

# Review on Combined Vehicle Routing Problem of Drones and Vehicles

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**Abstract:** On the one hand, the rapid development of e-commerce has put forward higher requirements and standards for the logistics industry, which has forced the transformation of the terminal logistics delivery model; on the other hand, drones have developed fast in the field of logistics terminal delivery due to their high flexibility and high efficiency. This paper summarizes the domestic and foreign research status of vehicle route problem of four combined distribution modes, and points out the future research direction.

**Keywords:** Drones; Vehicle Routing Problem; Terminal Delivery.

## 1. Introduction

The combination of vehicle and UAV distribution has multiple modes. Both vehicles and drones can participate in the delivery, or it can be delivered by one party only (with the other party as support). According to the different roles of vehicles and UAVs in the combined distribution process, they are divided into four types: the parallel delivery mode of drones and vehicles, the coordinated delivery mode of vehicles and drones, the delivery mode of drones support vehicles, and the delivery mode of vehicles support drones.

In view of the urgent need to solve the "last kilometer" problem, drones have advantages such as high efficiency and good flexibility, and the combination of vehicle and drone distribution has a good application prospect. However, no scholars have made a detailed review on the academic research in this field. This paper will comb through the domestic and foreign literature of the four combination modes to grasp the future possible development trend.

## 2. The parallel delivery mode of vehicles and drones

Parallel delivery mode of vehicles and drones means that both vehicles and drones participate in distribution, but they are two independent transport units, operating separately and not affecting each other. Drones travel to and from the distribution center separately, serving customers around the distribution center "point to point"; And the vehicle one - time matching goods, service distance is far from the customer.

### (1) PDSTSP Mode

The problem of parallel delivery of vehicles and drones was first proposed by Murray et al., who studied the distribution of one truck and several drones and called it PDSTSP (parallel drone scheduling traveling salesman problem). First, sort the customers for the vehicle service; The remaining customers were then assigned to multiple drones with the goal of minimizing completion time, with each customer's processing time determined by how long the drones flew to and from the distribution center to the customer.

### (2) TSP-DS Mode

Considering the limited flight range of drones in PDSTSP model, Kim et al. added a drone station closer to the customer but far away from the distribution center in the model to

provide cargo storage and charging services for drones. The goods delivered by drones are first sent from the distribution center to the drone station, and then distributed by the drone unit. Customers outside the reach of drones are delivered by vehicle. Based on the assumption that the location of the drone station is known, the paper constructs the MILP model of traveling salesman problem with a drone station (TSP-DS), and finds that TSP-DS is more efficient than PDSTSP.

### (3) MILP Mode

Schermer et al. studied the positioning problem of drone station, built MILP model with the goal of minimizing completion time, and expanded the problem to the extension of location-routing problem (LRP).

At present, there are few researches on the parallel delivery of vehicles and drones. Most literatures only study the situation of one vehicle delivery and one one-way delivery of a customer by drones. Therefore, the future research on parallel distribution of vehicles and drones can be carried out from the following aspects: 1) Considering the distribution scenario of multiple vehicles and drones, drones can deliver multiple orders in one way according to the endurance capacity, and can be further extended to the situation of multi-model vehicles and multi-model drones; 2) Consider the diversification of objective functions, such as minimizing the number of vehicles and drones and minimizing the total distance of distribution; 3) The expansion problem of parallel distribution is studied. In addition to pick-up and delivery and time window, multi-cycle distribution, multi-unmanned airports and other scenarios can also be considered. Dynamic factors are introduced to make the problem more practical by considering changes in customer demand and vehicle travel time.

## 3. The coordinated delivery mode of vehicles and drones

Vehicle and drone collaborative delivery mode refers to the vehicle carrying one or more drones, and the two deliver goods respectively for their respective customer nodes. Because the drone has poor endurance, small flight range and limited load capacity, it needs to return to the vehicle to charge after completing a node distribution task, then take off from the vehicle and continue to deliver goods to other customer nodes.

### (1) FSTSP Mode

Murray et al. named the coordinated distribution of a truck carrying a drone as FSTSP (flying sidekick traveling salesman problem), which stipulated that the drone could only deliver one node in one way. The drone and the vehicle ran along Euclidian distance and Manhattan distance respectively. And the vehicle is not allowed to launch the drone multiple times at the same node. They constructed a MILP model with the objective function of minimizing completion time.

### (2) TSP-D Integer Programming Model

Since MILP model takes a long time to solve and is not suitable for large-scale calculation, Agatz et al. built a TSP-D integer programming model based on MILP model. Slightly different from the FSTSP, TSP-D assumes that the drone's flight path in the air is the same as the vehicle's road path on the ground, and allows the vehicle to launch the drone multiple times from the same location.

### (3) VRP-D Model

Wang et al. extended the problem of vehicle and drone collaborative distribution from a single vehicle to multiple vehicles, and proposed VRP-D based on VRP model. Starting from a quantitative way, they analyzed the worst case in VRP-D by setting three parameters: the number of vehicles, the speed ratio and the number of drones carried by a single vehicle. The calculation found that even if each vehicle was only equipped with one drone, the collaborative delivery mode could cut the completion time by half if the drone and vehicle had the same speed and distance matrix.

At present, the research of vehicle and drone collaborative distribution is still in the initial stage. Most research models are relatively simple, setting many assumptions and ignoring many realistic factors. For example, many literatures assume that the drone can only deliver one customer in one trip, but the endurance capacity of the drone may meet the needs of multi-node distribution; Most studies assume that drones have a constant maximum flight distance or duration due to battery capacity limitations, but in actual operation, drone endurance depends on many factors, such as load, wind, etc. In addition, future research can consider a variety of constraints and conduct extended research.

## 4. The delivery mode of drones support vehicles

The delivery mode of drones support vehicles means that vehicles carry out distribution tasks and are supplemented by drones.

Dayarian et al. defined this mode as VRPDR (vehicle routing problem with drone resupply) and proposed that drones continuously pick up goods from the distribution center and provide goods in real time for trucks in the way of distribution. The model that enables a truck to deliver more goods in a given time window takes into account the case of only one distribution center, one truck and one drone.

Mccunney et al. set some transfer points in the model. Drones first transport goods to the transfer point, and then pick up the goods at the truck transfer point to serve customers in the specified area. According to the order arrival time, the number of transfer points, the number of vehicles and the number of drones, they take rural and urban areas as examples for comprehensive analysis.

At present, there are few researches on the delivery mode of drones support vehicle. However, since drone distribution

has just emerged and the corresponding supporting policies are not perfect, large-scale drone distribution may not be realized in the short term. Therefore, using drones support vehicle for distribution may be a better choice. Future research can further consider the situation of multi-vehicle, multi-drone and multi-distribution center, and can also consider the use of multi-model unmanned units for replenishment and scheduling according to the weight and size of customer orders.

## 5. The delivery mode of vehicles support drones

In the delivery mode of vehicles support drones, only the drone performs the distribution task, and the vehicle serves as the assistant to provide goods storage and charging services for the former. Some temporary stops are usually given as the contact points between vehicles and drones to realize the takeoff and landing, charging and delivery process of drones. The drone shuttles between the vehicle and the customer, taking goods from the vehicle and delivering them to the customer. During the drone delivery, the vehicle moves to the next contact point or stops and waits for the drone to return.

Mathew et al. defined this problem as HDP (heterogeneous delivery problem) and studied route planning problem of a truck supporting a drone distribution.

On the basis of HDP model, Othman et al. assumed that the vehicle driving route was known, took the planning of drone route as the main goal, and divided the problem into four sub-scenarios: the first and second scenarios assumed that the drone took off immediately after picking up goods from the vehicle, but the former allowed the vehicle to wait for the drone to land at the same node, while the latter did not. The third and fourth scenarios assume that the drone lands at a certain node, rides the "hitch" of the vehicle, and takes off at another node. The difference between the two scenarios is consistent with the first and second scenarios.

Due to the limited capacity of drones, most studies assume that drones can only serve one customer each way. Hu et al. relaxed this constraint and assumed that the drone could deliver multiple customer nodes at a time. Poikonen et al. considered parcel heterogeneity, that is, the weight of each parcel is different, and studied the route planning problem that drones can deliver multiple customer nodes at one time.

At present, there are few researches on the extension of vehicle support drone delivery. Future research can consider some uncertainty factors in the model, which will be more in line with the actual situation.

## 6. Conclusion

In this paper, the parallel delivery mode of drones and vehicles, the coordinated delivery mode of vehicles and drones, the delivery mode of drones support vehicles, and the delivery mode of vehicles support drones are summarized.

With the rapid development of intelligent logistics, there are still some problems worth exploring and new development directions. Future research can be considered from the following two aspects: 1) Consider the safety of drones. It is necessary to consider security-related constraints, such as no-fly zones for drones, as well as uncertain factors for drones such as wind and temperature. 2) Considering multi-mode combination. Since logistics distribution has a wide range of application scenarios, future research can combine the two modes to form a mixed distribution mode,

so as to achieve more reasonable distribution services.

## References

- [1] Murray C C, Chu A G. The flying sidekick traveling salesman problem: Optimization of drone-assisted parcel delivery[J]. *Transportation Research Part C: Emerging Technologies*, 2015, 54: 86-109.
- [2] Kim S, Moon I. Traveling salesman problem with a drone station[J]. *IEEE Transactions on Systems, Man, and Cybernetics: Systems*, 2019, 49(1): 42-52.
- [3] Schermer D, Moeini M, Wendt O. The traveling salesman drone station location problem[C]. *World Congress on Global Optimization*. Metz, 2019: 1129-1138.
- [4] Agatz N, Bouman P, Schmidt M. Optimization approaches for the traveling salesman problem with drone[J]. *Transportation Science*, 2018, 52(4): 965-981.
- [5] Wang X Y, Poikonen S, Golden B. The vehicle routing problem with drones: Several worst-case results[J]. *Optimization Letters*, 2017, 11(4): 679-697.
- [6] Dayarian I, Savelsbergh M, Clarke J P. Same-day delivery with drone resupply[J]. *Transportation Science*, 2018, 54(1): 229-249.
- [7] Mccunney B, Cauwenberghe K. Simulation test bed for drone-supported logistics systems[D]. Boston: MIT SCM Capstone Project, 2019.
- [8] Mathew N, Smith S L, Waslander S L. Planning paths for package delivery in heterogeneous multirobot teams[J]. *IEEE Transactions on Automation Science and Engineering*, 2015, 12(4): 1298-1308.
- [9] Othman M S B, Shurbevski A, Karuno Y, et al. Routing of carrier-vehicle systems with dedicated last-stretch delivery vehicle and fixed carrier route[J]. *Journal of Information Processing*, 2017, 25: 655-666.
- [10] Hu M L, Liu W D, Lu J Q, et al. On the joint design of routing and scheduling for vehicle-assisted multi-UAV inspection[J]. *Future Generation Computer Systems*, 2019, 94: 214-223.
- [11] Poikonen S, Golden B. Multi-visit drone routing problem[J]. *Computers & Operations Research*, 2020, 113: 104802.