Simulation Test Bed for Drone-Supported Logistics Systems

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Summary: Our research focused on the impact of using drones to resupply transshipment points on delivery times and travel distance, in an urban environment. We have developed an optimization model that uses the coordinates of customers and the actual travel times between these coordinates to fix the ideal location of the transshipment points. Using the coordinates, the travel times, and the transshipment point locations we made a simulation model of two cities. Our simulation indicates that using drones to resupply transshipment points can significantly reduce delivery times. The ideal number of transshipment points is highly dependent on the city and its topology. The number of drones, loading capacity, and speed of the drones have little to no impact on the delivery times and distance traveled.

Before coming to MIT, Brent worked for 2 years in offshore oil and gas as a field engineer at Schlumberger, where he supervised service crews. He then worked for 3 years as an application engineer at Flowserve, where he managed all products and services at a customer location. He holds a Bachelor of Science in chemical engineering from University of California Santa Barbara.

Before coming to MIT, Kristof worked for 10 years in the textile industry as the operations director at Sample King in China. He led various improvement and automation projects and turned the factory and products into an example for the industry. He holds a master's degree in business economics and a master's degree in Management Information Systems from KU Leuven.

KEY INSIGHTS

1. **Using drones to resupply transshipment points will greatly reduce delivery times and distance traveled.**
2. **The number of drones is determined by the interarrival time of the orders, drone capacity, and speed.**
3. **When choosing the number of trucks, there is a tradeoff between delivery time and distance traveled.**

INTRODUCTION

New technologies for urban delivery are being developed. One of these technologies is drones. These vehicles have become more and more capable. They carry heavier weights, fly longer distances, and are better able to avoid obstacles than previous drone designs and they do all this without the intervention of an operator.

As with most technologies, there are advantages and disadvantages with using drones, but what is generally accepted is that these vehicles can bring added value to the package delivery services currently offered. What is not as clear is how to use drones to best complement current package delivery techniques. The four models outlined below are all being researched or tested and have the potential to change conventional package delivery.

- Direct to Customer: In this scenario the drone leaves from the distribution center (DC) and delivers the package directly to the customers. Limitations such as batch deliveries and over-crowded airspace make this a less than ideal solution in an urban environment.
- Flying Sidekick: This is a model where the truck picks up the packages from a DC and a drone travels with the truck. The actual delivery is done by either the truck or the drone. This way of working allows the trucks to travel shorter routes as the drones can be used for supplying outlying customers. This model is inefficient for same-day delivery since the trucks need to return to the DC.
- Drone Resupply of Transshipment Points: In this model the drones continuously deliver packages from the DC to remote transshipment points (TPs) in the delivery area. The truck loads up at a local TP and delivers the packages. This model enables same-day delivery without the need for the truck to return to the DC.

- Drone Resupply of Trucks: The trucks are initially loaded at the DC and then set out on their route. While the trucks are doing their deliveries, drones constantly resupply them with new packages for same-day delivery. The truck handles the last mile by conventionally delivering the packages directly to the customers. This model allows for batching and same-day delivery. Packages do not need to wait at the DC for a truck to come back either.

The hypothesis is that by using the Drone Resupply of Transshipment Points model, both delivery time and travel distance can be significantly reduced when compared with traditional Truck-only models. Through a simulation model the potential delivery time improvements and truck travel distance reductions are quantified. A sensitivity analysis was done on various parameters influencing delivery times and travel distance.

METHODOLOGY

We used a subset of delivery locations in the city of Boston, MA, and the city of Pittsfield, MA, to model a realistic coverage area. All the packages are distributed from one distribution center in each city to the delivery points.

All packages start at the distribution center. The distribution center generates packages for different destinations using an exponentially distributed order interarrival time (IAT). The IAT is the calculated package arrival rate from a sample of packages delivered on a single day by a package delivery service. Any package that is being routed to a customer has two destinations: the transshipment point and the delivery address.

For each city the location of the TPs is determined by a mixed integer linear program that minimizes the total delivery time. In the optimization model every customer (Dots in Figure 1) must be served from one TP (Diamond shapes in Figure 1). This optimization was run for 1 to 4 TPs per city.

Since the DC for Boston is in the city (Green X in Figure 1), packages can be delivered directly to the customer. In contrast, the DC for Pittsfield is outside the city and therefore packages ship to the TP before they can be dispatched to a customer.

BOSTON RESULTS AND DISCUSSION

The city of Boston is an urban package delivery environment. Two package interarrival times, 1 minute and 0.5 minutes, were used as model parameters. The Truck-only and the Drone Resupply of Transshipment Points models are simulated and compared to our baseline.

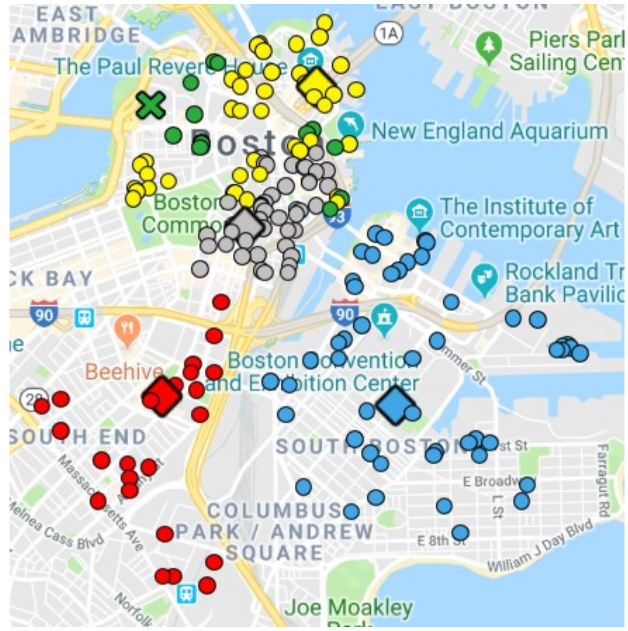

Figure 1: 4 Transshipment point locations in Boston

A Truck-only model was created in Boston to compare to the results of the Boston Drone Resupply of Transshipment Points model. To achieve a delivery time of about 3 hours, 7 trucks were used for an IAT of 1 minute and 14 trucks were used for an IAT of 0.5 minutes. The truck distance traveled doubled for the faster interarrival time as expected, but the average delivery time did not stay the same when doubling the number of trucks. (see Table 1).

Using drones and TPs for delivering packages has a big impact on delivery times (see Table 1). Adding one TP and using 5 drones for resupplying those TPs reduces the delivery time 25% to 28%. Adding 4 TPs and 5 drones results in a delivery time decrease of 66% to 73% for IATs of 1 minute and 0.5 minutes, respectively.

The impact on truck distance traveled is much less, however, still significant. Using 4TPs and 5 drones the total distance traveled by the trucks decreases 4% to 11% depending on the interarrival time. Both the package delivery time and total distance traveled by the truck decreases, except when the number of TPs increases from 1 TP to 2 TPs.

The reason for this is that the location of TPs was optimized using delivery times and this creates non-circular clusters. The cluster with 1 TP can still be considered circular and adding a second TP makes the clusters become less circular. As more TPs are being added, the clusters become more circular and the routes become more distance and time efficient.

The Drone Resupply of Transshipment Points model with four TPs was selected for the baseline scenario in Boston.

	Interarrival Time (minutes)	# TPs	# Trucks	# Drones	Drone Capacity (packages)	Drone Speed (km/hr)	Delivery Time (hours)	Truck Travel Distance (km)
Boston	1	4	7	5	5	50	2.95	571
	0.5	4	14	5	5	50	3.31	1134
Pittsfield	18	1	1	1	5	50	1.06	338
	9	1	1	1	5	50	2.66	254

Table 1: Baselines for Boston and Pittsfield

The simulations for Boston were most sensitive to the IAT, the number of trucks, and transshipment points. The number of drones and drone capacity were not as influential; these parameters were only significant when there are not enough drones to keep up with package delivery.

Drone speed does have a statistically significant impact on the package delivery time for an IAT of 0.5. The delivery time decreases by 10% when the drone speed is increased from 40 km/hr to 60 km/hr.

PITTSFIELD RESULTS AND DISCUSSION

Pittsfield is a more rural environment. A Truck-only model was created for the Pittsfield region to compare to the results from the Pittsfield Drone Resupply of Transshipment Points model. The baseline parameters used in Pittsfield are different from Boston's baseline parameters because one truck and one drone can reach a delivery time well below 3 hours for all simulations (see Table 1).

In Pittsfield, with an IAT of 18 minutes, adding a drone and 1 TP led to a 35% reduction in package delivery time and a 23% reduction in the number of kilometers driven. The 9-minute IAT simulation resulted in a reduction of delivery time of 20% but caused a slight increase (2%) in the distance traveled.

Choosing the number of TPs in Pittsfield is not straight forward. With 1 TP the delivery time is minimized, but with 2 TP the travel distance is minimized with a small penalty in delivery time (see Figure 2). The reason for the increase in travel distance is that there is only one truck servicing all the customers, and with more than 1TP the truck ends up traveling between TPs.

The Pittsfield delivery times were most sensitive to the IAT. The delivery time doubled when IAT is lowered from 18 to 9 minutes. In contrast to delivery time, the IAT has little effect on the distance traveled.

The number of trucks also has a big impact. Using 2 trucks reduces the delivery time from 2.1 hours to 0.7 hours and it also doubles the distance traveled.

The drone speed has some effect on the delivery times. The number of drones and the capacity of the drones do not affect delivery time or travel distance.

CONCLUSION

The region, the location of the customers, and the IAT of the orders are the most important factors that are needed for evaluating the impact of the Drone to Resupply Transshipment Points model. Depending on the number of TPs, delivery time and cost may vary, and the optimum will depend on the region and the IAT.

Our optimization model can determine the best TP locations for varying numbers of transshipment points. Using the attained TP locations in our simulation model will give an indication of delivery times and truck travel distance.

The optimum number of TPs and number of trucks will vary from region to region and on the trade-off between delivery times and distance traveled.

In all scenarios we must ensure that the number of drones, drone capacity, and drone speed can keep up with the demand requirements. When this is the case these variables have no major impact on delivery speed or travel distance.

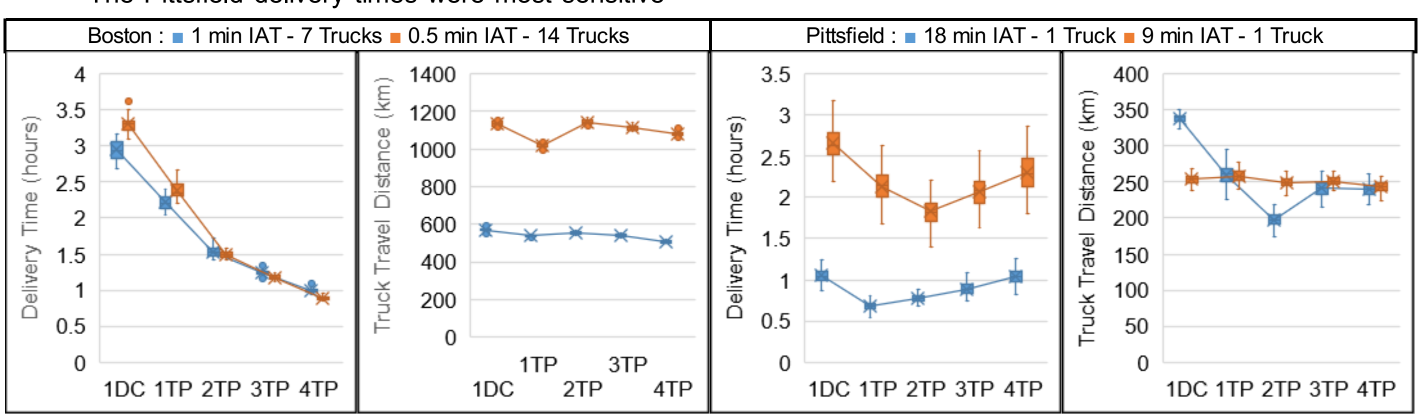

Figure 2: The impact of varying the number of transshipment points on delivery time and truck travel distance.