Stochastic Destination Open Vehicle Routing for crowd-shipping

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1. Introduction

Crowd-shipping has gained the attention of large companies (e.g., Amazon and Walmart) because of the potential to reduce shipping costs as well as reducing the environmental impact that a large fleet of commercial vehicles has. The idea of crowd-shipping is to utilize the vehicles that are already on the road, such as personal vehicles, to deliver packages. In a recent survey by Sampaio et al. (2019), the challenges and opportunities of crow-shipping are emphasized. The main challenge that comes from utilizing crowd-vehicles is the imperfect information about the properties of vehicles and drivers, e.g., willingness of drivers to performer routes, vehicle capacity or even destinations. A concept initially proposed by Walmart, is of to have in-store customers deliver packages to online customers Barr and Wohl (2013). With Walmart's vision, Archetti, Savelsbergh, and Speranza (2016) introduce the Vehicle Routing Problem with Occasional Drivers (VRPOD), and formulate a deterministic and static model where a set of delivery requests have to be fulfilled from a central depot by a mixed fleet of regular vehicles that complete closed routes, and a set of in-store customers that have a reduced capacity and are willing to deliver some packages as they go to their specific destination. The compensation of in-store customers is not very clear and could be based on different strategies. Archetti, Savelsbergh, and Speranza (2016) study three different compensation schemes that could be used by a platform to reduce total shipping costs and a multi-start heuristic is proposed to solve the problem. Different variants of the VRPOD have been presented where the dynamic aspects are considered in the model. Dayarian and Savelsbergh (2017) present a problem where in-store and online customers are dynamic, and develop a sample scenario planning approach. The routing is solved using a tabu search heuristic.

Although dynamic aspects of the problem have been considered, in all of the variants presented in the literature the destinations of in-store customers are considered to be deterministic and exact coordinates are assumed to be available for each driver. If in-store customers sign-up for a crowd delivery program previously some of their preferences and characteristics can be known beforehand. Having such a program is an excellent strategy that has worked well in practice for on-demand crowd-shipping e.g., AmazonFlex where at least the capacity of the vehicles are known beforehand. But it is not the case that in-store customers will always have the same destination after shopping. As some shoppers might decide to go somewhere else instead of their home even after signing up for a crowd-shipping program. Some days in-store customers might want to continue shopping at another store, or go to a friends house. A program could allow a customer to announce her destination for that specific day in an app, while she shoppes at the brick and mortar store. In any case this implies that the exact destination of customers will not be known at the beginning of the day and that it will become available as time progresses.

Cities are generally divided by neighborhoods and natural geographic barriers such as rivers and mountains. In realistic routing problems customers are generally clustered in different areas. We assume probabilistic information is available for in-store customer destinations that are contained within these neighborhoods.

In this paper we consider a case where a crowd-shipping platform (CSP) has a fleet of vehicles available as well as a program for in-store customers to become occasional drivers (OD), that allows them to deliver packages to online customers for a compensation based on a fixed and variable cost. We assume that OD are willing to deliver packages if the routes follow two primary conditions. Firstly, as long as the neighborhood of the last delivery on the route is the same neighborhood of the OD destination such that after completing the route the OD is not faraway from her destination, and secondly, if the route duration is not too long so that it does not exceed a value.

We divide the delivery requests by area and represent the probability of an OD heading to the area by a binomial distribution. The probabilistic information can be obtained from the historical data of OD destinations and of demographics for each area. The CSP has to deliver all packages with a mix of its own vehicles as well as the OD from a brick and mortar store where customers regularly shop.

The main contributions of our paper are the following:

- We present a two-stage stochastic framework that allows a CSP to plan routes for a mixed fleet of regular company vehicles and an unknown fleet of OD with stochastic destinations.
- We formulate a set covering model with additional variables that linearize the stochastic aspects of the problem.

- We provide an optimal dynamic policy to assign routes to OD as they dynamically become available throughout the planning horizon.
- We develop a Branch and Price algorithm to solve the problem as well as an innovative pricing problem to generate the needed columns for the master problem.
- Finally, we will perform extensive computational experiments on instances and perform a sensitivity analysis on different parameters.

2. Problem Statement

We consider a two-stage stochastic model where a crowd-shipping platform (CSP) has a set of delivery requests represented by a graph $G(A, V)$ where A represents the arcs and V the location of the customers including the central depot $\{0\}$. Each neighborhood $N_l \subset V$ contains a set of delivery requests, a binomial distribution B_l that describes the probabilistic information about the supply of OD that will have a destination within the neighborhood , and a route duration constraint such that routes that end in the neighborhood $l \in L$ are no longer than $\bar{d}_l$. The capacity of OD and regular vehicles (RV) are $Q_1 \leq Q_2$ respectively.

First stage decisions consist of creating routes for RV and for OD expecting an adequate supply of the latter to be available at the second stage. If the supply of OD is insufficient to fulfill all delivery requests then recourse actions need to be taken. We consider the recourse action of utilizing company vehicles to complete routes that where left unfulfilled by OD times a penalty.

3. Solution Approach

For each neighborhood the more OD routes that we have the less likely it is that they will all be fulfilled, since it is always less likely to have an additional OD available with a destination in the same neighborhood. Therefore the second stage decisions for each neighborhood consist in deciding which routes will be fulfilled by the available OD and which will fail do to the lack of supply. The available routes per neighborhood can then be ordered based on the cost of the recourse action that would need to be taken if the routes fail. The optimal dynamic policy is then to assign the most important route (w.r.t. recourse actions) to the first available OD that is headed towards that neighborhood (further information will be presented at the conference).

Let Ω be a set of all feasible routes for RV and Ω_l be a set containing all feasible routes for OD for all neighborhoods $l \in L$. The binomial distribution B_l has a maximum number of OD described by $M(l)$ for $l \in L$. Let λ_{ls}^r be a binary variable that equals one only if route r for neighborhood $l \in L$ has a priority of $s \in M(l)$. Variables with a sub-index 0, represent the RV. The costs c_{ls}^r can be computed easily by calculating the expected cost if route $r \in \Omega_l$ ends in neighborhood $l \in L$ with a priority of $s \in M(l)$ such that the probability of the supply of OD for $l \in L$ is equal to or higher

than $s \in M(l)$. The set-covering formulation for the stochastic destination OVRP is the following master problem:

$$MP = \min \sum_{r \in \Omega} c_0^r \lambda_0^r + \sum_{l \in L} \sum_{s=1}^{M(l)} \sum_{r \in \Omega_l} c_{ls}^r \lambda_{ls}^r \tag{1}$$

$$\text{s.t.} \quad \sum_{l \in L} \sum_{s=0}^{M(l)} \sum_{r \in \Omega \cup \Omega_l} a_{ir} \lambda_{ls}^r \geq 1 \qquad \forall i \in N \tag{2}$$

$$\sum_{r \in \Omega_l} \lambda_{ls}^r \leq 1 \qquad \forall s \in \{1, \ldots, M(l)\}, l \in L \tag{3}$$

$$\lambda_{ls}^r \in \{0, 1\} \qquad \forall s \in \{0, \ldots, M\}, r \in \Omega \cup \Omega'$$

The objective function (1) is to minimize the total cost of routing including the expected recourse actions that will need to be taken. Set covering constraints (2) guaranty that all customers will be visited at least once. The set of constraints (3) allow only 1 to have a priority of $s \in M(l)$ route per neighborhood $l \in L$.

An innovative labelling algorithm with Ng-routes and decremental state space relaxations is used to generate the columns for a restricted version of the MP. Branching is firstly done by total number of regular vehicles, secondly by total number of OD, and finally by arc variables from the classical network flow formulation for the VRP.

Computational experiments will be presented at the conference.

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