Urban Courier: Operational Innovation and Data-driven Coverage-and-Pricing

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Keywords: urban courier delivery, joint scheduling and pricing, data-driven pricing, distributionally robust optimization, maximum weighted coverage

Introduction: We study a novel urban courier delivery system, the Transshipment-based Urban Courier system (TUC system), proposed by industry partner DML-Express based in Beijing, China. The TUC system utilizes large capacity vehicles as moving warehouses to flexibly consolidate packages from individual couriers. The TUC system combines the merits of the traditional one-to-one delivery and the hub-and-spoke distribution system to balance the transportation costs and delivery efficiency. One of the critical problems in a TUC system is the joint transportation planning and pricing problem. We develop a data-driven coverage-and-pricing framework to address this issue.

Methodology: Partnering with DML-Express, we utilize the pricing experiment data to develop a data-driven coverage-and-pricing framework that can (1) learn the spatial and temporal demand-price pattern from data (2) optimize the delivery prices in coordination with the transportation schedules with the consideration of both the operational cost and the customer satisfaction level (3) achieve a robust performance both empirically and theoretically.

Results

Models and Algorithms: The data-driven coverage-and-pricing problem is a non-linear mixed-integer program. We develop efficient computational methods that achieve certain approximation ratios under regularity conditions. Specifically, our proposed algorithm is decomposition-based. It works by decomposing the objective function in the data-driven coverage-and-pricing model and reformulating the decomposed optimization problem as a maximal weighted coverage problem. Then we can apply column-generating-based approaches to solve the decomposed problem. We show that the column-generating subproblems can be efficiently solved by a dynamic programming algorithm in polynomial time.

Theoretical and Empirical Pricing Robustness: Our data-driven pricing model provides a tractable and robust pricing decision with a limited amount of pricing data. Our method falls into the distributionally robust optimization (DRO) but has an essential difference from the traditional distributionally robust optimization (DRO). In traditional DRO literature, the covariates in the data are assumed to be identical and independently distributed (IID). However, in our setting, this assumption is violated since the price is a covariate as well as a decision variable. Therefore, robustness guarantee results for traditional DRO fail to apply. Non-trivially, we give theoretical performance guarantees to demonstrate the robustness of our pricing policy. We also empirically demonstrate the robustness of our pricing tool with numerical experiments in the operational setting of DML-Express.

Case Studies and Managerial Implications: Extensive computational experiments based on historical pricing data and the DML-Express' operational setting demonstrate the performance of our method. Our experiment result is threefold: (1) the results highlight the value of pricing robustness with a limited amount of data or in an unstable market; (2) the results showcase the value of the coverage-and-pricing model, in comparison with the default setting in DML-Express. Besides, the results demonstrate the value of joint transportation planning and scheduling by comparing with a fixed transportation model and a fixed price model; (3) the results show that the firm should set lower prices when having larger transportation capacities or when the demand pattern is in-balanced demand.

Conclusion: In this paper, we introduce a novel urban courier delivery system: the TUC system. The success of a TUC system hinges on the coordination of the transportation services and prices in the service network. Therefore, we address the joint scheduling and pricing problem of the TUC system with a data-driven coverage-and-pricing model. In this model, we optimize the transportation schedule to cover the demand and set the delivery prices in coordination with the transportation coverage decision. In particular, we propose a data-driven robust pricing model to determine delivery prices that are robust with a limited amount of data.

Our contribution is threefold. First, to the best of our knowledge, we are the first to introduce and study the TUC system, which is an innovative operation for the urban logistics industry. We analyze and identify the key problem for the TUC system to be successful -- the joint transportation planning and pricing problem. Secondly, we tackle the joint transportation planning and pricing problem with a data-driven coverage-and-pricing framework. We give theoretical guarantees of the model performance with a limited amount of data. We develop a decomposition-based algorithm that solves the problem efficiently and achieves certain approximation ratios under regularity conditions. Third, we conduct extensive numerical experiments and case study based on the operational data from our industry partner DML-Express: we highlight the value of pricing robustness with a limited amount of data or in an unstable market; we showcase the value of the coverage-and-pricing model and demonstrate the value of joint transportation planning and scheduling; we show that the firm should set lower prices when having larger transportation capacities or when the demand pattern is in-balanced demand.

In the current model, we consider the uncapacitated transportation services. A future direction is to consider the capacitated case. Another direction is to consider a dynamic pricing policy that can adaptively incorporate more historical data.

Acknowledgment:
The authors thank Prof. Xiaoyu Ma and DML-Express for valuable support in the early stages of the manuscript and data collection.