing acceptable levels of risk (ALR) and introducing new operational roles, such as the Remote Flight Operations Supervisor (RFOS), to oversee multiple autonomous flights. It also proposes automation levels (AFR) to define the degree of human involvement required, advocating for reduced pilot workload and enhanced automation to safely manage multiple concurrent operations. Specifically, the ARC report links automation levels to pilot-to-UAS scalability, recommending threshold ratios such as 1:5 for AFR Level 2 systems and 1:20 for AFR Level 3 operations conducted in low-risk environments. Accordingly, the 1:10 scenario modeled in this study represents an intermediate case within the AFR Level 2 range greater than 1:5 but below 1:20, reflecting increased automation and supervisory capability.

2.2.2 The European Union Regulation

Within the European Union's UAS regulatory framework, advanced sUAS operations such as BVLOS and simultaneous control of multiple UAS (swarm) fall under the 'specific' category of EU Regulation 2019/947, which requires a risk-based operational authorization (EASA, 2024). To guide compliance, AMC3 UAS.SPEC.050(1)(d), an Acceptable Means of Compliance (AMC) issued by EASA, provides detailed expectations for operators seeking approval for complex operations. Specifically, it recommends that operators develop tailored theoretical and practical training modules for missions involving elevated risks, including BVLOS, urban airspace use, operations near people, and coordination of multiple UAS. The AMC outlines that such training should include scenario-based instruction, emergency procedures, crew role definition, and specific communication protocols. Although AMCs are not legally binding, they represent presumed compliance standards. For operations involving multiple UAS, AMC3 requires operators to establish clear chains of command and safety management structures that address both technical coordination and human oversight responsibilities.

In addition, European authorities are working on Unmanned Traffic Management systems – the EU's "U-space" framework launched in early 2023 to coordinate drone flights in designated airspace corridors with digital flight authorization and tracking services (EASA, 2021). European authorities are working on Unmanned Traffic Management systems – the EU's "U-space" framework launched in early 2023 to coordinate drone flights in designated airspace corridors with digital flight authorization and tracking services (MLIT, 2022). This is expected to facilitate higher-density drone operations (potentially including multi-UAS flights) in the future.

2.2.3 Asian Countries – South Korea and Japan

Asian regulatory frameworks, such as those in South Korea and Japan, currently constrain the economic scalability of sUAS delivery operations by enforcing strict VLOS requirements, without formally establishing operational concepts for 1:many control.

South Korea's current regulatory structure significantly restricts multi-sUAS operations due to strict Visual Line-of-Sight (VLOS) requirements. Specifically, regulations state: "Do not fly when the pilot cannot see the device directly with the naked eye (Drone Laws, n.d.)." Current regulations mandate that sUAS operators maintain VLOS during flights, which inherently limits the simultaneous control of multiple units by a single operator without additional support systems (UAV Coach, n.d.). Although sUAS light shows and public demonstrations involving multiple sUAS do occur in countries like South Korea and Japan, these are typically conducted under strict VLOS conditions with extensive pre-coordination and do not reflect broader regulatory support for multi-sUAS commercial package delivery operations. Therefore, such events should not be interpreted as evidence of regulatory flexibility in commercial multi-sUAS delivery contexts. While there is no explicit prohibition against multi-sUAS operations, the VLOS requirement effectively restricts such activities.

Japan’s Civil Aeronautics Act imposes specific restrictions on UAS operations to ensure safety and compliance. The Act mandates: “Flight not beyond visual line of sight (MLIT, n.d.).” While not formally prohibited, consequently, this limits the ability of a single pilot to control multiple sUAS simultaneously without additional approvals or support systems. However, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) allows operator to apply for specific permissions to deviate from this rule, provided they can demonstrate safe operational procedures.

2.3 Economic Insights from Industry Demonstrations and Trials

Leading global companies have provided compelling evidence supporting the economic and operational benefits of multi-sUAS commercial package delivery. Zipline's extensive operations in Rwanda and Ghana stand out prominently, where centralized distribution hubs coordinate simultaneous deployment of multiple drones for delivering critical medical supplies efficiently, thus significantly enhancing public health commercial package delivery and service scalability (Zipline, 2022). These operations are facilitated by supportive regulatory frameworks in both countries.

In Rwanda, the government has adopted a performance-based regulatory approach, allowing sUAS operators to conduct their operations upon demonstrating compliance with safety standards, thereby fostering innovation and scalability in sUAS commercial package delivery

(DroneLife, 2025). Specifically, the Rwanda Civil Aviation Regulations Part 27 stipulates: “Before operating an unmanned aircraft other than in accordance with the specific category, a person shall apply for an Unmanned Aircraft Operator Certificate in accordance with Regulation 27.207 (Rwanda Civil Aviation Authority, 2024).” According to RCAR Part 27.050, the standard operational rule requires that “the person operating the UA operates only that UA,” reflecting a default 1:1 pilot-to-sUAS constraint (Rwanda Civil Aviation Authority, 2024). However, Part 27.055 provides a mechanism for deviation through area-specific approvals, allowing operators to request authorization for operations under special conditions or in designated airspace. Most notably, Part 27.110 introduces the concept of ‘Highly Automated UAS Operations,’ under which the Authority may approve non-standard operational models, subject to defined conditions.

Similarly, Ghana’s regulatory framework, overseen by the Ghana Civil Aviation Authority (GCAA), provides guidelines for Remotely Piloted Aircraft Systems (RPAS) operations, GCAA Directive Part 28 (GCAA, 2018). Part 28 explicitly states that “No person shall control more than one RPA (Remotely Piloted Aircraft) with an RPS (Remote Pilot Station) at any given time unless otherwise authorized by the Authority.” In other words, a single remote pilot may generally only fly one sUAS at a time, unless special authorization is granted by GCAA. An approval for 1:many operation must undergo GCAA’s Advisory Circular (AC) 28-003 (Issue 2, 2024) on developing an RPAS Concept of Operations to declare if their remote pilot will control more than one sUAS at a time (GCAA, 2024). That is, it suggests GCAA uses a case-by-case waiver process, ensuring the operator proves an equivalent level of safety.

In Asia, regulatory frameworks have historically been cautious regarding multi-drone operations, but recent initiatives demonstrate a growing openness to innovation. Notably, Japan's

New Energy and Industrial Technology Development Organization (NEDO), in partnership with Japan Airlines (JAL), successfully conducted comprehensive trials as part of the Realization Advanced Air Mobility Implementation Project (ReAMo Project) in October 2024. In these trials, a single remote operator simultaneously controlled five drones deployed across four separate geographic locations. This ambitious demonstration showcased advanced remote-control technologies and provided practical insights into managing multiple drones concurrently. It also identified specific operational challenges inherent in multi-drone scenarios, such as maintaining reliable communication between sUAS units and RPIC and ensuring effective real-time decision-making by RPIC through simultaneous situational awareness through collected data. Such trials significantly contribute to understanding the technical and regulatory requirements for scaling multi-sUAS commercial package delivery in complex environments (Japan Airlines, 2024). The trial highlighted three critical insights. First, it validated the feasibility of assigning centralized responsibility to a remotely located pilot, confirming the need for clear regulatory guidance on remote operator accountability. Second, it demonstrated the vital role of a comprehensive monitoring system, capable of integrating flight data, environmental conditions, and route status for multiple sUAS in real time. Third, it underscored the importance of automated irregularity notifications such as low battery alerts or proximity conflicts enabling the operator to intervene when necessary and maintain safety in compliance with the operations manual. These findings are expected to inform both Japan's regulatory advancement towards future commercial CONOPS for large-scale drone logistics.

Another compelling demonstration of simultaneous multi-drone operations comes from Europe, where RigiTech successfully conducted groundbreaking cross-border medical drone deliveries in November 2024. In collaboration with partners Royal Dutch Touring Club

(ANWB), Touring Club Switzerland (TCS), and ÖAMTC, RigiTech coordinated three autonomous drones operating concurrently across Switzerland, Austria, and the Netherlands, all managed centrally from a single control tower in Amsterdam. This ambitious trial validated not only the technical feasibility but also the operational benefits of centralized multi-drone commercial package delivery, demonstrating significant efficiencies in medical supply deliveries across national boundaries. RigiTech's achievement underscored the potential for drones to enhance healthcare commercial package delivery through seamless integration and coordination at an international scale, setting a notable precedent for future multi-drone and cross-border operations (RigiTech, 2024).

2. 4 Research Initiatives

Significant academic and governmental research trials have advanced the understanding of multi-sUAS operational feasibility, primarily addressing the technological dimensions of autonomy, communication and airspace integration. These studies establish the technical prerequisites for safe multi-UAS operations, thereby providing the foundation upon which this research extends the analysis toward economic feasibility, evaluating how operational efficiency, cost structures, and scalability are influenced once such technological capabilities are achieved.

NASA's Urban UAS Traffic Management (UTM) trials in Nevada and Texas extensively tested the simultaneous operation of drones in urban environments, successfully demonstrating critical technologies and operational procedures for collision avoidance, airspace management, and communication protocols needed for scalable urban air mobility (Martin et al., 2020a; Martin et al., 2020b). They validated essential technologies and protocols, including remote identification, cooperative collision avoidance systems, and robust communication networks, which collectively contribute to the safe scaling of urban drone operations. While these trials did not directly test 1:many control within a single company but demonstrated inter-company airspace sharing, these technological and procedural components are directly transferable to future 1:many operations within a single operator. For instance, the ability to simultaneously track multiple sUAS, update mission parameters in real time, and manage distributed sUAS behavior through a centralized control platform are all essential capabilities for enabling a single remote pilot to supervise multiple sUAS safely and efficiently in urban environments. These insights from NASA's UTM research inform the infrastructure and procedural standards that would be required to support high-density, intra-company multi-sUAS delivery services at scale.

Building on NASA's foundational research, the FAA conducted its UTM Pilot Program Phase 2 in 2021, performing operational trials in densely populated environments within New York and Virginia. These demonstrations emphasized real-world applicability, showcasing high-density sUAS flights managed through coordinated, automated UTM services (FAA, 2021). The FAA's trials successfully validated integrated airspace management concepts, including flight intent sharing, strategic and tactical deconfliction, and effective remote sUAS identification procedures. These outcomes significantly advanced practical understanding of how scalable multi-drone can be safely implemented within existing national airspace systems. UTM functions as a digital infrastructure layer that allows operators to safely deploy and monitor multiple sUAS in high traffic areas without requiring constant manual oversight. Therefore, the findings of UPP2 substantiate the view that UTM services will be a foundational component for the sustainable growth of multi-sUAS delivery services in complex, scalable delivery ecosystems.

Recent NASA research by Chandarana, Shyr, and Tyson (2023) investigated the feasibility of managing multiple drones per operator by studying scenarios where a single remote operator supervised up to twelve autonomous delivery drones simultaneously. They specifically examined emergency situations that required rapid rerouting of drones due to unexpected temporary airspace restrictions. Using a machine-learning approach, the authors developed a predictive model based on a Support Vector Machine (SVM) classifier to estimate operator workload during these events. Their model, achieving approximately 60–75% accuracy, identified key factors influencing operator workload, such as the number of required route adjustments and the operator's response times. This predictive capability could inform the design of real-time support systems, ensuring operators remain within manageable workload limits. While their findings support the technical possibility of a single operator managing multiple drones under controlled conditions, the authors emphasized the importance of carefully managing human workload through advanced automation and user-friendly interfaces to maintain safe and effective operations (Chandarana et al., 2023).

In 2021, NASA's Ames Research Center, in collaboration with industry partners such as Uber, conducted human-in-the-loop simulations to develop operational concepts for effectively managing multiple small drones in commercial package delivery missions (Smith et al., 2021). Their study emphasized scenarios where a single human operator supervised several delivery drones simultaneously, employing cognitive walkthrough evaluations with domain experts to identify potential hazards, operator workload thresholds, and critical design factors for ground control stations (GCS). The research concluded that careful balancing of responsibilities between human oversight and automated drone functions is essential, highlighting that automation should primarily handle routine tasks, thereby freeing human operators to focus on strategic decision-making and intervention in unexpected events. These findings substantiate the feasibility of safe, scalable multi-drone delivery operations, emphasizing the necessity of intuitive GCS interfaces and adaptive automation that proactively manage operator workload and maintain situational awareness in complex operational environments (Smith et al., 2021). Building on these findings, the study also highlighted key technical and operational considerations necessary for scaling 1: many sUAS delivery. Specifically, the research emphasized the importance of highly automated systems that handle routine flight operations including navigation, conflict detection, and emergency responses with minimal human intervention. It identified Ground Control Station (GCS) design as a critical factor, recommending clear visualizations, prioritized alerts, and user-centric layouts to reduce cognitive load. Expert participants noted that while a single operator could potentially supervise multiple drones up to 9 or more in low-complexity scenarios, this capacity was highly contingent on system reliability, task automation, and interface intuitiveness.

In the UK, Blue Bear Systems Research's drone swarm trials demonstrated that multiple autonomous drones could be effectively operated by a single individual under BVLOS conditions. These trials highlighted key aspects of drone autonomy, inter-drone coordination, and advanced operational safety frameworks crucial for future drone swarm commercial package delivery scenarios (Blue Bear Systems Research, 2020).

Collectively, such technological demonstrations confirm the technical feasibility of supervised multi-UAS operations and provide empirical grounding for this study's subsequent analysis of their economic and regulatory implications.

2.5 Gaps and Opportunities

Despite the demonstrated successes of multi-sUAS commercial package delivery operations through various industry trials and regulatory developments, significant gaps persist in both academic and practical domains. A primary gap identified is the limited comprehensive economic analyses specifically targeting regulatory impacts. While existing literature, trias and early operations, such as those conducted by Zipline, Matternet, Google Wing, JAL, and RigiTech, predominantly emphasize technological feasibility, operational efficiency, and safety protocols, the critical issue of detailed cost-effectiveness and long-term profitability under varying regulatory scenarios remains underexplored. Addressing this gap, future research should explicitly focus on the economic implications of progressively relaxing FAA pilot-to-drone ratio restrictions. Detailed economic assessments focusing on scalability, infrastructure investment costs, and profitability thresholds under different regulatory conditions will provide necessary insights to industry stakeholders and policymakers.

While preliminary analyses indicate significant cost reductions achievable through increasing sUAS-to-pilot ratios, detailed, scenario-based economic modeling incorporating real-world operational constraints and regional variations such as weather conditions, urban density is required. Such targeted research will enhance understanding of the precise conditions under which multi-drone commercial package delivery become economically sustainable.

Among the many variables affecting the economic feasibility of multi-sUAS commercial package delivery, weather represents one of most influential factors determining operational availability. Adverse weather conditions such as precipitation or high winds impose non-negotiable no-fly constraints for sUAS operations.

San Francisco has been identified as one of the most viable cities for Urban Air Mobility (UAM) operations when evaluated against weather-related constraints. Reiche, Cohen, and Fernando (2021) conducted a comparative climatological analysis across major U.S. metropolitan areas and reported that San Francisco demonstrated a relatively low average of weather-impacted operational hours (4.75 hours/day), in contrast to cities such as New York

City, which exhibited 8.0 hours/day. Although these findings were derived from UAM operational parameters, they provide a useful meteorological baseline for assessing how regional weather variability may similarly affect the operational availability and cost-efficiency of multi-sUAS commercial package delivery. The study highlights San Francisco's inclusion among the top three cities alongside Honolulu and Los Angeles with consistently favorable weather conditions for aerial operations. By comparing two geographically distinct locations, San Francisco, characterized by mild and stable weather, and New York City, known for more frequent weather-related disruptions, the analysis aims to demonstrate that despite variations in operational days due to weather, labor cost consistently emerges as the dominant economic factor shaping the viability of multi-sUAS commercial package delivery.

Chapter 3 - Materials and Methods

3.1 Introduction

This chapter outlines the research methodology employed to evaluate the economic feasibility of multi-sUAS package delivery operations, specifically comparing varying pilot to sUAS ratios (e.g., 1, 10, and 20). The study incorporates a quantitative approach, utilizing comparative analysis of economic outcomes such as operational costs and profitability across different operational scenarios. The methodology is structured to assess how varying pilot-to-sUAS ratios impact economic outcomes, including operational costs and profitability within multi-sUAS commercial package delivery sector. Specifically, this study incorporates a detailed cost-benefit analysis (CBA), comparing all projected costs (e.g., labor, hardware depreciation, maintenance) against quantifiable benefits (such as increased efficiency, reduced delivery times, and scalability advantages). The cost-benefit analysis mentioned refers to the comparative operational cost and revenue projection charts provided later in the chapter. It involves structured tabular comparisons of projected economic outcomes under each scenario.

3.2 Primary Data Sources

The primary data for this study focuses on labor-related operational costs associated with different pilot-to-sUAS ratios, as labor represents a critical factor impacting the economic feasibility of multi-sUAS commercial package delivery operations (McKinsey, 2023). Operational cost data has been collected and analyzed for three distinct regulatory scenarios drawing from publicly available FAA documentation, waiver granted for multi-drone operations, industry demonstrations such as Matternet’s approved pilot-to-sUAS ratios, and academic research, NASA trials and FAA UTM demonstrations.

1. Labor Costs related to Pilot-to-sUAS ratios

1.1 Evaluating scenarios of 1, 10, and 20 sUAS per pilot.

1.2 Assessing impacts on:

1.2.1 Operational cost per delivery

1.2.2 Total Labor cost

1.2.3 Overall operational efficiency and scalability

3.3 Variables and Definitions

The study analyzes dependent and independent variables to measure the economic viability of integrating sUAS into commercial commercial package delivery.

1. Dependent Variables

1.1 Operational Cost per Delivery in USD

The capital cost of using a drone hardware, DJI FlyCart 30, is estimated at approximately $20,889 per unit (DroneNerds, 2025), while complete kit versions including extra batteries, charging hub, winch system, and ancillary equipment retail at approximately $36,385 (Drone Deer Recovery, 2025). Therefore, for modeling full operational readiness, this study assumes a configuration cost of $36,385 to represent a fully equipped operational setup. Although the DJI FlyCart 30 exceeds the FAA Part 107 sUAS weight limit of 55 lb, it is referenced here as a representative heavy-payload delivery pltform to contextualize cost trends for next generation package delivery UAS. Moreover, to set up a corridor of sUAS delivery operation, two vertiports on both departing and arriving points are assumed in this model, aligning with the infrastructure configurations observed in existing UAS package delivery frameworks. Recent industry implementations from Zipline and Matternet demonstrate that fixed-route package or medical UAS networks typically employ dedicated take-off and landing sites at each terminus to enable scheduled, repeatable operation. In actual commercial drone delivery operations, both the point of departure and the destination are equipped with dedicated hubs or pads that enable efficient launch, landing, and cargo exchange processes. For instance, Matternet has implemented Landing Stations across its urban network to facilitate automated landing, battery swapping, and parcel handover between drones and ground handlers (Matternet, 2024). Similarly, Zipline's P2 system incorporates autonomous docking decks that allow drones to land, recharge, and reload autonomously at destination sites, forming a scalable and fully automated end-to-end delivery model (Kolodny, 2023). This setup ensures operational reliability, safe ground handling, and scalability, aligning with standard practices in structured corridor-based sUAS delivery. A type of vertiport is decided, depending on radius miles to be covered and characteristics of operating area. Vertipads represent the smallest structures and typically serve as spokes within a hub-and-spoke network. They are often created by retrofitting existing structures and are suitable for sUAS operations, particularly in suburban or rural locations positioned up to 50 miles from the core network hub (Mckinsey & Company, 2022). While the 50-mile figure reflects infrastructure distribution in network design not individual flight range under current FAA Part 107 rules, it provides a conceptual framework for estimating infrastructure requirements. The use of vertipad cost in this analysis is based solely on capital and operational expenditure modeling. It does not imply regulatory authorization for operation over 50-mile distance under Part 107. McKinsey&Company estimated its cost $200,000 to $400,000 to build and $600,000 to $900,000 per year to operate which means $300,000 for construction cost and $750,000 for annual operation cost for its infrastructure (McKinsey & Company, 2022). According to FAA report, the number of crewmembers directly involved during a normal UAS/Drone operation is two based on 50.4% of the total response from UAS organizations researched (FAA, 2023). In this study, a "normal" operation refers to current commercial sUAS missions under Part 107 with

VLOS. While the specific crew composition may vary depending on platform and operational complexity, the assumption of two personnel, one remote pilot and one visual observer or ground support staff, is consistent with industry practice and regulatory compliance requirements.

2. Independent Variables

2.1 Technology Capability of sUAS

Zipline, drone delivery and commercial package delivery company based in the USA, has brought up two platforms that cover both middle-mile and last-mile deliveries. Platform 1 is capable of covering more than 120 miles roundtrip with 4 pounds of payload targeting enterprise and government. On the other hand, Platform 2 covers a 10-mile service radius one way with between 6 and 8 pounds of payload. Their cruise speeds are reported at 60 miles and 70 miles per hour respectively (Zipline, n.d.). While Amazon was conducting drone delivery services in College Station, Texas, its platform flew delivering packages weighing up to five pounds in one hour or less. Furthermore, its new platform is designed to fly as far as 7.4 miles (BBC, 2023).

These specifications serve as the empirical basis for the independent variables of range. Specifically, the range values (3-mile for multirotor and 50-mile for fixed-wing), payload capacity (4–8 lb), and cruise speeds (60–70 mph) were integrated into the cost and operational efficiency calculations that determine delivery frequency, labor distribution, and infrastructure requirements. By anchoring these parameters to verified industry data, the model ensures that economic outcomes across the 1:1, 1:10, and 1:20 pilot-to-sUAS scenarios reflect realistic and technologically feasible performance conditions.

2.2 Weather Condition

To estimate the average number of operational days for sUAS, this study will evaluate two representative regions, San Francisco and New York City, which exhibit the most and least favorable weather conditions for Urban Air Mobility (UAM) operation respectively. Building on the regional selection discussed earlier, the median number of operationally feasible days between these two locations is used as the baseline. Furthermore, since sUAS may be more susceptible to certain weather conditions than eVTOLs, we are calculating a chance of moderate rain or thunderstorms in those areas to find days of operations with sUAS (Dulia et al., 2022). These weather conditions were selected because precipitation and convective activity are primary determinants of sUAS flight cancellations, directly reducing the number of operational days available for commercial delivery. The most favorable weather for operation of Urban Air Mobility (UAM) is along the Californian coast[1], but much less favorable weather conditions show in Denver, New York City, and Washington D.C (Reiche et al., 2021). However, as sUAS is more susceptible to the weather condition than eVTOLs used for UAM (National Center for Atmospheric Research, n.d.), a chance of moderate rain or thunderstorms will be computed to retrieve uninterrupted operational days for a year in San Francisco and New York City where have the most and less favorable weathers for UAM operation.

3.4 Hypothesis

This study hypothesizes that relaxing FAA regulations to allow multiple sUAS per pilot significantly improves the economic feasibility of sUAS-based commercial package delivery operations by substantially reducing labor costs per delivery, thereby enhancing overall profitability. Under current FAA regulations (14 CFR 107.35), commercial sUAS operations under Part 107 are limited to a 1:1 pilot-to-sUAS ratio without a waiver, increasing labor costs and restricting scalability. However, 1:many operations are permitted under Part 135, provided

[1] Specifically, this refers to major coastal cities such as Los Angeles and San Francisco.

that the operator obtains an Air Carrier Certificate and meets additional safety and operational requirements. Additionally, operations are constrained by the Visual Line-of-Sight (VLOS) requirement, meaning that even with a waiver for multi-sUAS control, each aircraft must remain within sight unless a separate Beyond Visual Line-of-Sight (BVLOS) waiver is obtained. Given that labor expenses constitute a major portion of total operational costs in sUAS delivery, increasing the number of sUAS a single pilot can control from 1 to 20 is expected to reduce per-unit delivery costs by distributing labor expenses across more flights. However, such scalability would only be feasible under a minimum viable regulatory framework that permits supervised one-to-many operations such as those envisioned in the FAA's BVLOS ARC recommendations where autonomation reliability, remote oversight, and safety management systems collectively satisfy an equivalent level of safety standard.

To test this hypothesis, the study evaluates three clearly defined scenarios derived from actual FAA policies and real-world waiver examples:

- **Scenario 1 (Baseline)**: 1 Pilot → 1 sUAS (Part 107 without waiver)
- **Scenario 2 (Moderate Relaxation)**: 1 Pilot → 10 sUAS (Under FAA BVLOS ARC recommendations)
- **Scenario 3 (Full Relaxation)**: 1 Pilot → 20 sUAS (based on Matternet's FAA Part 107.35 waiver approval) (DroneDJ, 2023)

The anticipated economic outcomes as the sUAS-to-pilot ratio increases are:

1. Lower labor costs per delivery
2. Improved fleet utilization
3. Higher profit margins

3.5 Data Analysis Methods

1. Regression Analysis

This study uses multiple regression analysis to quantify how changes in the sUAS-to-pilot ratio influence operational cost per delivery. The regression model includes:

1.1. Dependent Variable:

Operational cost per delivery (aggregating labor, hardware depreciation, maintenance, insurance, infrastructure, and related expenses)

1.2. Independent Variables:

1.2.1. Pilot-to-sUAS ratio:

Number of sUAS simultaneously managed by one pilot, specifically tested at ratios of 1, 10, and 20 based on current FAA Part 107 regulations and granted waivers.

1.2.2. Delivery volume per operational period:

Defined as the total number of completed deliveries per day by the entire sUAS fleet, directly influencing operational efficiency and cost distribution.

1.2.3. Number of operational days (to account for weather variability):

Derived from historical weather analysis, specifically calculating days without significant weather disruptions that could impede sUAS flight operations.

This model evaluates the degree to which these factors drive cost outcomes, isolating the economic effects of regulatory flexibility on labor efficiency and profitability.

3.6 Simulation Modeling

The study also employs scenario-based simulation modeling using Microsoft Excel to project operational and financial outcomes across the three scenarios. For each scenario (1, 10, and 20 sUAS per pilot), structured comparative tables calculate projected cost-per-delivery values and estimated profit margins. Importantly, the three scenarios represent distinct regulatory conditions that directly influence operational feasibility. Scenario 1 reflects current FAA Part 107 restrictions, permitting only one-to-one VLOS operations. Scenario 2 represents a minimum viable regulatory framework consistent with the FAA BVLOS ARC Final Report (2022), envisioning supervised one-to-many operations with validated automation and detect-and-avoid systems. Scenario 3 reflects advanced waiver-based operations under Part 107.35, as demonstrated by Matternet's FAA-approved test site in California (DroneDJ, 2023).

The simulation is designed around an integrated operations model that combines fixed-wing and multirotor platforms within a shared logistics network. This integration allows fixed-wing aircraft to extend delivery range and endurance, while multirotor systems provide last-mile precision. Accordingly, the model assumes coordinated flight operations between both platform types within a hub-and-spoke corridor architecture, consistent with prior AAM infrastructure studies (McKinsey & Company, 2022). Moreover, when UAS organization covers fixed-wing and multirotor, target customers exist more than when it only utilizes a single type of unmanned aircraft. To support this operation concept, two pilots operating each type of sUAS should be considered because they act as a controller and responder to emergency procedure respectively. Besides this, each type of unmanned aircraft, fixed wing and multirotor, has different cost elements that are differences of its H/W and maintenance cost.

The following section presents the financial analysis and projected economic outcomes of multi-drone operations under different FAA regulatory scenarios. These results validate the hypothesis by quantifying how cost efficiency improves as sUAS-to-pilot ratios increase.

The cost model used in this analysis incorporates seven major components: sUAS hardware and software, infrastructure (vertipad) installation and operation, labor, insurance, and maintenance. These cost components were selected to represent the major and publicly verifiable expenses necessary to realize the proposed concept of operations. Indirect or secondary costs such as energy use, communication services, or administrative licensing were excluded because reliable quantitative data are limited and their marginal influence on total operational cost is comparatively minor. This approach ensures analytical focus on the dominant cost drivers, particularly labor expenses, which most significantly affect the economic feasibility of multi-sUAS operations.

Multirotor cost is estimated at approximately $36,385 per unit, reflecting the full-package configuration of the DJI FlyCart 30 including batteries, charging hub, winch system, and ancillary equipment based on verified commercial pricing date (Drone Deer Recovery, 2025). Vertipad installation cost is assumed to be $300,000, depreciated over 27.5 years according to IRS building asset guidelines (IRS Publication 946, 2023). The vertipad represents a small-scale launch and recovery site designed within a hub-and-spoke network, typically supporting short-range operations (up to 50 miles) for commercial sUAS logistics. The estimated installation cost of $300,000 is drawn from McKinsey & Company (2022). This assumption is consistent with the sUAS performance modeled in this study, specifically, a 3-mile multirotor range and a 50-mile fixed-wing range, which represent compact, light-infrastructure configurations suitable for platforms comparable to Zipline or Matternet. Annual vertipad operation and equipment cost is estimated at $750,000, falling within the range ($600K–$900K) of urban drone infrastructure estimates discussed in McKinsey & Company's commercial package delivery analyses. Labor costs are set at $160,000 per year for a two-operator crew, based on the FAA UAS Air Carrier Operations Survey (2023), which reports a two-person crew as the most common staffing structure (50.4% of organizations). The salary figure of $80,000 per pilot is supported by U.S. industry data showing typical drone pilot salaries ranging from $81,500 to $129,500 (ZipRecruiter, 2025). Insurance cost of sUAS is assumed at $3,500 per unit per year, based on publicly disclosed quotes from U.S.-based commercial sUAS service providers. Maintenance cost is modeled at 20% of hardware cost annually, consistent with standard engineering estimates used in sUAS service contracts and commercial package delivery planning.

Each hardware item was annualized over a three-year service life, while vertipad installation was depreciated over 27.5 years. Because the hardware price already represents a ready-to-fly configuration, software costs were not added separately. All costs were computed on a 365-calendar-day basis, as depreciation, insurance, and maintenance accrue regardless of weather-related operational downtime. This cost calculation represents an annualized operational cost model rather than a financial accounting statement, meaning that depreciation is treated as a distributed usage cost to reflect realistic yearly expenditure.

These assumptions form the foundation of the daily and annual cost structures presented in Tables 3.1-3.12 A1 through C4, under various pilot-to-sUAS regulatory scenarios. To establish a baseline economic scenario for multirotor operations, Table 3.1 (A1) outlines the daily operational cost components for a single unit. It includes capital expenses, labor, insurance, maintenance, and infrastructure-related costs based on a one pilot to one sUAS ratio under current FAA regulations.

Table 3.1. Operational Cost per day with a single unit of multirotors in a year (A1)

List	Total Price (USD)	Price/unit (USD)	Unit	Note
sUAS Platform	36,385	33	One unit per day	Depreciation year (3) One-time payment
Vertipad installation	300,000	30	Per day	Depreciation year (27.5) (One-time payment)
Vertipad operation/Equipment	750,000	2,055	Per day	Annual payment
Labor	160,000	439	Per day	Two operators (Annual payment)
Insurance	3,500	10	Per day	One year contract (Annual payment)
Maintenance	7,277	20	Per day	20% of the hardware price (Annual payment)
Total	1,257,162	2,587		

To compare platform-specific costs, Table 3.2 (A2) summarizes the daily operational expenses of a fixed-wing sUAS unit under the same regulatory baseline. This comparison highlights the differences in hardware costs, maintenance requirements, and overall operating expenditure between multirotor and fixed-wing platforms.

Table 3.2. Operational Cost per day with a single unit of fixed wing in a year (A2)

List	Total Price (USD)	Price/unit (USD)	Unit	Note
sUAS Platform	42,263	38	One unit per day	Depreciation year (3) One-time payment
Vertipad installation	300,000	30	Per day	Depreciation year (27.5) (One-time payment)
Vertipad operation/Equipment	750,000	2,055	Per day	Annual payment
Labor	160,000	439	Per day	Two operators (Annual payment)
Insurance	3,500	10	Per day	One year contract (Annual payment)
Maintenance	8,453	24	Per day	20% of the hardware price (Annual payment)

Total	1,264,216	2,596		

Table 3.3 (A3) calculates annual revenue, costs, and profit margins for both multirotor and fixed-wing sUAS operations in San Francisco. The analysis assumes that four pilots meaning two per platform and incorporates regional weather conditions and daily flight capacity.

Table 3.3. Annual profit with a single unit of multirotors and fixed wing having four pilots in San Francisco (A3)

Number of flights per unit and day	Number of pilots	Revenue (Annual) USD	Cost (Annual) USD	Profit (Annual) USD	Profit Margin %
133 (M)	4	91,238	1,130,770	-988,597	-695.4
9.92 (F)		50,935			

Note: (M) = Multirotor, (F) = Fixed-wing

Total revenue is calculated based on the number of flights per day, price per parcel and annual operational days in San Francisco and New York City. Operational days in a year were counted when it has no precipitation but as cost factors such as depreciation of asset, insurance, and maintenance are counted regardless of working hours, it is calculated in 365 calendar days. Four pilots are counted because each type of sUAS should be operated by two pilots under the assumption of setting up the concept of operation. Based on the number of pilots set up, the number of flights per day is based on a calculation below.

$$Number\ of\ flights\ per\ day\ = \frac{Operational\ radius}{Speed\ of\ aircraft} \times Working\ hour\ per\ day$$

This calculation method reflects standard engineering practices used in the early-stage design of sUAS delivery concept of operations. While it is not drawn from a specific academic source, it is widely applied in industry when estimating operational requirements and assessing concept-level feasibility. Operational radius varies depending on the type of sUAS and a multirotor can fly up to a 3-mile radius and a fixed wing covers 50-mile radius based on their own performance capability. As multirotors cover the last mile, price per parcel and route is estimated at $2. On the other hand, a fixed wing covers more customers who benefit more than the ones using the last mile, so its price is set up at $15. After calculating all these numbers, its annual revenue is estimated at 91,238 and 50,935 for multirotors and fixed wing respectively, which results in significantly negative profit margin about -695.4%.

Under the same condition in terms of the number of pilots that can be utilized, the number of flights per unit and day and operational costs associated to support this operation, operating sUAS in New York allows a service provider to have more limited operational days annually that are counted to 320 days.

Table 3.4 (A4) provides a parallel analysis using New York City's operational environment, where more frequent weather disruptions reduce the number of annual flight days. This comparison highlights the sensitivity of sUAS profitability to regional operational limitations. It should be noted that these figures are not drawn from a specific company's financial statements but are based on scenario-based modeling using realistic assumptions and cited industry data.

Table 3.4. Annual profit with a single unit of multirotors and fixed wing having four pilots in New York City (A4)

Number of flights per unit and day	Number of pilots	Revenue (Annual) USD	Cost (Annual) USD	Profit (Annual) USD	Profit Margin %
133 (M)	4	85,120	1,130,770	-998,034	-751.9
9.92 (F)		47,616			

Note: (M) = Multirotor, (F) = Fixed-wing

When two pilots can control each type of ten units of sUASs simultaneously, costs of sUAS platforms, insurance and maintenance increase at the same rate of increase in the number of fleets controlled. However, the other cost elements such as sUAS S/W, vertipad installation and equipment and labor do not change due to the fact that their unit number does not change regardless of expansion of the number of fleets managed to support its operational concept.

To simulate a moderately relaxed FAA regulatory scenario (1:10 pilot-to-sUAS ratio), Table 3.5 (B1) outlines the updated operational costs for a fleet of 10 multirotors managed by two pilots.

Table 3.5 Operational Cost Variables per day with 10 units of multirotors having two pilots (B1)

List	Total Price (USD)	Price/units (USD)	Unit	Note
sUAS Platform	363,850	332	ten units per day	Depreciation year (3) One-time payment
Insurance	35,000	96	ten units Per day	One year contract

				(Annual payment)
Maintenance	7,277	20	ten units Per day	20% of the hardware price (Annual payment)
Total	406,127	448		

Similar to the multirotor case, Table 3.6 (B2) presents the daily cost variables for operating 10 fixed-wing units under the same pilot allocation. This supports a direct cost-performance comparison under equal regulatory relaxation.

Table 3.6. Operational Cost Variables per day with 10 units of fixed wing having two pilots (B2)

List	Total Price (USD)	Price/units (USD)	Unit	Note
sUAS Platform	422,630	386	ten units per day	Depreciation year (3) One-time payment
Insurance	35,000	96	ten units Per day	One year contract (Annual payment)
Maintenance	84,526	232	ten units Per day	20% of the hardware price

				(Annual payment)
Total	542,156	714		

As the number of flights per day with 10 units increases in 10 times, the capacity of increasing the revenue also increases significantly. It shows that generating revenue from an increase in the number of sUASs makes more benefits beyond its cost.

Table 3.7 (B3) summarizes the annual financial results of operating 10 units of each platform type in San Francisco. It reflects increased delivery capacity and scaling efficiencies enabled by the 1:10 pilot-to-drone ratio.

Table 3.7. Annual profit with 10 units of multirotors and fixed wings having four pilots in San Francisco (B3)

Number of flights per 10 units and day	Number of pilots	Revenue (Annual) USD	Cost (Annual) USD	Profit (Annual) USD	Profit Margin %
1,330 (M)	4	912,380	1,505,625	-82,861	-5.82
99.2 (F)		510,384			

Note: (M) = Multirotor, (F) = Fixed-wing

On the other hand, in New York City where allows limited operational condition in terms of weather, it cannot achieve a positive profit margin but it still shows the significant improvement in the negative profit margin from -751.9% to -5.82%.

Table 3.8 (B4) applies the same 10-unit operational model to New York City. It shows the regional impact on annual profitability when weather-limited operational days are considered.

Table 3.8. Annual profit with 10 units of multirotors and fixed wings having four pilots in New York City (B4)

Number of flights per 10 units and day	Number of pilots	Revenue (Annual) USD	Cost (Annual) USD	Profit (Annual) USD	Profit Margin %
1,330 (M)	4	851,200	1,505,625	-178,265	-13.43
99.2 (F)		476,160			

Note: (M) = Multirotor, (F) = Fixed-wing

When the regulation of limiting the number of operations per pilot becomes more relaxed to 20 units managed by the same number of pilots, its performance of generating revenue dramatically increases. However, the amount of costs of increase in the number of sUAS H/W, insurance and maintenance should be considered whether the performance suppresses or outperform those costs.

Under a fully relaxed scenario (1:20 pilot-to-drone ratio), Table 3.9 (C1) presents the per-day operational cost for managing 20 multirotor drones with two pilots.

Table 3.9. Operational Cost per day with 20 units of multirotors having two pilots in a year (C1)

List	Total Price (USD)	Price/unit (USD)	Unit	Note
sUAS Platform	727,700	665	twenty units Per day	Depreciation year (3) One-time payment
Labor	160,000	439	Per day	Two operators (Annual payment)
Insurance	70,000	192	twenty units Per day	One year contract (Annual payment)
Maintenance	145,540	399	twenty units Per day	20% of the hardware price (Annual payment)
Total	1,103,240	1,695		

Table 3.10 (C2) provides the comparable operational cost structure for managing 20 fixed-wing drones, highlighting how cost components scale with fleet size under full regulatory relaxation.

Table 3.10. Operational Cost per day with 20 units of fixed wing having two pilots in a year (C2)

List	Total Price (USD)	Price/unit (USD)	Unit	Note
sUAS Platform	845,260	772	twenty units per day	Depreciation year (3) One-time payment
Labor	160,000	439	Per day	Two operators (Annual payment)
Insurance	70,000	192	twenty units Per day	One year contract (Annual payment)
Maintenance	169,052	464	twenty units Per day	20% of the hardware price (Annual payment)
Total	1,244,312	1,867		

The financial performance of a 20-unit fleet per platform in San Francisco is calculated in Table 3.11 (C3). This scenario demonstrates the highest scalability and shows significant improvements in profitability.

Table 3.11. Annual profit with 20 units of multirotors and fixed wings having four pilots in San Francisco (C3)

Number of flights per 20 units and day	Number of pilots	Revenue (Annual) USD	Cost (Annual) USD	Profit (Annual) USD	Profit Margin %

2,660 (M)	4	1,824,760	2,845,528	463,903	16.3
198.4 (F)		1,020,768			

Note: (M) = Multirotor, (F) = Fixed-wing

San Francisco shows a substantial improvement in profit margin, indicating that expanding the operational scale from 10 to 20 units significantly enhances cost efficiency. The profit margin rises from -5.82% with 10 units to 16.30% with 20 units, representing an annual profit increase of approximately $463,903 USD.

Table 3.12(C4) replicates the 20-unit analysis in the weather-constrained environment of New York City. Despite operational limitations, this scenario shows dramatic improvement in profit margins due to scale effects.

Table 3.12 Annual profit with 20 units of multirotors and fixed wings having four pilots in New York City (C4)

Number of flights per 20 units and day	Number of pilots	Revenue (Annual) USD	Cost (Annual) USD	Profit (Annual) USD	Profit Margin %
2,660 (M)	4	1,702,400	2,381,625	273,095	10.29
198.4 (F)		952,320			

Note: (M) = Multirotor, (F) = Fixed-wing

In New York City, expanding the fleet from 10 to 20 units improves profitability despite higher operational costs. The profit margin increases from -13.43% to 10.29%, with annual profit rising to approximately $273,095 USD.

Chapter 4 - Limitations and Future Research

While this study successfully establishes a reproducible cost and profit model for multi-drone operations under current FAA regulatory frameworks, several limitations remain that warrant further exploration.

First, the model assumes constant operational capacity throughout a 365-day calendar year. In practice, adverse weather, maintenance downtime, and airspace congestion can cause operational interruptions, especially in dense urban areas such as New York City. Future studies should incorporate stochastic or dynamic scheduling models that reflect daily or seasonal variations in flight frequency.

Second, this research employs static cost parameters for hardware, labor, insurance, and vertipad infrastructure. As commercial UAS technologies continue to evolve, cost components, particularly hardware depreciation and maintenance, are likely to change rapidly with economies of scale and regulatory adaptation. A future analytical framework could adopt sensitivity analysis to evaluate how variations in these parameters influence overall profitability.

Third, the current model excludes indirect operational costs, such as energy consumption, communication service fees, or administrative licensing expenditures. Including these variables in future research could improve the realism of economic feasibility estimates, particularly when extending the model to large-scale or intercity UAS networks.

Finally, while this study focuses on economic feasibility from a single-operator perspective, future work should explore system-level optimization under collaborative or networked operations, where multiple operators share airspace and infrastructure. Integrating such inter-operator dynamics into the model could help policymakers and industry stakeholders better evaluate the social and economic implications of large-scale Beyond Visual Line of Sight

(BVLOS) deployment. Additionally, future research should incorporate comparative policy analysis to evaluate the global applicability of U.S.-based models.

Chapter 5 - Conclusion

This study evaluated the economic feasibility of multi-sUAS logistics operations by developing a scenario-based simulation model under varying FAA pilot-to-drone regulatory conditions. By integrating fixed-wing and multirotor aircraft within a unified logistics framework, the study demonstrated how operational scalability significantly affects cost efficiency and profit generation.

Results show that expanding the operational scale from one-to-one pilot assignments to one-to-many configurations can transform unprofitable operations into viable business models. In San Francisco, profitability improved from −5.82 percent with 10 units to 16.30 percent with 20 units, while in New York City, it rose from −13.43 percent to 10.29 percent. These results validate the hypothesis that operational scalability and regulatory flexibility play a critical role in achieving sustainable UAS logistics operations.

The study contributes a reproducible economic model that standardizes all cost components such as hardware, maintenance, labor, insurance, and vertipad operations based on integer daily values, ensuring that future researchers can precisely replicate and expand upon the findings. Furthermore, the comparative analysis between San Francisco and New York highlights how local environmental and regulatory factors influence financial feasibility, offering a useful reference for policymakers considering region-specific BVLOS implementation.

Overall, this research provides a quantitative foundation for evaluating the future of multi-drone logistics in AAM ecosystems. By aligning operational modeling with realistic regulatory assumptions, it bridges the gap between theoretical cost analysis and practical commercial deployment, paving the way for further interdisciplinary studies in policy, infrastructure design, and unmanned aviation economics.

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