A Robust Optimization Approach to Crowdsourcing Last-Mile Deliveries

Last-mile deliveries are one of the most expensive components of supply chain logistics, and as customers demand cheaper and faster deliveries, firms can significantly differentiate themselves if they can offer cost-efficient and fast last-mile deliveries. Crowdsourcing last-mile deliveries allows firms to have more control over these expensive logistics, manage demand uncertainty better, and minimize their delivery costs.

One of the main challenges in managing online deliveries (crowdsourced or otherwise) is that there is uncertainty in customer demands (when will a customer place an order, and where are they requesting delivery) as well as delivery service times (delivering to a house differs from delivering to an apartment, or a gated community). These uncertainties make it challenging for retailers to satisfy their customer orders on time, with high probability, in a cost-effective manner. In our paper we utilize uncertainty sets, whose structures are motivated by limit theorems of probability, for handling these uncertainties. This approach allows us to apply robust optimization, a modern approach to decision making under uncertainty, that does not require the specification of stochastic distributions. This is appealing since there is ample evidence in the literature that misspecified distributions in stochastic programming can result in sub-optimal solutions, and robust optimization results in better outcomes. Another reason for choosing a robust optimization approach is that satisfying customer demands on time is critical, and we construct constraints that ensure that, in the worst case, customer deliveries are made on time.

We study a novel application of crowdsourcing last-mile deliveries to independent drivers via a robust optimization. In particular, we study a hybrid system where crowdsourcing deliveries can either support or replace traditional third-party logistics (3PL). In this context, our model minimizes the worst-case delivery cost of a firm, subject to delivering all customer orders
on-time, with high probability. In the proposed model, the probability that customers receive their order on time is tunable via the robust uncertainty sets' parameters, which also allows the firm to determine the tradeoff between conservatism and cost.

Our model builds upon the robust queueing framework introduced by Bandi et al. 2015, which utilizes uncertainty sets motivated by the central limit theorem, by adding a non-trivial routing component whose associated uncertainty set is motivated by the probabilistic limit theorem for the optimal TSP tour (Beardwood et al. 1959). This robust optimization approach is appealing in that few parameters (e.g., means and standard deviations) are needed to parameterize the uncertainty sets, rather than full distributions in stochastic optimization (that are prone to estimation error).

We analyze the proposed robust optimization model and derive closed-form expressions for the worst-case delivery cost and system times of all customers in the crowd-delivery system, which allows us to derive a non-robust counterpart for the main model that is easily solvable. We show that, if the firm designs its crowd-delivery system optimally, even the worst-case delivery cost is significantly cheaper than traditional 3PL firm costs, especially for fast same-day deliveries. Parameterizing on real data from FedEx, we find that the firm's cost savings for same-day deliveries is 13.8%, and for very fast 2-hour deliveries, the savings is 20.8%. We provide detailed managerial advice for how these savings can be achieved by recommending 1) the optimal proportion of packages that should be assigned to the crowd, 2) the optimal number of packages per driver, 3) the optimal service region for the crowd, and 4) the optimal crowd workforce.

We also provide policy recommendations that would result in better parameters for our model that would further reduce cost. Specifically, we observe that the firm can benefit
significantly from decreasing the standard deviations of on-site service times via standardization and improved driver training. Moreover, we show that the firm can significantly increase its cost savings rate by decreasing the expected on-site service time by, for example, better training its drivers or focusing on faster deliveries for crowdsourcing (e.g., delivering to a house is typically faster than to an apartment in a complex).

The results of this paper are applicable to firms such as Amazon, Walmart, and Target that handle their own fast same-day deliveries, and also to firms such as Instacart, Deliv, and UberRush/UberEATS that offer fast deliveries to other firms.

References:
