AI Drone-Based Delivery Systems

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Abstract — This paper discusses a document-centric systems engineering approach to an AI drone-based delivery system. Key components include the definition of needs, problem statement, feasibility study, and the beginning stages of the conceptual design and workflow. It addresses the challenges of current drone delivery systems and the implementation of a new framework.

***Keywords*— AI in Logistics, Autonomous Drone Delivery, Last-Mile Delivery Optimization, Unmanned Aerial Vehicles, Sustainable Logistics**

I. Introduction

Delivery Drones have been envisioned as the next promising business model for delivering packages. Drones can transport small objects like restaurant food, groceries, prescription drugs, and medical samples. As long as a drone can reasonably lift it, it can deliver it with a target delivery time of one hour.

This delivery method has the advantage of being able to ignore traffic and terrain, allowing it to arrive faster with time-sensitive materials. This method also introduces an environmentally friendly method solution to this last-mile delivery challenge. Where Traditional vehicle-based delivery methods would struggle to deliver to rural areas with bad infrastructure, drones can only need to fly through the air to reach their destination.

Multiple barriers exist to a business model based on a drone delivery service. The target delivery time is one hour because lithium polymer batteries only hold about one hour of charge before needing a recharge. These batteries also last only a few hundred times before they become unusable [1]. A drone has a limit to its carrying capacity; it cannot reasonably lift anything heavier than itself. Someone (or something) has to accept and deny requests while recognizing the weight capacity of a drone and the cost of a trip. An average drone battery costs on average $1200. Considering that a battery can be charged only a few hundred times, the trip will have to cover the cost of a portion of the battery usage. Consequently, the heavier an item is, the more battery will be consumed transporting it.

A drone can deliver to further distances depending on how many depots there are in the area. For example, a depot closest to a hospital can dispatch a drone to a distant location. The drone will eat up most of its battery flying this distance. However, after the medicine has been delivered, it can fly to a depot it is closest to rather than flying back. Here, the battery will be swapped for a different one, and its current one will be recharged for the next drone for maximum efficiency.

Delivery Drones are being introduced in consumer, medical, and emergencies. Its adoption is being tested and implemented in several places, indicating that this concept can be applied in the real world. With advancements in AI and battery life, we may see delivery drones accepted and used in the near future.

II. Problem Statement

Last-mile delivery - the final step of getting a package from a distribution center to the customer is one of the biggest challenges in modern logistics.

It accounts for a significant portion of total shipping costs, often exceeding 50% of overall delivery expenses [2]. Traditional delivery methods, such as trucks and couriers, are constrained by road congestion, fuel costs, and labor shortages, leading to inefficiencies and delays. In densely populated urban areas, traffic slows down deliveries, while in rural regions, long distances and limited infrastructure make traditional logistics expensive and slow.

Autonomous drone delivery presents an innovative solution by reducing reliance on road transportation, enabling direct-to-customer deliveries, and cutting operational costs. Drones can navigate over traffic, take optimized flight paths, and complete deliveries within minutes, significantly improving efficiency. Additionally, they reduce carbon emissions compared to fuel-based delivery vehicles, making them a more sustainable alternative [3]. As the demand for faster, more cost-effective, and environmentally friendly logistics grows, drone delivery is emerging as a transformative technology in last-mile logistics.

III. MARKET DEMAND

The global drone delivery market is expanding rapidly, driven by rising e-commerce demand and the push for contactless, ultra-fast deliveries. Since COVID-19, businesses and consumers increasingly prefer autonomous solutions for speed and convenience [4]. Companies like Amazon, FedEx, and UPS are already investing in drone logistics to enhance efficiency [5][6].

IV. USE CASES AND STAKEHOLDERS

Drone delivery has diverse applications across industries. In healthcare and emergency services, drones enable the rapid transportation of critical medical supplies such as vaccines, blood samples, and first-aid kits, ensuring timely assistance in emergencies. Food and grocery delivery services can use drones for quick, automated deliveries, reducing reliance on human couriers and meeting increasing consumer demand for fast service. In retail and e-commerce, businesses can leverage drone technology to offer lower-cost same-day deliveries, improving customer satisfaction while reducing supply chain inefficiencies.

The success of drone-based delivery involves multiple stakeholders. Customers benefit from faster and more convenient deliveries. Retail and e-commerce companies gain a competitive edge with reduced costs and enhanced delivery efficiency. Drone manufacturers see expanding business opportunities as demand for reliable, high-performance drones increases. Finally, logistics providers like FedEx, DHL, UPS, and Amazon can optimize their operations by integrating drones, lowering fuel expenses, and enhancing last-mile delivery capabilities

By addressing key logistical challenges, drone delivery is set to transform last-mile logistics, making it faster, more cost-effective, and highly efficient.

V. NEEDS AND IDENTIFICATIONS

A. *Medical and Emergency Needs*

The medical field requires supplies to be delivered on time. Medicine and other medicinal supplies like blood must be delivered without any damage. Medical supplies that get damaged can be considered as contaminated and can no longer be usable in certain situations. Preliminary results have found that blood delivered this way maintains its quality and can be used for clinical trials [7]. Furthermore, medical supplies must be stored and safely managed at a certain temperature. For example, “Red blood cell concentrates can be stored for 42 days at 2–6°C and platelets can be stored for 5 days at 20–24°C,” and these both typically have a short lifespan. [8]. Many low-income countries require blood transfusions during childbirth to prevent severe anemia and hemorrhage, which is the leading cause of maternal deaths [8].

There are certain areas where a standard delivery cannot be done. Areas in Africa like Rwanda do not have the road infrastructure able to handle emergency medical supply deliveries. The difficult terrain prevents road vehicles from traversing. The delivery must be done by an airdrop to reach the demands. This is one area where drones can provide a faster solution in these life-changing situations. Even in a regular scenario where cars and trucks are not hindered by difficult terrain, drone delivery is marginally faster in a city setting [9]. Zipline is a company that utilizes drones to provide medical supplies and relief in remote parts of Africa. As stated, Rwanda has poor infrastructure which creates a need for delivery through alternative means. Zipline used its delivery drones to provide in-need supplies to hospitals faster than any other mode of transportation. They deliver to 21 different hospitals in the area [10].

During disaster relief, there is a need to distribute supplies to those stranded and unable to receive help. Difficult terrain extends to these scenarios where manpower is not available to distribute supplies. Drones can be used in emergencies to quickly and safely transport food, and medical supplies to areas that would otherwise be hard to reach [11]. In an area where there is no infrastructure available to deliver, drones can bypass this by delivering straight to a location. These emergencies also include when an individual is stuck or hurt in an area without supplies like hiking or camping in remote areas. Drones can provide life-saving assistance by delivering first aid kits, water, or even communication devices to stranded individuals. The ability to traverse difficult terrain and deliver emergency supplies makes drones essential for disaster response.

B. *E-Commerce and Last-Mile Delivery Challenges*

E-commerce has seen unprecedented growth, leading to a significant increase in package deliveries. However, last-mile delivery remains a critical bottleneck, accounting for over 50% of total shipping costs [2]. Consumers demand faster, more reliable, and cost-effective solutions while businesses struggle to meet these expectations efficiently. Drone delivery offers a potential solution to minimize delays, reduce operational costs, and improve delivery accuracy.

One major concern for e-commerce is the issue of package theft, commonly referred to as porch piracy. In 2023, over 119 million packages were stolen in the United States alone, leading to losses exceeding $8 billion [12]. Traditional delivery services rely on static drop-off locations, leaving packages vulnerable to theft. Drones, on the other hand, can deliver directly to secure, pre-authorized locations, such as smart lockers, rooftop access points, or even hand-to-hand delivery using authentication technology. This enhances security, reduces theft-related losses, and increases consumer trust in online shopping.

Beyond security, drones can reduce the environmental footprint associated with last-mile delivery. Traditional trucks and vans contribute significantly to urban congestion and carbon emissions. Studies suggest that drone-based delivery, when deployed efficiently, can lower emissions per package by up to 54% compared to gasoline-powered vehicles [3]. As cities push toward greener logistics solutions, drones provide a sustainable alternative.

C. *Food and Grocery Delivery Needs*

Food delivery services face several challenges, including spoilage, delivery delays, and increased demand for fresh, on-time meal deliveries. The growing preference for quick commerce (Q-commerce) has led consumers to expect grocery and meal deliveries within 30 minutes or less. However, traditional ground-based delivery services struggle with traffic congestion, high labor costs, and inefficiencies in urban areas [5]. Drone delivery provides a direct aerial route, bypassing traffic and unpredictable road conditions to ensure timely deliveries.

Maintaining food safety and freshness is another key need. Certain perishable items, such as dairy, seafood, and frozen foods, require strict temperature-controlled conditions. Modern delivery drones can be equipped with insulated and climate-controlled compartments to preserve food quality during transit. Studies have shown that autonomous drone systems can deliver perishable goods up to 50% faster than ground-based alternatives, reducing food waste and improving customer satisfaction [13].

In densely populated urban areas, finding parking and navigating crowded streets is a challenge for food delivery workers. Drones eliminate this issue by delivering directly to balconies, rooftop landing pads, or designated drone pickup hubs. As food delivery services continue to grow, particularly with the expansion of ghost kitchens and on-demand meal services, drones offer a scalable solution to meet the increasing demand for faster, contactless, and more efficient food delivery.

D. *Environmental and Sustainability Needs*

With global efforts to combat climate change, there is a growing push to reduce emissions in logistics and transportation. Traditional delivery vehicles contribute significantly to urban pollution, with delivery vans alone accounting for 4% of total city emissions in major metropolitan areas [14].

Drones offer a low-emission alternative that reduces dependency on fossil fuels. A study by the University of Washington found that electric drones use 94% less energy per mile compared to diesel-powered delivery trucks [6]. This makes drone delivery an attractive option for companies looking to achieve net-zero carbon goals and comply with sustainability regulations.

Additionally, urban areas experience severe traffic congestion, leading to increased fuel consumption and air pollution. Drone-based delivery reduces the number of delivery vehicles on roads, easing congestion and improving air quality. Some cities are exploring the integration of drones into smart urban mobility systems, where AI-powered autonomous delivery fleets coordinate with ground-based transportation networks to optimize delivery efficiency.

Governments are also offering incentives and tax breaks for businesses adopting sustainable delivery methods. By integrating drones into last-mile logistics, companies can reduce their environmental footprint while cutting costs associated with fuel, vehicle maintenance, and labor.

VI. Feasibility Study

Another aspect of the conceptual design includes a high-level feasibility study. A high-level feasibility study consists of an assessment of the overall project, breaking down the major elements, and ensuring the idea is executable. For our project, we broke down the feasibility study into three different aspects: technical, economic, and regulatory.

A. *Technical Feasibility*

Deeping diver into the technical feasibility, first will be the component of drones. For payload capacity, according to Flyeye.io, there are three important factors: motor power, battery life, and environmental conditions. Flyeye.io offers a payload capacity calculator that factors in max thrust: maximum thrust produced by the drone’s motors, safety margin: percentage of thrust reserved for safety to ensure stable flight, and drone weight: total weight of the drone without payload (Flyeye.io) [15]. These different variables are important and are crucial to make calculations for a drones’ payload capacity to which we will take into big consideration for our system. One important note to factor is how much weight can current drones hold. Small drones are fixed-wing drones which can hold up to 44 pounds and multirotor drones can hold up to 55 pounds (Vergouw et al.) [16]. With this in mind, we can take a look at which drone will be best suited for the industry we want to select for the drone delivery AI system. Vergouw also mentions how a drone that does have a higher altitude position will allow better previews and images which can be crucial for the navigation and control of the drone.

In terms of flight range and speed, there are a number of different drones out there with various types of flight range and speed. Monkey King, which utilizes a Mach 4 supersonic drone, is capable of flying at twice the speed of sound with an altitude of 12.4 miles above ground. The drone utilizes two detonation engines which contain a propulsion system that generates thrust by rapidly burning fuel through a self-sustaining denotation wave (Bose) [17]. The two crucial points from this very advanced drone is how 1) the need for a higher altitude to achieve its desired speed and 2) the type of fuel being used for the drone.

For the navigation and control of the drone, there has to be some sort of sensors on the drone itself. One popular use in the majority of drones is cameras and microphones which are able to provide useful intelligence such as recognizing people and buildings in particular areas (Vergouw et al.) [16]. Cameras will be used with LiDAR recognition in order to be able to recognize these obstacle detections for a fully sufficient AI navigation system. Another important aspect is what navigation system is being used. Muhuri mentions two networks, Generative Adversarial Networks and Convolutional Neural Networks, which have been used for real-time obstacle detection and path planning for navigation (Muhuri) [18].

The last crucial step is making sure the drones have the right battery and power sources to be able to last the duration of the delivery path and flight. The most commonly used power source is simply battery cells which have a short range and require less operating time. Fuel cells, airplane fuel, and solar cells are not ideal for drones (Vergouw et al) [16]. By selecting battery cells, it allows us to narrow down the power source for our drones. Lithium polymer (LiPo) batteries are the most popular. However, lithim iron phosphate (LiFePO4) batteries are considered to be more safe and have a longer life cycle (Mehendale) [19]. By utilizing battery cells of either LiPo and LiFePO4, the drones will be able to deliver the packages safely.

B. Economic Feasibility

Focusing more on economic feasibility, one important factor is the cost of the whole entire system. Based on an MIT paper done by Butcher and Lim [20], they did a study based on a delivery system in Los Angeles, California. They came up with these estimated costs for the system which include: $10,000 estimate for delivery drone, $40,000 for IT upgrades and implementation costs: covers required software, hardware, and administrative resources. Drone systems are very expensive for the initial investment as they require a lot of technology and labor for full implementation. Another aspect of their study which was quite interesting was the need for a close radius to a local airport. The figure [20] below shows the percentage of customers greater than X miles from a major airport in San Diego, California. 88% of customers are at least 3 miles from an airport, but only 36% are 3.5 miles away. The main takeaway of trying to figure out the customers' distance to an airport is to try and focus where to expand and lobby for expansion within a certain mile radius. In the figure, focusing on expanding that radius at 3 miles would allow for the drone to increase the percentage of customers reached for eligible drone deliveries. By using this method, our system will be able to figure out its core consumer base and radius.

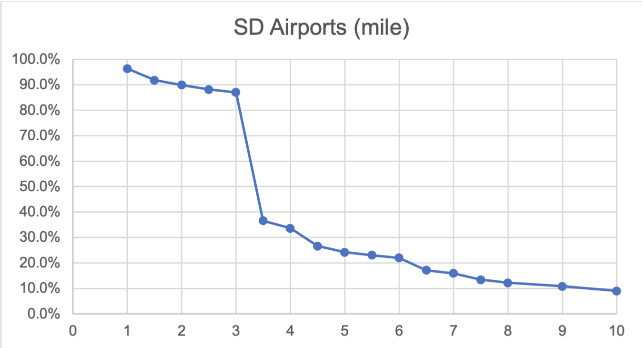


Fig. 1. percentage of customers greater than X miles from a major airport in San Diego, California [6]

Some aspects that should be considered in optimizing costs would be fuel, driver costs, and vehicle maintenance costs (Butcher and Lim) [20]. By focusing on these aspects as the business scales, it will allow for the operational costs to go down over time making the business sustainable.

C. Regulatory Feasibility

The first aspect of regulation is ensuring our drones and systems are FAA-compliant with regulations and the airspace restrictions in the delivery zone. There are many flight and airspace rules in each city and we want to make sure our drones do not violate the rules. Some areas require approvals, licenses, or permits for commercial-use flying which will ensure it is completed by the time of testing and service [21].

An important aspect of the drones includes safety concerns to ensure no air collisions and harm to other humans, animals, and buildings. Privacy concerns also arise as there are implications for a drone with cameras flying over private property. These are both concerns that deal with the external environment that may take a longer time to process as they involve different applications to the city for commercial use.

Lastly, making sure our drones and systems are fully insured in the case of collision, damage, or violation. We want to investigate and make sure who is responsible if one of these cases were to happen and how to proceed with lawyers and the insurance company.

D. Environmental Feasibility

The environmental issue of delivery drones is primarily noise pollution and energy consumption. College Station, Texas, news reported residents' opposition to Amazon drones based on the reason that they were too loud, rather than a "giant hive of bees."Furthermore, animals like birds may be irritated or even attack drones, recognizing them as a threat. On the other hand, studies indicate that drones delivering light packages within a short range have the capability of reducing greenhouse gas emissions by 54% compared to diesel trucks, even though this benefit will be dependent on the power source used in charging [22]. The need for additional infrastructure, such as warehouses and waystations, might also erase energy savings. Popular opinion among the public about drone deliveries varies, with industrial sites enjoying highest acceptance and residential sites lowest acceptance. Research suggests that privacy, noise, and safety issues influence acceptance levels; however, real exposure to drone delivery has been shown to boost public perception, as in the case of Christiansburg, Virginia, where 87% of the residents surveyed had a positive opinion of the service [23]-[25].

VII. Conceptual Design and Workflow

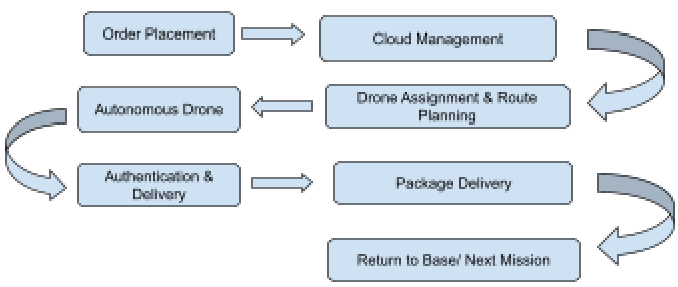
The last-mile logistics will be automated and optimized by the drone delivery platform with the help of three essential components: autonomous drones, cloud management system, and a simplified delivery confirmation system.

Autonomous drones are the first main delivery drones. Equipped with environment and weather adaptive AI navigation, real-time sensing, and autonomously collecting packages, delivering packages, and dynamically routing through weather and environment, every drone is also fitted with a secure payload bay to carry packages undamaged, and an interface for automated charging stations to enable round-the-clock use [26].

Second, the cloud-based control system is the command center. The command center issues orders, deploys drones depending on availability and geolocation, and decides best route flight trajectories using intelligent algorithms. The system also monitors operational drones in real-time, monitors batteries, complies with airspace regulation, and stores operating history to provide predictive maintenance as well as real-time performance optimization [26].

Third, the authentication delivery system offers secure package delivery to the authentic recipients. Upon arrival of the drone at the point of delivery, the drone is taken through an authentication process of scanning a QR code, OTP via SMS, or facial recognition [27]. Upon confirmation of the recipient's authenticity, the package is offloaded through secure landing or lowered down using a winch hidden in case there is no adequate space to land.

TABLE I. DRONE DELIVERY PLATFORM - LOGISTIC WORKFLOW



The logistic workflow is initiated by an order. The cloud system is automatically assigned a specific drone whenever a coming order comes in. The drone continues on its path to the drop-point, achieving verification by the receiver and successfully marking the system as being updated. It returns to base later for refueling or simply goes to the next mission.With a mix of these, the system ensures fast, safe, and economical deliveries as well as increased performance dependability and effectiveness.

VIII. MAINTENANCE AND SUPPORT

Typically a drone will need maintenance every 15 to 20 flights. During this time, a drone will be unusable until maintenance is complete. Routine maintenance is required to increase efficiency and decrease the likelihood of an accident, which can save on repair costs [28]. However, regular inspection of a drone is recommended before and after each flight. A more in-depth inspection includes but is not limited to cleaning the frame, motor, propellers, and camera of any dust and debris, and checking and testing the battery to ensure battery life. parts that may have deteriorated such as the battery and propellers will need to be replaced [29]. Batteries degrade over time and will run anywhere between 200 and 500 cycles depending on the type of battery. Replacement batteries ensure that the drone can fly a long distance. Damaged propellers can impact stability and efficiency, which can eat up more battery charge. Additionally, it is recommended that drones are kept up to the latest firmware and updates to reduce any software failures.

Additional external support is required during the pre and post-check. The pre-check needs to confirm the battery level and ensure the payload is properly secured. The post-check requires checking for any cracks, dents, or other irregularities in the drone’s frame, landing gear, or electronic equipment. Like with any machine, proper care and maintenance for these drones will extend their usefulness, and reduce failures, and ensure reliability.

IX. TECHNICAL PERFORMANCE MEASURES

Technical performance measures are quantitative values that describe the performance of our system. Below are the technical performance measures of an AI-based drone delivery system.

TABLE II. TECHNICAL PERFORMANCE MEASURES

Technical Performance Measure	**Definition / Goal**	**Quantitative Requirement ("Metric")**	**Relative Importance (%)**
Reliability (MTBF)	Metric used to measure the reliability of the system. Average time between failures that can be repaired.	≥ 1000 hours of flight time before failure	15%
Maintainability	The average time between maintenance periods.	≤ 30 minutes for standard repairs	10%
Maintenance Down Time (MDT)	Amount of time the system is not working during maintenance.	≤ 5% of total operational time	8%
Availability (Ao)	Amount of time the drone is working and available for delivery.	≥ 95% uptime	12%
Delivery time/response time (minutes)	The amount of time it takes from start to finish.	≤ 30 minutes for urban areas	10%
Flight range/delivery distance	How far the drones can go.	≥ 10 km	5%
Velocity (mph)	How fast the drones can go.	≥ 30 mph in standard conditions	5%
Payload capacity	How much load the drone can hold.	2–5 kg (depending on model)	5%
Delivery location accuracy	Accuracy of precision of the delivery location	≥ 98% accuracy	5%
Obstacle-detection accuracy	Accuracy to detect and avoid obstacles.	≥ 95%	10%
Fail-Safe Mechanism Activation Time	Time taken for the drone to activate emergency protocols (e.g., auto-landing, return-to-home) during system failure.	≤ 3 seconds	10%
Battery life	How long the batteries can last.	≥ 60 minutes	5%
			100%

X. CONCLUSIONS

Autonomous Delivery Drones offer a faster and more efficient way of transporting small packages. Many advancements such as improvements to the life of a battery and weight limitations allow this concept to become an up-and-coming business model. This business model allows companies to attack last-mile delivery by cutting out inefficient truck and courier delivery and reducing the reliance on standard infrastructure. Additionally, it provides a more environmentally friendly solution. This competitive method becomes a better solution for companies to save money, and for consumers to receive their packages faster by subverting the logistical challenges with standard delivery methods.

Delivery drones have already been implemented in parts of the world such as with Zipline delivering medical supplies in rural parts of Africa, and Amazon testing delivering packages in parts of America. As drone limitations become less restricting, this delivery method will become a key player in the future of logistics transportation.

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