Same-Day Delivery with a Heterogeneous Fleet of Drones and Vehicles

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Same-day delivery (SDD) is a powerful tool for online retailers to increase sales. In SDD, customers order goods online and receive them the same day. To this end, providers dynamically dispatch a fleet of delivery vehicles transporting goods from a warehouse to the customers. SDD is convenient because customers can order online and do not need to go to the store and wait in lines. Further, customers often receive their good within a few hours. Thus, SDD narrows the gap of instant-gratification between online and brick-and-mortar shopping (Anderson, 2015). As a result, SDD is experiencing high two-digit growth rates per year (Yahoo! Finance, 2016).

Offering SDD leads to significant cost challenges for service providers (Ram, 2015). To overcome the cost challenges of SDD, companies have begun to incorporate drones into their SDD operations (Kim, 2016). Drones have the advantage that they enable fast and direct delivery from the depot to a customer regardless the traffic conditions. Still, they can only transport one item per trip and require recharging or a battery swap afterward. Thus, drones may not be able to entirely replace conventional delivery vehicles, particularly when volumes are high (Wang, 2016).

This research analyzes the question whether and how a combination of delivery vehicles and drones may reduce the required delivery costs and increase the number of customers served in SDD operations. The resulting problem is the *same-day delivery routing problem with heterogeneous fleets* (SDDPHF). During a shift, a fleet of vehicles and a fleet of drones deliver goods from a depot to customers. These customers request orders during the shift and are unknown before the time of their order. For each ordering customer, the provider must decide whether or not the order can be served on the same day and whether a vehicle or a drone performs the delivery. If SDD is offered, either a drone is loaded and sent to the customer or a vehicle picks up the order at the depot and delivers it within the delivery deadline. The objective is to maximize the expected number of customers served with SDD.

One main question for the SDDPHF is whether to use a drone or a vehicle for delivery. The question of drone or vehicle needs to account for the impact of the immediate decision on our ability to meet as yet unknown future requests. To do so in problems of this scale where the state and actions spaces of a dynamic programming model grow exponentially, researchers often turn to the techniques of Approximate Dynamic

Programming (ADP). ADP seeks to provide high quality solutions while also providing a tractable means of problem solving.

In our case, we seek to identify a good heuristic decision making policy. We take advantage of the intuition that, generally, vehicles may be suitable in downtown areas close to the depot and with with high customer density while using drones may be beneficial for more distant suburban areas with widely dispersed customers. Based on this idea, to facilitate decision making, we use an ADP approach known as parametric policy function approximation (PFA). In a PFA, one usually seeks to determine the best values for a parameterized policy. In our case, the parameter is a threshold of travel distance from the depot splitting the service area into two zones. Customers in the zone within the threshold are preferably served by vehicles and customers in the zone further distant than this threshold are preferable served by drones. The PFA is highly runtime-efficient allowing for immediate responses to customers.

Our PFA increases the number of same-day services significantly compared to other PFA benchmark policies. Notably, we show that serving closer customers with vehicles and further customers with drones is an effective heuristic. We also compare our PFA to a more sophisticated rollout approach and demonstrate that the PFA performs comparably with much less computational effort and much greater transparency. In addition, we use the PFA to evaluate how the combination of vehicles and drones significantly reduce the delivery costs compared to SDD only performed by drones or by vehicles, respectively.

Our contribution is as follows. We develop a runtime-efficient PFA leads to high quality solutions. We finally present a comprehensive computational study to analyze our policies. We derive two main managerial insights:

1. Partitioning the service region in areas preferably served by drones and in areas preferably served by vehicles, which we call geographic districting, improves the overall number of potential services. The results indicate that our proposed method of districting is particularly effective. The improvement is between 5.5% and 8% if drones are used to serve customers in less populated areas and distant to the depot while vehicles serve populated areas close to the depot. Further, in 332 of the 400 instance settings, the PFA outperforms all benchmarks. In the other 68 cases, the PFA and benchmarks serve all orders, and solution quality is 100%.

2. The combination of drones and delivery vehicles has the potential to reduce delivery costs. Our results show that the addition of only one or two drones to a delivery vehicle fleet can replace the productivity of one vehicle for lower demand levels and around four drones replaces a vehicle at higher demand levels.

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