Selecting Shipments at An Urban Consolidation Center for Last-mile Delivery with Cost Uncertainty

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Abstract: To address the challenges of last-mile delivery in an urban area, goods from different shippers may be first consolidated at an urban consolidation center (UCC) before they are transported to the city center. Due to the UCC's limited delivery capacity and significant delivery costs, only a selective set of shipments can be served. Selecting the shipments is challenging because the delivery costs are uncertain due to traffic conditions, weather conditions, and other factors. We propose an auction mechanism to solve the shipment selection problem under delivery-cost uncertainty. We introduce four solution approaches that require different levels of information on the delivery-cost distributions. The first approach considers only the mean delivery costs and maximizes the mean profit. The second and third approaches control the downside tail of the profit distribution, while maximizing the mean profit. The former requires full information of the delivery-cost distributions, while the latter needs only partial information. The last approach maximizes the robustness of a solution, while ensuring the profit is no less than a pre-specified target. Surprisingly, although the last approach requires only the support sets and the mean values of the delivery costs, this robust-optimization-based method performs comparably with the second and third approaches.

Problem Description

Uncoordinated last-mile delivery in an urban area causes high-density logistics activities and creates great impact on a city's stakeholders. For the city's government or local authority, uncoordinated last-mile delivery leads to traffic congestion in the city center. This in turn generates pollution for the environment and poses safety issues that make the city less livable. For retailers that receive the goods, uncoordinated last-mile delivery reduces their service levels and profit margins.

To address the problem of last-mile delivery, we study the concept of urban consolidation center (UCC). A UCC is a facility where freight flows are consolidated with an objective to reduce the intensity of distribution activities in the city center. A UCC's primary function is to consolidate shipments to the city center and it usually operates its own limited fleet of trucks for the last-mile delivery. To maximize the UCC's profit, we propose an auction mechanism to allocate the trucks' capacity to the shipments. In this auction mechanism, each delivery job is submitted to the UCC as a bid specifying its volume, destination, arrival time, and delivery deadline together with the corresponding bid price. The UCC then chooses the winning bids and allocates its fleet accordingly. The challenge is that the UCC needs to determine the winners without knowing the exact delivery costs, which are generally uncertain.

Methodology

A key component of the proposed auction mechanism is a winner determination problem. We propose four different approaches to identify the winners of the auction under delivery-cost uncertainty. Each approach requires a different level of information on delivery-cost distributions. The first approach considers the mean delivery costs and maximizes the UCC's mean profit. This approach is especially useful if only the mean values of the delivery costs are available. We introduce the second approach for a

situation in which the delivery-cost distributions are precisely known. In this case, we impose constraints on the Conditional Value-at-Risk (CVaR) of the UCC's profit to control its downside tail, while maximizing the mean profit. The third approach considers a collection of delivery-cost distributions that are characterized by the support sets, the mean values, and a bounded covariance matrix of the delivery costs. We impose constraints on the worst-case CVaR so that the resultant CVaR is bounded for all possible distributions in the collection. The last approach is based on Target-oriented Robust Optimization (TRO) in which we first set a profit target. The approach finds a solution that maximizes a delivery-cost set such that all delivery-cost realizations from the set will yield a profit no less than the specified target. In this approach, only the support sets and the mean values of the delivery costs are used. Each of the four approaches described above can be formulated as a mixed-integer program or a second-order cone program, and can be solved using a commercial or open-source solver. To reduce computational burden, we also propose several heuristics to solve large problem instances.

Findings

We conduct an extensive set of experiments to demonstrate the advantages of the proposed approaches. We first compare the four winner determination approaches. Our numerical results suggest that the first approach, which maximizes the mean profit without any other control, results in a wide range of profits (see the mean and variance of the profit under Solution 1 in Figure 1). In contrast, the other approaches can better balance the resultant profit's mean and variance (see the mean and variance of the profit under Solutions 2 and 3 in Figure 1). The TRO approach is especially appealing because it requires less distribution information (only the support sets and the mean values are required), while still maintaining a delicate balance between the mean and the variance of the UCC's profit (see the mean and variance of the profit under Solution 3 in Figure 1).

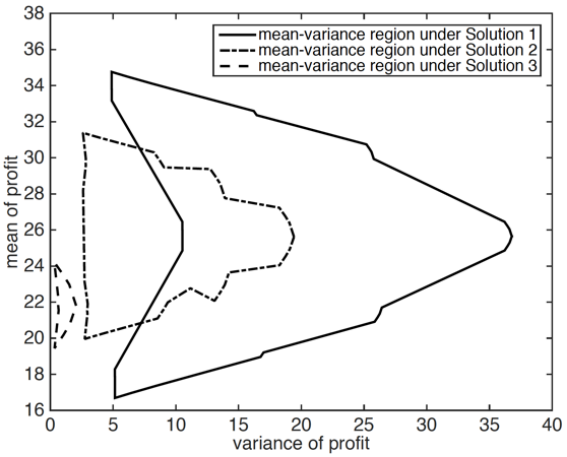

Figure 1. Profit mean and variance

We also compare the performance of the proposed heuristics with that of CPLEX. Our results suggest that the heuristics generate solutions comparable to that of CPLEX in a reasonable amount of time. More importantly, for very large problem instances where CPLEX fails to obtain a solution, our heuristics still manage to find good-quality solutions.

Conclusion

We propose an auction mechanism for a UCC to select shipments of last-mile delivery to a city center with cost uncertainty. We introduce four winner determination approaches to handle different levels of information on delivery-cost distributions. Our numerical results suggest that the proposed approaches can achieve a good balance between the mean and the variance of the UCC's profit. Furthermore, our heuristics can find good-quality solutions for large problem instances within a reasonable amount of time.