The Airborne Fulfillment Center: Understanding the Feasibility and Limitations of the Flying Vessel

Evan Engler, Eric Cheon, Gabriella Fajardo Gomez, Lance Wharton, Jakob Teksler and Mohamed Awwad
Industrial and Manufacturing Engineering Department
California Polytechnic State University
San Luis Obispo, CA 93407, USA
eengler@calpoly.edu, echeon@calpoly.edu, gafajard@calpoly.edu, lwharton@calpoly.edu, jteksler@calpoly.edu, mawwad@calpoly.edu

Abstract

The purpose of this paper is to explore the potential application of Airborne Fulfillment Centers (AFC) supporting last-mile delivery. An AFC is an airship that flies over high-density areas and uses unmanned drones to complete last-mile delivery. Our research will focus on the viability of AFCs in high-density areas for last-mile delivery. Specifically analyzing the possible efficiencies and deficiencies of the model on supply chain logistics. Additionally, we will analyze the environmental and regulatory aspects of AFC implementation. Amazon and Walmart have patents for possible AFC designs, which will be evaluated. The goal of this paper will be to provide recommendations on possible AFC applications and overall viability in the near future.

Keywords
Airborne Fulfillment Centers, Last Mile Delivery, Logistics, UAV Delivery, B2C Business, Supply Chain Network

1. Introduction
The “Place Order” button is clicked, and the multi-day wait for delivery ensues – or maybe not. Maybe, a drone zips by the backyard and slows onto the porch, where it gently drops the package on the doorstep. Ding! A notification that the package has been delivered just hours after purchase. This scenario may soon become a reality with recent technologies and innovations in the supply chain field. Companies and consumers alike want packages delivered faster and cheaper, and Airborne Fulfillment Centers may provide an answer to that problem.

In this paper, we want to explore the potential of Airborne Fulfillment Centers (AFC) as well as their possible applications and limitations. The current goal of an AFC is to carry products and unmanned aerial vehicles (UAV) to assist in completing last-mile deliveries. Both Amazon and Walmart are two big players in this idea, as they have both filed patents for similar AFC designs. And while these patents may be speculative in some sense, the hope to see an AFC in the air is rooted in quantitative calculations.

Currently, there is some research on AFCs, but more needs to be done before it can conclusively be said that AFCs should be roaming the skies. With the growing popularity of UAVs in last-mile delivery, companies are starting to look at alternative ways to expand their reach. But, there are concerns with UAVs, especially surrounding their limited flight time and battery restrictions of about 30 minutes currently (Jeong et al. 2022). However, during descent they will use essentially no power until at a proper altitude close to ground level. According to the Amazon patent, an AFC delivery system would let customers receive their packages within 10 minutes after placing their orders (Jeong et al. 2021). One of the main objectives for companies like Amazon and Walmart is to expand it’s last-mile delivery operation in order to increase its customer base. A recent study found that 25% of consumers are willing to pay a large shipping premium for same-day or near instant delivery (Jeong et al. 2021). AFCs would help to alleviate these concerns and potentially expedite the process of implementing UAVs – and other alternative methods – into the global supply chain.

Figure 1. Goodyear Blimp (Goodyear 2022)

2. Literature Review

The following literature review was conducted to determine the viability and required framework for a successful supply chain model using Airborne Fulfillment Centers.

2.1 Last Mile Logistics

Over the last couple of years, the demand for last-mile logistics has risen due to the impact of COVID on supply chains and transportation networks. As more customers are asking for faster and more reliable last-mile delivery, there has been a greater need for technological advancement in transportation.

Last-mile logistics deals with the movement of goods from a hub to a final destination. The level of customer service, type of delivery, geographical area, market, density, fleet, and environment all factor into last-mile-related costs (Gevaers 2014). It is essential to be efficient in the delivery process, minimize costs, and maintain customer service.

Research in last-mile logistics has considered new trends and implemented technological developments such as digitization, automation, and robotic systems (Demir 2022). Additionally, there's been greater attention towards sustainability and decarbonization to account for the share of emissions from transportation. According to the IMA, various authors have come up with different algorithms to address customer requirements while reducing emissions. These mathematical techniques consider the negative externalities of freight transportation to identify tradeoffs between conflicting objectives, including dynamic traffic environments. Furthermore, because of the large amounts of data involved, AI decision-making processes have been used to create optimal vehicle routes and schedules (Demir 2022).

2.2 Last Mile Logistics with Drones

Drones, also known as UAVs, are growing as a future mode of transportation in a wide variety of applications in the logistics industry. An unmanned aerial vehicle (UAV) is an aircraft without any pilot and can be partially or fully autonomous (Demir 2022). During the pandemic, many logistics and retailer companies started employing more UAVs for last-mile deliveries, as it was deemed appropriate.

In 2013, Amazon introduced the use of drones for direct deliveries from fulfillment centers. Henceforth, drones have gained more recognition for their faster service and affordability. According to a study by Wang, 86% of Amazon packages weigh less than 5 lbs, and 70% of all Americans live within 5 miles of a supermarket (Wang 2016). With this in mind, a majority of e-commerce deliveries can be serviced with drones that amount to $0.88 per package compared to $5.99 with Amazon prime (Keeney 2015). Another case study by Sudbury estimates that the cost per delivery by drones is $0.30 opposed to $1.20 by truck (Sudbury 2016). Moreover, in Europe, Flytrek implemented its first drone system and was able to reduce delivery time for groceries and food from 25 minutes by car to 4 minutes by drone (Shivali 2017).

Compared to conventional vehicles, drones offer several advantages, including directness of travel and constant and high travel speed (Thiels 2015). UAVs also have no need for physical road infrastructure (Foth 2017) and exposure to traffic (Thomalla 2019). As a result, drones reduce significant delivery time and increase the responsiveness of logistic systems. Within urban areas, due to underdeveloped road infrastructures, drone usage has risen to deliver packages, especially containing medical supplies and emergency services (Moshref-Javadi 2021). Although UAVs have played a significant role within urban areas, legal challenges and public perception still need to be addressed before the full employment of drones.

2.3 Ground Fulfillment Centers

A successful and efficient supply chain requires the seamless interaction of many different operations. This includes manufacturers, distribution warehouses, retailers, and fulfillment centers. A standard fulfillment center is a “physical space where operations are set up to consistently receive inventory and package and deliver online orders, on time and intact” (Champion 2022). Typically fulfillment centers deal with business-to-customer (B2C) brands allowing products to be stored, packed, and then sent directly from the fulfillment center to the customers’ doorstep. This allows businesses to completely outsource the storage, packaging, and shipping of their products instead of doing it directly at the manufacturer (BigCommerce 2022). According to Champion (2022), fulfillment centers’ activities include; Real-time inventory management, picking and packing, order processing and fulfillment, and transportation. It is also important to note that fulfillment centers and standard warehousing are not the same. Standard warehousing involves long-term storage of bulk products, primarily used for Business to Business (B2B) sales. It is much slower moving than a fulfillment center and is not designed for next-day shipping operations (Lopienski 2018).

2.4 Urban Fulfillment Centers

When a business moves into urban locations, it becomes less feasible to have a single large space for fulfillment activities. Purchasing a large space will most likely force companies to move their fulfillment center out of the city and further from the customers increasing transportation costs. Businesses have learned to combat this with micro fulfillment centers located within the city. An example of this includes the Swisslog Automated Micro fulfillment center, which allows businesses to set up mini fulfillment centers throughout the city that are completely automated. Allowing them to store, package, and ship products directly to their customers over short distances. Decreasing transportation costs and decreasing ship times (Swisslog 2020). Urban fulfillment is becoming increasingly important, with 74% of urban customers using their phones to make purchases and 45% of them expecting same-day delivery (Kammerer 2019). Without fulfillment centers located within urban cities, these expectations are impossible to meet.

2.5 Airborne Fulfillment Centers

To tackle this logistical difficulty of choosing the right location for a full fulfillment center, especially in urban cases, a non-traditional method has been suggested: the Airborne Fulfillment Center. This system is considered unconventional because it does not rely on “traditional means of transportation, logistic networks, or even commonly used energy sources” (Kim and Awwad 2017). The airborne fulfillment center is located at a high altitude above a desired delivery area. Inventory shuttles up to the fulfillment center in small blimps, and then packages are distributed to the ground using drones or UAVs. This allows businesses to eliminate the geographical constraints of a physical fulfillment center allowing mobility based on geographical demand. Companies like Amazon and Walmart have even created their own patents for this idea.

2.6 Amazon and Walmart AFC Models

The development of UAVs to support global supply chains is an exciting field, but their limited battery supply is a major drawback to the implementation of such possibilities. Moveable stations, or fulfillment centers, are exciting systems that have yet to show their full potential. Amazon, however, sees that potential as they have filed a patent for an Airborne Fulfillment Center, or AFC for short. Amazon’s patented AFC would fly at an altitude of 45,000 feet, holding thousands of products that wait to be delivered by unmanned drones in high-density urban areas. In this patent, the drones fly up with the AFC, then carry packages down to the drop area. “As the UAVs descend, they can navigate horizontally toward a user-specified delivery location using little to no power, other than to stabilize the UAV and/or guide the direction of descent” (Margaritoff 2019). After that, they fly back to a ground fulfillment center for redeployment. The described process can be visualized in the picture below (Jeong et al. 2022).

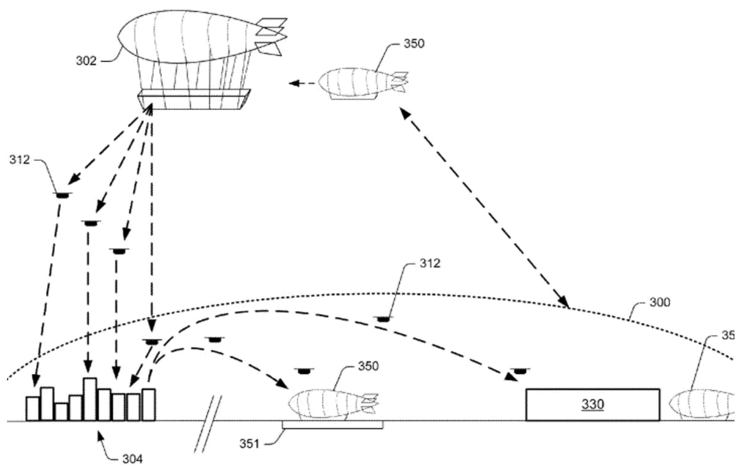

Figure 2. Amazon's AFC Delivery System (Coxworth 2016)

Walmart, the largest retailer in the US, also sees the potential of AFCs. Walmart has also filed a patent for an AFC system but with slightly different specifications. The patent states that Walmart's AFC design would "fly at heights between 500 feet and 1,000 feet (as much as 305 meters), contain multiple launching bays, and be operated autonomously or by a remote human pilot." Like Amazon, Walmart sees the AFC supporting the ongoing challenge of last-mile delivery. However, another stark difference between Walmart's and Amazon's patent is that Walmart's design has drones flying back to the vessel instead of flying to a ground distribution center. This would allow the AFC to move from town to town to expand its service area (Boyle 2017).

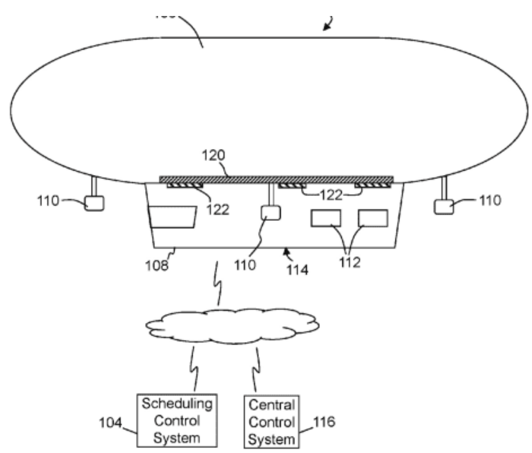

Figure 3. Walmart's AFC Delivery System (Thomas 2017)

3. Cost Analysis

Before we attempt to analyze the true viability of the AFC model in current supply chain networks, a few factors must be analyzed. The most obvious is cost. Is it economically viable to build, maintain, and operate an AFC? As a benchmark, a standard Fulfillment center costs between $240,000 and $380,000 for 20,000SqFt (Jacobs 2022). The standard amazon fulfillment center is approximately 800,000SqFt (Data Watch 2022). Using the approximations above, we can determine that a standard amazon fulfillment center costs anywhere from $ 9.6 million and $ 15.2 million. Also, note that operating costs for a standard fulfillment center are around $3/SqFt. Of course, translating these costs to an airborne fulfillment center requires some estimations. However, a standard Goodyear blimp is estimated to cost around $ 20 million, with smaller blimps costing around $ 10 million (Flanagan 2019). The additional UAVs can cost between $5,000 to $50,000 each. With this in mind, it is fair to estimate a complete AFC model with a single large blimp, multiple shuttles blimps, and hundreds of individual drones could cost a business over $ 50 million dollars. However, there are only fixed costs. The operating costs of an AFC model would drastically increase compared to a standard ground fulfillment center. The cost for the crew, maintenance, and fuel is likely to cost approximately $5Million dollars a year (Ausick 2013). On top of this, blimps require helium to float, which is extremely expensive, costing around $100,000 per trip (Cutolo 2022). This brings the total to approximately $55Million dollars for a single AFC system, excluding the extra costs of whatever drone software or employees are required to manage the fulfillment center. A detailed breakdown can be seen in Table 1.

Table 1. Cost Breakdown

Model (Qty = 1)	Equipment Cost	Operating Cost	Totals
Ground Fullfilment (800,000 Ft^2)	$9.6M - $15.2M	$2.4M /year	~$14.8M
AFC Model (300,000 Ft^3)	$50M +	$5M /year	~$55M

4. Results and Discussion

4.1 Viability and Limitations

The proposed AFC models have the opportunity to increase supply chain efficiency by removing a fulfillment center's geographical constraints, removing delays caused by traffic, and decreasing last-mile delivery time with UAVs. However, as much as the idea of unmanned UAVs delivering packages rapidly sounds extremely innovative, there are certain regulations and limitations that have to be addressed. According to the FAA, Blimps are classified as Airships and have a set of rules and regulations that differ from standard aircraft. These regulations include minimum altitude requirements, pilot qualification requirements, and operating requirements. The tricky part is that these regulations are geographically specific, and in order to operate an Airship under the Special Federal Aviation Regulation (SFAR), you must have approval from the state. The FAA also requires flight plans to be filled before a flight, limiting AFCs from spontaneous movements based on rapid demand changes. UAVs have their own set of rules and regulations from the FAA, which must be addressed as well. The drones must be registered and are restricted from flying over certain areas like government buildings or facilities.

Not only that, but there are three main restrictions for UAVs: the maximum flying height for UAVs, the UAV geofence, and the segregated airspace for UAV flights. The FAA states that "the UAV flying height must be less than 122 m (400 ft) Above Ground Level (AGL) in uncontrolled or "Class G" zones" (Xu. C 2000). As seen in Figure 4, where the maximum flying heights of UAVs are portrayed, more than 99% of the countries have a requirement of 300 m AGL. Whereas half of the countries allow between 122 m and 150 mm, and 5%, allow below 60m. Leaving 6.1% of countries that have banned UAVs as a whole, such as Russia, leaving them to fly in extreme conditions and circumstances.

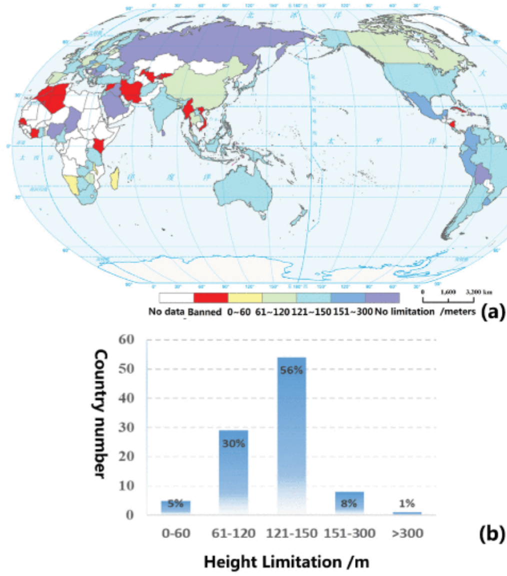

Figure 4. a) Global maximum flying heights of UAV (b) analysis for countries with specific limitations. (Note: Both professional and entertainment UAVs at micro, light or large scales were surveyed, and the height limitations here were the maximum values for different types and different scales of UAVs. (Xu. C 2000)

Next on the restrictions is geofencing for UAVs. In 2015, a hobbyist lost complete control of a small UAV, which resulted in a crash on the southeast side around the grounds of the White House. Since then, it has been proposed by multiple countries to publish temporary and permanent no-fly zones. Geofencing, the technique that defines virtual boundaries, has become the new solution for this, prompting Senator Charles Schumer to propose "a law requiring UAV manufacturers to build geofencing constraints to prevent UAVs from flying near airports and sensitive areas in 2016." (Xu. C 2000). Other countries have agreed with the geofencing method as a way to protect their properties and civilians from further UAV incidents.

Finally, legislation has been shifting to create segregated airspace for UAV flights. Government officials seek to "accommodate user demands and recent technological developments while aiming to maintain safe operations, especially for industrial applications" (Xu. C 2000). A project proposed by Amazon in 2015 called "Prime Air" proposed to divide the airspace into exclusive airspace for UAVs. As you can see in Figure 5 below, the first level is "Low-Speed Localized Traffic" and is between 61m and 200. The second level is the "High-Speed Transit," which is between 122 m and 400 m. And finally, the third level is the "No Fly Zone," which is between 152 and 500m. All of these levels depend on the building and obstacles that the drones face on their way. (Xu. C 2000).

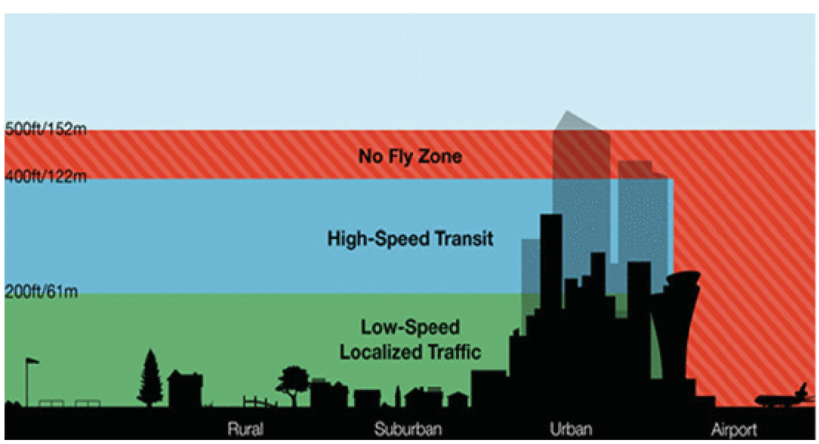

Figure 5. Airspace division for UAVs proposed by Amazon. (Xu. C 2000)

On top of the regulations, the training requirements for blimp operation are extensive. There are only 128 people in the entire United States qualified to pilot an Airship (Blimp). This is because it takes pilots at least 15 hours to learn how to operate the blimp and then another 25 to 40 hours for the flight team before they are allowed to fly solo and obtain their license (Cutolo 2022). Even after all these regulations are met, there are a few benchmarks that AFCs will need to meet in order to be considered efficient and cost-effective enough to be implemented. According to Xu et al. (2020), airships have a high potential to be "long endurance and low operating cost" high altitude vessels, but improvements in the energy storage of photoelectric cells that convert solar energy into electrical energy need to be made in order for this type of airship to be viable. Amazon's patent describes a high-altitude airship but does not mention exactly how it will be powered. The low-cost approach would be using solar energy for this high-altitude airship, but the current state of solar cells is relatively inefficient compared to other methods of energy storage.

Another roadblock that must be addressed before the successful implementation of the AFC model can be maintained is property inventory management. Specifically, determining the most effective inventory mix. Obviously, the physical storage of an AFC is limited compared to a standard ground fulfillment center. Because of this, determining the proper inventory mix is crucial. In some cases, this can be easily determined by the geographical location of the AFC model. For example, AFCs have been proposed to visit locations like sports arenas in order to deliver specific products like hot dogs or beer. In general urban fulfillment cases, there would have to be multiple AFC blimps operating over one city to maintain the supply of all the necessary products customers desire.

4.2 Proposed Improvements

A potential improvement to this system could be a similar system in low earth orbit. This system has drawbacks but also carries a lot of benefits. It is not viable with the current cost of sending goods to low earth orbits, but NASA is predicting that the cost of sending goods to space will drastically reduce in the coming decades, as shown in Figure 7. Once the cost decreases, it would be viable to have fulfillment centers in lower earth orbit. The benefit of this is that they do not use energy to stay in orbit. Once an object is in orbit, it can stay in orbit without thrust (Tonken 2020). This drastically reduces operating costs and emissions. It also allows these fulfillment centers to service a much larger area as the delivery drones have a longer distance to fall back to Earth, allowing them to use their own potential energy to achieve greater distances. The technical implication for the drones is that they would need to be able to survive reentry through the Earth's atmosphere repeatedly as well as they would be added payload weight on the shuttles back to the fulfillment center. A potential solution for the resupply shuttles is using a larger scale, more advanced version of technology recently developed by SpinLaunch called a suborbital accelerator. This technology spins an object at a high enough angular velocity in a controlled environment on the Earth's surface that the object has the velocity to reach lower earth orbit when released, as depicted in Figure 6.

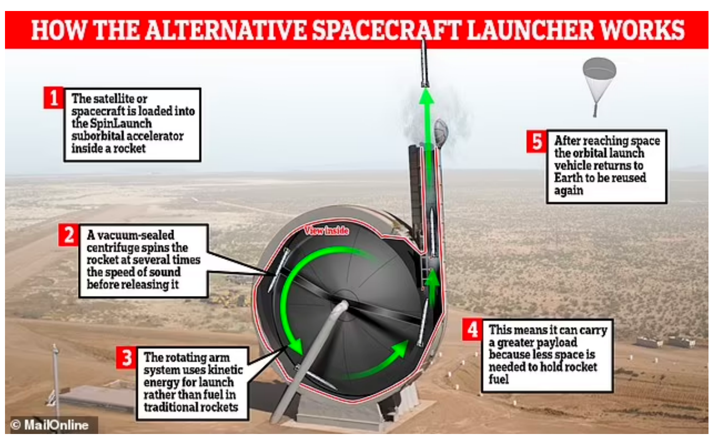

Figure 6. Alternative Rocket Launch System (Tonkin and Chadwick 2022)

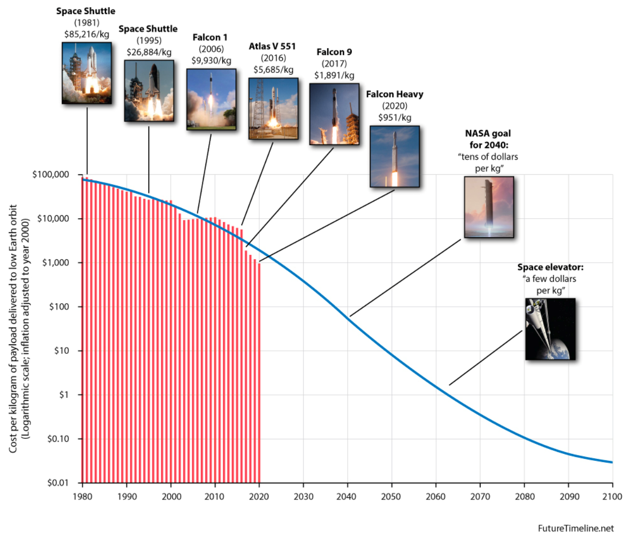

Figure 7. Launch Costs to Low Earth Orbit (FutureTimeline 2018)

5. Conclusion

As the previous sections have mentioned, the innovative technology of Airborne Fulfillment Centers (AFC) supporting last-mile delivery with UAVs will change the way the supply chain industry operates forever. Customers will be happier knowing that their packages will arrive at a faster rate with a lower price, which will overall improve the industry as a whole. Amazon and Walmart are currently trying to bring the idea of an AFC carrying products and unmanned aerial vehicles (UAV) delivering packages to life with patents. However, certain roadblocks have prevented the acceleration of this process.

Even though this drone technology can bring a lot of benefits, it's extremely costly. In this report's cost analysis, it's rather evident that having a standard ground fulfillment center would be cheaper. However, it wouldn't be as optimal as the AFC. Not only that, but there are various limitations that make the process of bringing the AFC and UAVs to life more difficult. These roadblocks include strict restrictions and legislation, power constraints, automation errors, lack of human support, and a possible AFC inventory mixup.

The real question stands, will we see AFCs in the near future? The answer remains unknown, but in order to get there, there are certain roadblocks and limitations that need to be overcome in order to achieve it. Figuring out a way to lower the cost of the technology, finding more ways to distribute airspace evenly so UAVs will have more safe space to fly, improving solar energy to power the AFC, and coming up with a self-sufficient inventory process could all be potential solutions. With this push of resolutions and the right funding, one day, we could all be receiving our packages with the help of drones, at our doorstep, at a snap of a finger.

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Biographies

Evan Engler is currently a senior at California Polytechnic State University in San Luis Obispo, California. Evan is studying Industrial Engineering with interests in optimization, supply chain, and data analytics. He has industry experience in supply chain management, warehouse management, and information technology. Evan plans to graduate in the Spring of 2023 and begin working as a Technical Software Consultant in San Francisco, California. In his free time, he enjoys hiking, cooking, and staying active.

Eric Cheon is currently a senior Industrial Engineering student pursuing my Master's in Engineering Management at California Polytechnic State University in San Luis Obispo. Eric has industry experience in project management, process improvement, and operations. Eric plans on graduating in the Spring of 2024 and looking into careers related to process improvement and project management. In addition, Eric enjoys playing music, cooking, and basketball outside of academics.

Gabriella Fajardo Gomez is a senior Industrial Engineering student at California Polytechnic State University in San Luis Obispo, California. She has industry experience in manufacturing, process improvement, operations, cybersecurity, systems, and sales engineering. Gabby plans on graduating in June of 2023 and pursuing a career in technical consulting or sales engineering. She loves hanging out with my friends and family, painting, and DJing in her free time.

Lance Wharton is a senior Industrial Engineering student at the California Polytechnic University in San Luis Obispo, California. Lance has an industry experience in inventory management and supply chain logistics working for Inspired Flight Technologies (a UAV manufacturer in San Luis Obispo), as well as Naoma systems in Fair Oaks, California. This summer, Lance will be an Industrial Engineering intern at TechnipFMC, Schilling Robotics located in Davis, California, and in the fall, I plan to pursue a master's in engineering management.

Jakob Teksler is a senior Industrial Engineering student at California Polytechnic State University in San Luis Obispo, California. I have industry experience in ERP systems, WIP processes, WIP documentation, WIP storage, and Inventory management. He is also interested in the fields of Supply Chain, Operations Research, and data analytics. He will graduate spring of 2023 and currently looking into career opportunities. In his free time, Jakob enjoys working on and racing cars, 3D printing, and watersports. He is also interested in automotive, high-tech, and space fields.

Mohamed Awwad is an Assistant Professor in the Department of Industrial and Manufacturing Engineering at California Polytechnic State University (Cal Poly), San Luis Obispo, CA. He received his Ph.D. and M.S. degrees in Industrial Engineering from the University of Central Florida, Orlando, FL, USA. Additionally, he holds M.S. and B.S. degrees in Mechanical Engineering from Cairo University, Egypt. Before joining Cal Poly, San Luis Obispo, Dr. Awwad held several teaching and research positions at the State University of New York at Buffalo (SUNY Buffalo), the University of Missouri, Florida Polytechnic University, and the University of Central Florida. His research and teaching interests include applied operations research, logistics & supply chain, blockchain technology, distribution center design, unconventional logistics systems design, and OR applications in healthcare and the military.