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Heuristic Method for Collaborative Parcel Delivery with Drone*

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Abstract

Purpose – Drone delivery is expected to revolutionize the supply chain industry. This paper aims to introduce a collaborative parcel delivery problem by truck and drone (hereinafter called “TDRP”) and propose a novel heuristic method to solve the problem.
Research design, data, and methodology – To show the effectiveness of collaborative delivery by truck and drone, we generate a toy problem composed of 9 customers and the speed of drone is assumed to be two times faster than truck. We compared the delivery completion times by ‘truck only’ case and ‘truck and drone’ case by solving the optimization problem respectively.
Results – We provide literature reviews for truck and drone routing problem for collaborative delivery and propose a novel and original heuristic method to solve the problem with numerical example. By numerical example, collaborative delivery is expected to reduce delivery completion time by 12~33% than ‘truck only’ case.
Conclusions – In this paper, we introduce the TDRP in order for collaborative delivery to be effective and propose a novel and original heuristic method to solve the problem. The results of research will be help to develop effective heuristic solution and optimize the parcel delivery by using drone.

Keywords: Drone Routing, Collaborative Delivery, Heuristic Method, Synchronization Constraints.

JEL Classifications: C44, C61, C65.

1. Introduction

A delivery drone, is an unmanned aerial vehicle (UAV) utilized to transport packages, food or other goods and the delivery of parcel or package using drone is inspired by the increasing interest of commercial companies such as Amazon, Google, DHL, and Walmart (Poikonen et al., 2017). According to The Walker Sands Future of Retail 2016 Study, 79% of United States consumers said they would be “very likely” or “somewhat likely” to request drone delivery if their package could be delivered within an hour. And 73% of respondents said that they would pay up to $10 for a drone delivery.

Drone delivery is expected to revolutionize the supply chain industry and we can see many application areas of delivery drones such as healthcare, food and postal services since UAVs can transport medicines and vaccines, and retrieve medical samples, into and out of remote or otherwise inaccessible regions.

In 2015, the FAA(Federal Aviation Administration) of United States approved the drone delivery of medicine to a rural medical clinic in a program called "Let's Fly Wisely“. Furthermore, Flirtey, a drone specialist, has partnered with Domino’s Pizza to pioneer the first commercial pizza-by-drone delivery service.

Amazon is another pioneer to use drones to deliver parcels to people in the UK. Amazon's autonomous drones can fly at heights of up to 400ft at speeds of up to 55mph and carry parcels up to 5lbs. Amazon plans to make thousands of items available for drone delivery, ranging from personal electronics to food items.

Japan Post as well as USPS(United States Postal Services) is considering using drones in step for postal service.

It is known that drone delivery has many economic advantages over delivery by trucks or motorcycle(Goodchild & Toy, 2017). First of all, drones can fly in a straight line to

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their destination and they can avoid traffic congestion. Furthermore, drones are ideal for delivery of medicine to remote areas and drone deliveries have minimal environmental impact compared with traditional deliveries by road, rail, or air.

However, investment and operating cost of drone delivery is unpredictable and is not that much. Amazon's cost per package for delivery would be roughly 88 cents. Amazon's Prime Air program will require 30,000-40,000 drones making 30 deliveries a day to serve their customers and each drone will cost $1000-$3000. Roughly 6,000 human operators will be needed to pilot the drones to comply with regulations and additional costs will be spare batteries ($200 each), maintenance ($15 million per year) and fuel ($4 million per year).

However, there are some limitations for drone delivery compared with truck delivery (Pulver & Wei, 2018). Drones are battery-operated such that there are some constraints for weight, distance, flying time and have limited service range as you can see in <Table 1>.

<Table 1> Comparison of transportation medium

	Speed	Constraints	Coverage	Operation
Drone	Fast	Limited (weight, distance, flying time)	Narrow	Semi-autonomous
Truck	Normal (traffic congestion)	Unlimited	Wide	Autonomous

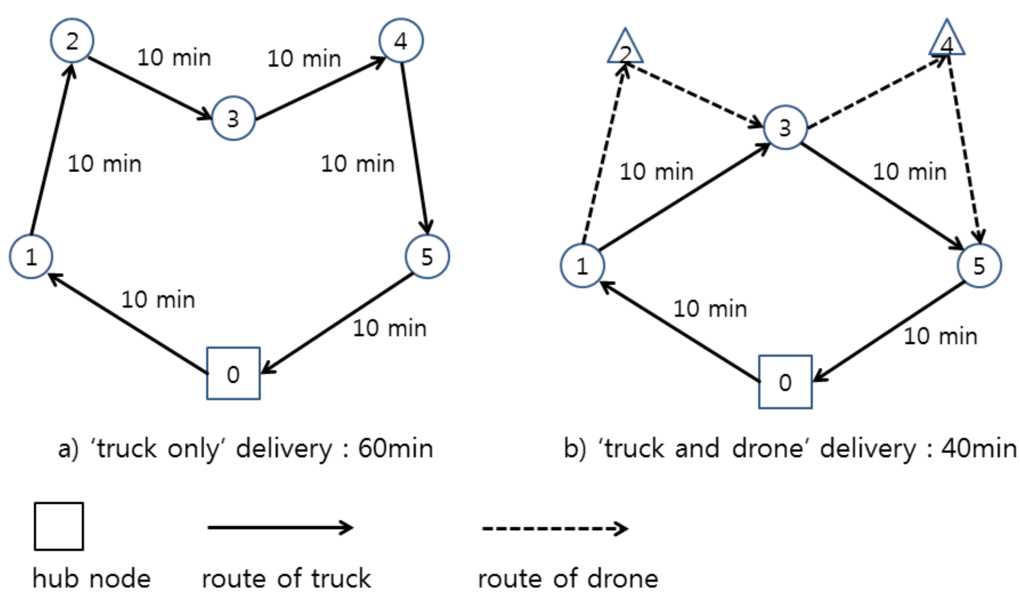
Source: Murray & Chu (2015).

To overcome the shortcomings of drones delivery, a hybrid or collaborative delivery system with truck and drone is proposed by researchers (Murray & Chu, 2015; Agatz et al., 2015; Ha et al., 2017; Poikonen et al., 2017; Wang et al., 2017).

As the truck makes deliveries, the drone is launched from the truck to service a nearby customer with a parcel. While the drone is in service, the truck continues its route to further customer locations. The drone then returns to the truck at a location different from its launch point. Drones can travel on trucks or fly; but while flying, drones can only carry one parcel at a time and have to return to a truck to charge after each delivery (Murray & Chu, 2015).

Suppose that there are 5 customers to deliver a parcel from a hub node. If you visit each customer by truck only and return to a hub node following sequence 0-->1-->2-->3-->4-->5-->0, it takes 60 minutes as you can see in <Figure 1>. However, if you visit a second customer and fourth customer by drone, you do not have to visit two customers by truck and you can finish a delivery within 40 minutes following sequence 0-->1-->3-->5-->0. This example motivates our research and shows the potential benefits of collaborative delivery by truck and drone.

The rest of paper is organized as follows. Literature reviews for the problem are provided in section 2. In section 3, we provide a novel heuristic method for the problem with numerical example. In section 4, we provide experimental results to show the effectiveness of collaborative delivery. Concluding remarks and future direction of research are provided in section 5.



<Figure 1> Time savings by collaborative delivery

2. Literature Reviews

Our problem is basically related with the well-known vehicle routing problem (VRP). VRP is a combinatorial optimization problem to find an optimal set of routes for a fleet of vehicles to traverse in order to deliver to a given set of customers. And there are many variations of VRPs depending on the special constraints of applications such as Vehicle Routing Problem with Pickup and Delivery, Vehicle Routing Problem with Time Windows, Vehicle Routing Problem with Multiple Trips (Braekers et al., 2016). Background material on VRP can be found in (Ahuja et al., 1992; Braekers et al., 2016).

However, in order for collaborative delivery to be effective, synchronization of truck and drone routes should be done in time at appropriate depot. The most critical and difficult constraint for collaborative delivery is a ‘synchronization en movement’ constraint.

Recently, many researchers has tackled drone routing problems as we have summarized in <Table 2> below. Drexl (2012) introduced a ‘synchronization en movement’ constraint for truck and trailer routing problem. Murray and Chu (2015) introduced the "Flying Sidekick Traveling Salesman Problem" (FSTSP). A mixed integer liner programming (MILP) formulation and a heuristic are proposed. Their heuristic is based on a "Truck First, Drone Second" idea, where they first construct a route for the truck by solving a TSP problem and then repeatedly run a relocation. Agatz (2015) studied similar problem of Murray and Chu (2015) except that the drone has to follow the same road as the truck and may be returned to the same location launched. Kim et al. (2015) reviewed the approaches of controlling UAV from origination to destination in previous in-country researches because the delivery involves the routing planning and the efficient and effective routing plan is critical to success to delivery mission using UAV. Min and Chung (2016) suggested the simple heuristic which is motivated by the minimum spanning tree algorithm and neighborhood search heuristic for TSP. Daknama and Kraus (2017) suggested an algorithm that is based on two nested local searches, thus the definition of suitable neighbourhoods of solutions is crucial for the algorithm. Empirical tests show that our algorithm performs significantly better than a natural Greedy algorithm. Moreover, the savings compared to solutions without drones turn out to be substantial, suggesting that delivery systems might considerably benefit from using drones in addition to trucks. Goodchild and Toy (2017) estimated CO2 emissions and vehicle-miles traveled levels of two delivery models, one by trucks and the other by drones and suggest that within an environmental framework, a blended system would perform best (emit the least) with drones serving nearby addresses and trucks delivering to ones farther. Ha et al. (2017) introduced a new variants of TDRP to minimize operational costs including transportation cost and waste time a truck has to wait. They suggested tow heuristic algorithms TSP-LS and GRASP. Kim (2017) addressed the drone-aided delivery and pickup planning of medication and test kits for patients with chronic diseases who are required to visit clinics for routine health examinations and/or refill medicine in rural areas. Wang et al. (2017) introduced the vehicle routing problem with drones (VRPD) and established some worst-case bounds under a number of assumptions. Tavana et al. (2017) propose a new bi-objective multi-product combined cross-docking truck-scheduling model with direct drone shipping and multiple fleets. The proposed model considers two conflicting objective functions (scheduling cost and time) within a multi-objective mixed integer mathematical programming problem.

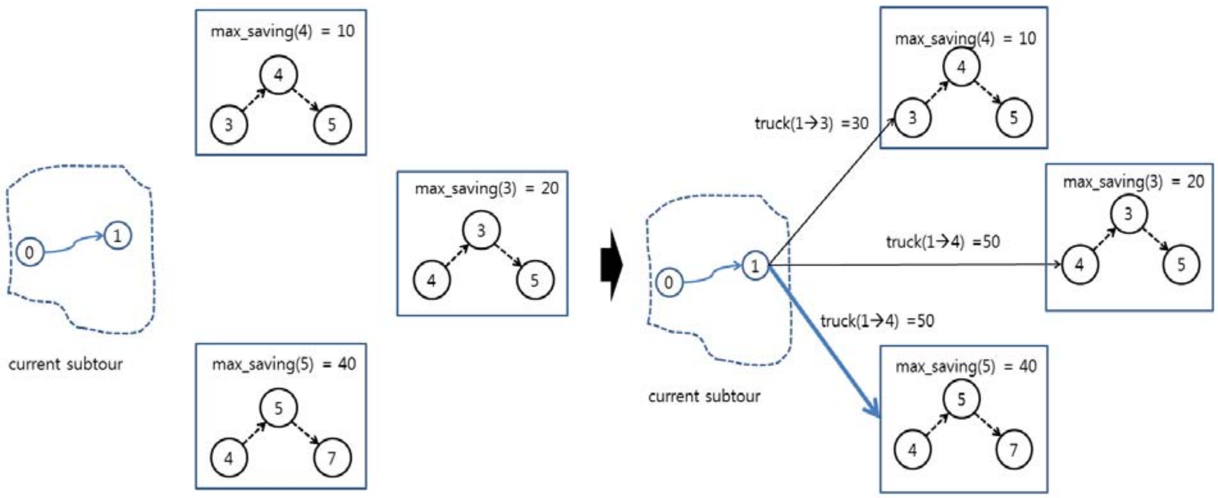
<Table 2> Summary of literature review

Researcher	Objectiveness or Considerations or Results
Dexl (2012)	Consider ‘synchronization en movement’ constraint for truck and trailer routing problem
Agatz (2015)	Drone has to follow the same road network as the truck
Murray & Chu (2015)	First proposed truck and drone routing problem and minimize delivery completion time
Min & Chung (2016)	Suggest the simple heuristic which is motivated by the minimum spanning tree and neighborhood search heuristic for TSP
Daknama & Kraus (2017)	Empirical tests show the considerably benefit from using drone
Goodchild & Toy (2017)	Collaborative delivery would emit the least pollutants
Ha et al. (2017)	Minimize total operational cost of system considering both transportation cost and waste time
Tavana et al. (2017)	Propose a cross-docking truck scheduling problem with drone shipping
Wang et al. (2017)	Consider multiple trucks and drones

3. Novel Heuristic Method

In this paper, we suggest a novel and original heuristic method for the TDRP. Our heuristic method is based on the potential savings from using drone after moving forward by truck. We call our heuristic method as TSATGH (Two Step Ahead Tour Growing Heuristic) since we grow the tour by calculating the savings by drone and the cost of moving to get the drone savings.

As you can see in <Figure 2>, if you move forward node 3, you can expect maximum savings delivered by drone as 10. Then total costs by moving forward node 3 is 20 since the moving cost to node 3 by truck is 30.



<Figure 2> Example of TSATGH

Likewise, if you move forward node 4, you can expect maximum savings by drone as 20. Then total costs by moving forward node 4 is 30 since the moving cost to node 4 by truck is 50. If you move forward node 5, you can expect maximum savings by drone as 40. Then total costs by moving forward node 5 is 20 since the moving cost to node 3 by truck is 50. Therefore, node 5 is selected as a next node to visit.

Let pp be a subtour with <n1, n2, n3, ..., np>, where first(pp)=n1, end(pp)=np.

Let truck(i→j) be a time required by truck moving from node i to node j, drone(i→j) be a time required by drone moving from node i to node j and truck(i→k→j) be a time required by truck moving from node I to node j after visiting node j. i.e., truck(i→k→j) = truck(i→k) + truck(k→j)

Let savings(k; i, j) be time savings by using drone for visiting node k at node I. savings(k; i, j) means the time difference between visiting all nodes by truck and using drone for node k. i.e., savings(k;i,j) = truck(i→k→j) - max{truck(i→j), drone(i→k)+drone(k→j)}

TSATGH (Two Step Ahead Tour Growing Heuristic)

Step 1 : Initialization.
  Calculate savings(k;i,j) for all k,i,j∈N
Step 2 : Tour growing.
  Connect a least cost node m to a subtour pp
  where, m = $\min_i$ {truck(end(p), i) - savings(k;i,j)}
Step 3 : Termination.
  If end(pp) is a staring node, terminate. Else goto Step 4
Step 4: Update.
  pp ← pp + <m, k> = <n_1, n_2, n_3, ..., n_p, m, k>

4. Experimental Results

4.1. Experimental settings

For the experiments, we generate customers from 5 to 9 and the distance between customers are generated randomly from 2.5km to 10km. We assume that delivery speeds of truck and drone are 30km/h and 60km/h, respectively. Furthermore, we assume that there is no time required for battery change or charge.

<Table 3> Distance between 9 customers and Hub node

from \ to	1	2	3	4	5	6	7	8	9	Hub
1	-	10	5	5	10	20	15	10	5	10
2		-	15	20	15	15	20	10	20	15
3			-	10	15	20	15	15	15	10
4				-	20	15	15	20	15	5
5					-	15	20	5	20	20
6						-	5	10	5	15
7							-	15	20	20
8								-	10	5
9									-	10
Hub										-

4.2. Performance of collaborative delivery

In this section, we compare the performance of collaborative delivery compared truck only delivery by calculating delivery completion time. To solve the truck only delivery problem, we depend on the excel optimization solver. To solve the truck and drone delivery problem, we depend on the TSATGH explained in section 3.

In <Table 3>, “Truck only” means a delivery time and delivery route by truck stating from Hub node by conventional vehicle routing problem. And “Truck +Drone” means a delivery time and delivery route by truck by collaborative delivery mode and “drone visited customer” means customers delivered by drone. “GAP” means delivery time reduction ratio compared with conventional truck only delivery.

As you can see in <Table 3>, collaborative delivery of truck and drone shows the delivery time reduction compared with the truck only delivery. In case of 6 customers, collaborative delivery shows 33.3% reduction of delivery time and in case of 9 customers, collaborative delivery shows 11.8% reduction of delivery time.

<Table 4> Comparison of delivery time

mode / customers	Truck only (a)	Truck + Drone (b)	drone visited customer	GAP*
5 (5~9)	50 min (Hub-8-5-7-6-9-Hub)	40 min (Hub-8-5-9-Hub)	7,6	20.0%
6 (4~9)	60 min (Hub-8-5-7-6-9-4-Hub)	40 min (Hub-8-5-6-9-Hub)	4,7	33.3%
7 (3~9)	75 min (Hub-3-4-7-6-9-5-8-Hub)	55 min (Hub-4-7-6-8-9-Hub)	5,3	26.7%
8 (2~9)	85 min (Hub-4-7-6-9-8-5-2-3-Hub)	65 min (Hub-8-2-9-6-7-Hub)	4,5,3	23.5%
9 (1~9)	85 min (Hub-8-5-2-1-3-4-7-6-9-Hub)	75 min (Hub-1-3-4-7-8-9-Hub)	6,5,2	11.8%

*GAP=(a-b)/a*100

5. Discussion and Implications

5.1. Summary

Drone delivery is expected to revolutionize the supply chain industry and we can see many applications of drone delivery such as healthcare, food and postal service. Drone delivery has many advantages over trucks or motorcycles since it is free from traffic congestion and has minimal environmental impact. However, there are some limitations for independent drone operations since drone is battery-operated and has limited service range. Collaborative delivery model with truck and drone has been proposed to utilize each advantage.

This paper aims to introduce a collaborative parcel delivery problem by truck and drone and propose a novel heuristic method to solve the problem. Our heuristic method is based on the calculation of the moving cost by truck and potential savings by drone in two steps. Based on computational experiments, we showed the effectiveness of collaborative delivery compared with truck only delivery.

5.2. Implications.

To support a stable operation of truck and drone, an effective solution algorithm is required. Considering a computational complexity of problem, a heuristic method must be developed. In this paper, we suggest a novel heuristic method which is based on the potential savings from using drone after moving forward by truck.

The results of research will be help to develop an effective heuristic solution and optimize the parcel delivery by using drone.

5.3. Discussion

This study is based on the some assumptions and has the following limitations. First, technology for collaborative operation of truck and drone is not verified and under laboratory level. Second, our research model assume a collaborative delivery by only “one” truck and “one” drone. Furthermore, laws or regulations for drone delivery have not been established and under discussion. Customer information securing a place where drones can be landed and taken is not understood. Extending our research results for multiple trucks and drones are one of the further research topics.

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