2018 ASEE Annual Conference & Exposition
June 24-27, 2018 Salt Palace Convention Center Salt Lake City, UT
Paper ID #22477

# Truck-Drone Two-tier Delivery Network Design

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I highly enjoyed working with Dr. Sangho Shim at Robert Morris University where I graduated summa cum laude with a B.S. in Engineering concentrating in Industrial Engineering. Dr. Shim encouraged me to be a better student and professional during our work together on research and in the classroom. After success at RMU, I accepted a full time position as an Industrial Engineer with FedEx Ground where I apply many of the principles learned through my academic career.

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Dr. Sangho Shim is an Assistant Professor in the Department of Engineering at Robert Morris University (RMU) in Pennsylvania.

Before he joined RMU in Fall 2015, he had performed research projects on combinatorial optimization as a research staff member of Kellogg School of Management at Northwestern University. He also performed the General Motors Renewable Energy Portfolio project with Industrial Engineering and Management Sciences Department of Northwestern University since 2011. At Northwestern University and Georgia Institute of Technology, he also conducted the KT (Korea Telecom Corp) Smart Grid Project and the KT-LG Illinois Smart Building Project as Manager of KT in 2010-2011.

Dr. Shim was an Instructor at Georgia Institute of Technology in 2009-2010 since my PhD degree in Industrial and Systems Engineering from the institute.

Before he came to the US, he got BS in Mathematics at Seoul National University and MS in Computational Mathematics at POSTECH in Korea.

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# Parcel Delivery Utilizing Drone Technology: Optimal Truck-Drone Network Flow

## 1. Introduction

It is said that necessity is the mother of invention. With the growing demand for quick and low cost deliveries many companies are searching for ways to best meet demands. Delivery drones are the invention many companies are finding may be the answer. Drones like other new technologies require the acceptance of both public and government. According to the Federal Aviation Administration (FAA), drones are currently not allowed to be flown for commercial deliveries in the United States [1]. They have approved certain exceptions which have allowed companies to test drone delivery technology, and these tests have been successful. Once safety can be established, companies will still have to determine how best to utilize drones, increase payload and establish drone networks. The outlook for commercial delivery using drones does appear to be bright and getting brighter every year.

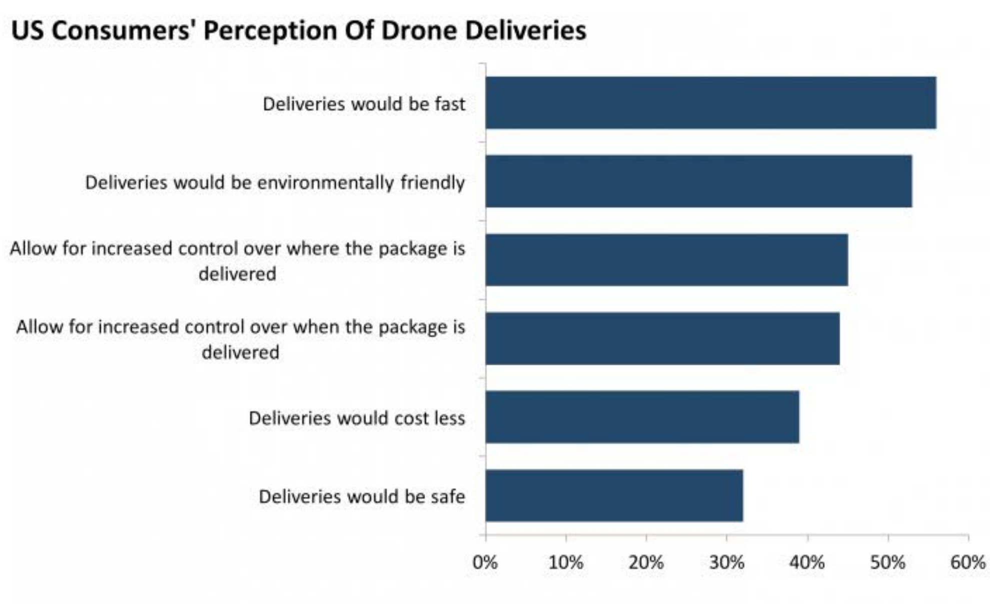


**Figure 1:** US Consumers of Perception,
Source: United States Postal Service Public Perception of Drone Deliveries Report [2]

With the rapid demise of snail mail and the explosive double digit growth of e-commerce, postal companies have been forced to seek new ways to move past their traditional letter delivery business models. Different postal companies from Australia, Switzerland, Germany, Singapore and Ukraine have undertaken various drone trials as they test the feasibility and profitability of unmanned delivery drone services. On the 13th of March 2015, in Sheffield, England, FPS Distribution completed the first commercial delivery using an Unmanned Aerial Vehicle (UAV). UAVs can transport medicines or vaccines and retrieve medical samples from in and out of remote or otherwise inaccessible regions. "Ambulance drones" rapidly deliver defibrillators in the crucial few minutes after cardiac arrests, and include live stream communication capability allowing paramedics to remotely observe and instruct on-scene individuals in how to use the defibrillators [3]. In July 2015, the FAA approved the first such use of a drone within the United States, a UAV to deliver medicine to a rural Virginia medical clinic in a program called "Let's Fly Wisely" [4].

## 2. Prospects and Challenges in Implementing Drone Technology for Delivery

According to "The Energy Implications of Drones for Package Delivery A Geographic Information System Comparison," the 20-percent drone scenario would require 13 fewer truck routes, 468 fewer truck miles, and 46.8 fewer gallons of diesel fuel (assuming an efficiency of 10 miles per gallon (MPG), which is consistent with the National Renewable Energy Laboratory NREL data) [5]. The drone delivery would involve 1,550 drone trips totaling 9,406 miles flown. Drones, however, are much lighter than trucks and thus take less energy to move—even in flight. Assuming a tilt-rotor fixed-wing design, other work in this project suggests a delivery drone fuel economy on the order of 460 MPGe (MPG equivalent), allowing all the drone deliveries to be conducted with the energy equivalent of 20.4 gallons of diesel. This results in a savings of the equivalent of 26.4 gallons of diesel for a net savings of about 5.7 percent when drones are used to cover 20 percent of the stops as compared with using trucks to make the same deliveries.

| Categories Analyzed | Baseline: 100 Percent Trucks/0 Percent Drones | Scenario: 80 Percent Trucks/20 Percent Drones | Difference |
|---|---|---|---|
| Truck delivery areas | 86 delivery areas | 73 delivery areas | 13 fewer truck delivery areas |
| Truck miles | 4,596 miles | 4,128 miles | 468 fewer truck miles |
| Truck fuel use (10 MPG) | 459.6 gallons | 412.8 gallons | **46.8 fewer gallons** |
| Drone stops | 0 stops | 1,550 stops | 1,550 more drone stops |
| Drone miles | 0 miles | 9,406 miles | 9,406 more drone miles |
| Drone fuel use (450 MPG) | 0 gallons (MPGe) | 20.4 gallons (MPGe) | **20.4 more gallons (MPGe)** |

NOTE: MPG = miles per gallon. MPGe = miles per gallon equivalent.

Figure 2: Results of the Energy Analysis [5]

The drone delivery system is currently still undergoing several studies and has not been fully deployed by any company as of today. It seems that UPS and Amazon are the companies that are more open to their recent trials with using the drone delivery system, as FedEx is not admitting or denying their intentions to use the technology [6].

Amazon, UPS, and FedEx have worked together in the development of this technology to gather flight data that will help prove that the drone technology is safe to use. UPS has made several drone test flights in a race to gather safety data for the technology. They used a simulated situation in Massachusetts that required drones to deliver medical supplies to the area. The purpose behind this move was to hopefully have regulations loosened in the United States when it comes to using robotic aircrafts [6].

As of 2016 the FAA stated that the testing conditions of drone delivery included that the aircraft had to be under 55 pounds, not fly over the people involved in the operation, and must remain in sight of the operator. Waivers have come about to let the aircraft go outside of the view of the operator to test the operations in different weather conditions [6].

Late in December of 2016 Amazon delivered its first package by drone legally in the United Kingdom. The test took place within five miles of the initial testing facility and was a success. Britain’s Civil Aviation Authority will allow addition deliveries to occur once there is data to prove the safety of the drone operation. Amazon will continue to test the drone operations in rural areas and lead into suburban areas after data is collected. There are weather conditions that have to be considered when testing the drone in the UK, but there are not regulations on how far out of sight the drone can go from the operator [7].

According to Fortune.com, reporters believe it will be several years until drones can be used to deliver everyday items to customers. In February of 2017 UPS reported they successfully used a drone to drop off a package in Tampa, Florida. This test was not the first but included extra technology regarding the battery power and charging stations of the drone. The drones require a large amount of power, and most can only fly for approximately 30 minutes due to the power needed. UPS is working on a technology that will use a van as a mobile charging station for the drone. This process is not the optimal solution to the battery power shortage but is still efficient to use while technology is still being processed and studied [8]

Although drone technology is making major advancements, there are still a few obstacles that can restrict this new technology. The three main conflicts that really stand out are safety regulations, technological capability, and cost [9]

First, safety regulations are the biggest factor restricting drone technology. Before drones will be able to be placed into the air, they must get authorization from the FAA, which can sometimes be a difficult process. The purpose of the FAA is to eliminate harmful drone flights. According to the article “Drone (legally) delivers packages, but the technology still needs work,” the sky environment needs to ensure the FAA that there will be no other traffic in the air and that the surrounding environment is free of any disruptions in order to be considered safe [9]. The placement of the drone must be in a wide open space. With this being said, it raises the question of how drone technology would work in areas with larger populations or rural areas that are filled with trees and hills.

While the convenience of drones sounds ideal, they still can run into the factor of crashing into civilians, homes, or other obstacles. It is a really scary fact that with a large number of whirling blades, a malfunctioning drone could potentially cause wreckage to people or property.

As far as the technological capability, with a test conducted where a drone from Oakwood, VA was flown to a remote medical facility in Wise County, VA, the batteries in the drones were not progressive enough to allow the drone to travel the 20 mile distance [9]. This could cause a problem when finding a battery strong enough to travel further distances. Graham Starr reports that technology hasn't gotten to the point that it can properly observe a street address, and that it must have exact GPS coordinates.

Finally, the delivery drone must meet customer demands. In doing this, the process must be cheaper and more efficient than traditional delivery methods. If the delivery cost for a drone is more expensive than a tradition method, then the profits will be less [9].

## 3. Approach

In order to examine the effect drone deliveries could have on the Pittsburgh area, we chose to investigate possible drone hub locations using current FedEx locations. There are ten locations possible to utilize as new drone hubs. The main criteria for choosing a location is the distance between the possible hub and different zip codes.

In this project, we used a multi-nodal drone delivery network, combining line haul and UAVs, over a linear programming formulation known as big-M in order to generate optimal route solutions based on minimizing costs.

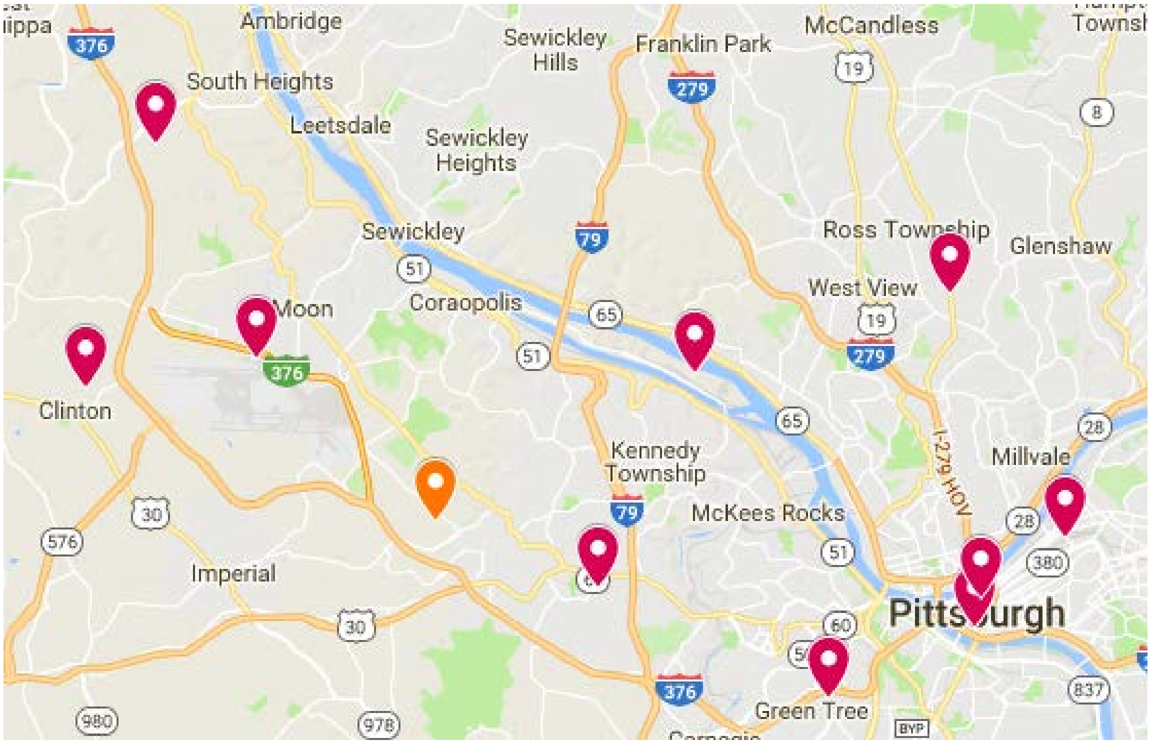


Figure 3 FedEx hubs used in analysis.

The Hub Headquarters, located in Moon, is denoted by the orange pin. We hadpreviously completed this analysis on a smaller scale chose to use the FedEx Ground Headquarters in Moon Township, PA as the network's main hub. FedEx Office locations were chosen as potential drone distribution facilities (denoted as "hubs" in our analysis) based on their proximity to the office in Moon. Ten zip-code locations were chosen within the Pittsburgh area to use as drone drop off locations with zip-code populations serving as product demand.

We used Google Map technology to obtain best highway route, mileage, and time determination for truck travel. Latitude and longitude information for each zip-code was also obtained. After longitude and latitude coordinates were determined, Haversine's Formula, which calculates distance between points on spheres, was used to calculate distance between drone facilities and zip-code destinations.

Figure 4 shows the addresses of all ten hubs as well as their latitude and longitude information and their distance from the main distribution center.

| Name | Latitude | Longitude |
|---|---|---|
| Hub HQ | 40.46344 | -80.177522 |

**Level 2 Nodes**

| Name | Latitude | Longitude | Dist. HQ (miles) | Time |
|---|---|---|---|---|
| Hub 1 | 40.500546 | -80.091268 | 8.3 | 19 |
| Hub 2 | 40.504396 | -80.237471 | 5.1 | 8 |
| Hub 3 | 40.520763 | -80.005793 | 18 | 23 |
| Hub 4 | 40.497291 | -80.294606 | 8.9 | 14 |
| Hub 5 | 40.558238 | -80.270988 | 11.3 | 17 |
| Hub 6 | 40.447132 | -80.122989 | 4.1 | 9 |
| Hub 7 | 40.419361 | -80.046478 | 9.3 | 13 |
| Hub 8 | 40.437209 | -79.997934 | 12.5 | 18 |
| Hub 9 | 40.459723 | -79.967097 | 15 | 24 |
| Hub 10 | 40.444138 | -79.995882 | 12.6 | 20 |

| Name | Address |
|---|---|
| Hub HQ | 1000 FedEx Dr, Coraopolis, PA 15108 |
| Hub 1 | 2702 Neville Rd, Pittsburgh, PA 15225 |
| Hub 2 | Rte 60 Cargo Building 2, Pittsburgh, PA 15231 |
| Hub 3 | 4771 McKnight Rd, Pittsburgh, PA 15237 |
| Hub 4 | 2291 Sweeney Dr, Clinton, PA 15026 |
| Hub 5 | 800 Corporation Dr, Aliquippa, PA 15001 |
| Hub 6 | 1140 Omega Dr, Pittsburgh, PA 15205 |
| Hub 7 | 962 Greentree Rd, Pittsburgh, PA 15220 |
| Hub 8 | 210 Grant St, Pittsburgh, PA 15219 |
| Hub 9 | 351 32nd St, Pittsburgh, PA 15201 |
| Hub 10 | 960 Penn Ave, Pittsburgh, PA 15222 |

Figure 4: Addresses of ten hubs with Latitude and Longitude Information

## 4. Results

Figures 5a and 5b above show calculations using OpenSolver in Excel. Fixed costs were calculated using the average rent per square foot per month in the Pittsburgh area, which is $1.83. That amount was multiplied by the approximated square footage of the specific FedEx hub. Variable costs are based on the distance from that hub to the FedEx headquarters in Moon.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25620 | | | | Fixed Costs | 9,150 | 0 | 14,640 | 0 | 10,980 | 0 | 7,320 | 0 |
| 69428.96 | | | Balance HQ | Variable Costs | 8.3 | 0 | 5.1 | 0 | 18 | 0 | 8.9 | 0 |
| min 95048.96 | = MIN | | -211054 | | Hub 1 | | Hub 2 | | Hub 3 | | Hub 4 | |
| | | | | | | | | | | | | |
| | | | | | | 0≥ 0 | | 0≥ 0 | | 0≥ 0 | | 0≥ 0 |
| | | | = -211054 | | 0 | b 0 | 0 | b 0 | 0 | b 0 | 0 | b 0 |
| | | Zip Code | Population | | 0= 0 | Dist To Zip | 0= 0 | Dist To Zip | 0= 0 | Dist To Zip | 0= 0 | Dist To Zip |
| | | 15236 | 29724 | 29724 | 0 | 12.545 | 0 | 17.679 | 0 | 12.566 | 0 | 19.80272 |
| | | 15216 | 23350 | 23350 | 0 | 6.814 | 0 | 12.263 | 0 | 7.863 | 0 | 14.68509 |
| | | 15071 | 9956 | 9956 | 0 | 8.131 | 0 | 6.985 | 0 | 12.345 | 0 | 8.163989 |
| | | 15211 | 11081 | 11081 | 0 | 6.149 | 0 | 12.536 | 0 | 6.317 | 0 | 15.16883 |
| | | 15221 | 31060 | = 31060 | 0 | 12.362 | 0 | 19.825 | 0 | 9.061 | 0 | 22.67192 |
| | | 15214 | 14352 | 14352 | 0 | 4.006 | 0 | 11.553 | 0 | 2.914 | 0 | 14.48242 |
| | | 15108 | 40153 | 40153 | 0 | 5.189 | 0 | 2.513 | 0 | 9.784 | 0 | 5.500365 |
| | | 15102 | 29529 | 29529 | 0 | 12.766 | 0 | 16.443 | 0 | 13.991 | 0 | 18.15538 |
| | | 15136 | 21849 | 21849 | 0 | 2.329 | 0 | 7.109 | 0 | 6.504 | 0 | 9.885038 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 8,235 | 0 | 13,725 | 13725 | 11,895 | 11895 | 12,810 | 0 | 7,320 | 0 | 18,300 | 0 |
| 11.3 | 0 | 4.1 | 17191.15 | 9.3 | 52237.81 | 12.5 | 0 | 15 | 0 | 12.6 | 0 |
| Hub 5 | | Hub 6 | | Hub 7 | | Hub 8 | | Hub 9 | | Hub 10 | |
| | | | | | | | | | | | |
| | 0≥ 0 | | 0≥ -139096 | | 0≥ -71958 | | 0≥ 0 | | 0≥ 0 | | 0≥ 0 |
| 0 | b 0 | 71958 | b 1 | 139096 | b 1 | 0 | b 0 | 0 | b 0 | 0 | b 0 |
| 0= 0 | Dist To Zip | 0= 0 | Dist To Zip | 0= 0 | Dist To Zip | 0= 0 | Dist To Zip | 0= 0 | Dist To Zip | 0= 0 | Dist To Zip |
| 0 | 21.48604 | 0 | 10.55724 | 29724 | 6.505954 | 0 | 6.78393 | 0 | 8.301649 | 0 | 7.245166 |
| 0 | 15.88586 | 0 | 5.064047 | 23350 | 0.731223 | 0 | 2.904056 | 0 | 5.149123 | 0 | 3.30947 |
| 0 | 11.0937 | 9956 | 4.360268 | 0 | 7.579353 | 0 | 10.27806 | 0 | 12.21813 | 0 | 10.48099 |
| 0 | 15.89127 | 0 | 5.544921 | 11081 | 1.575115 | 0 | 1.263121 | 0 | 3.458436 | 0 | 1.601236 |
| 0 | 22.60107 | 0 | 13.31492 | 31060 | 9.392598 | 0 | 6.731871 | 0 | 5.285064 | 0 | 6.627007 |
| 0 | 14.25122 | 0 | 5.87214 | 14352 | 4.415935 | 0 | 3.176685 | 0 | 3.114378 | 0 | 2.78395 |
| 0 | 5.856245 | 40153 | 5.075349 | 0 | 9.381255 | 0 | 10.99073 | 0 | 12.04319 | 0 | 10.91097 |
| 0 | 20.46162 | 0 | 9.812046 | 29529 | 6.875115 | 0 | 8.397368 | 0 | 10.39054 | 0 | 8.887752 |
| 0 | 10.42716 | 21849 | 1.721637 | 0 | 4.838202 | 0 | 6.313848 | 0 | 7.547006 | 0 | 6.261267 |

Figure 5 Excel calculations for OpenSolver in Microsoft Excel

According to the calculations using OpenSolver in the Excel worksheet, Hubs 6 and 7 appear to be viable options for the drone parcel delivery. However, upon closer examination, Hub 6 is more than 10 miles away from a few of the zip codes listed. Since one of the limitations is a 10 mile distance maximum, Hub 6 cannot be used. Therefore, Hub 7 is the only option. This FedEx office is located in Greentree, and from this location an estimated 207,000 people could be serviced with drone deliveries. As noted in the top right corner of Figure 5a, the minimum cost for this network configuration was determined to be $95,049.

## 5. Conclusion

There should be more research on using the drone technology for delivery of parcels by combining the truck-drone network. There are various technological and societal challenges that should be overcome and practical aspects of the problem should be considered. Testing must still be done to ensure safety, but using trucks or vans in tandem with the drone technology would save costs, help with battery life of drones, and create and intricate and efficient delivery network that would require less human effort.  Adding drones to truck deliveries to aid in last mile deliveries could add great value to shipment companies, and more research and analysis into this concept would definitely be beneficial on a long-term, large scale.

This work serves an initial starting point for application of general facility location problems to a specific problems for drone delivery using a very common and easy to use platform Microsoft Excel. It serves as an educational tool for introducing linear programming models to the students for providing a research opportunity for a very popular and interesting hot field. The study comes with the limitations such as only the distance is considered in the analysis, but as well as the distance, demand information is a very important factor for facility location decisions. Incorporating the demand in the analysis would also contribute to the scalability of the solution to a similar problems and the student project in the future might be expanded to incorporate various considerations such as no-fly zones, more accurate distance metrics, incorporating demand information, and technical aspects of the drone etc.

**Acknowledgement.** Dr. Sangho Shim must thank the Center for Innovative Teaching at Robert Morris University for supporting his presentation at ASEE 2018.

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