An Online Cost Allocation Model for Horizontal Supply Chains

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Project Objective

With the increasingly market for world trade, massive amounts of goods are constantly transported to satisfy the needs of customers all over the world. Logistics has become the crucial force to drive the productivity and mobility of various industries. The goal of this research project is to shed some insights into the practicability of cost sharing in a dynamic vehicle routing environment. It would also advance the applicability of horizontal cooperation to help reduce the environmental, economical, and social impact of logistic activities.

Problem Statement

Numerous problems exist inside the logistics sector, including low capacity usage, excessive packaging, high energy consumption, low work force welfare, etc. Among efforts that target these deficiencies for improvement, horizontal cooperation stands out as the one that has seen both theoretical development and real world application. In particular, the pooling of transportation networks helps companies to reduce and share operating costs and alleviate the impact on traffic congestion by reducing the number of total vehicle miles. In the freight transportation industry, however, such cost sharing systems are still in their infancies. One of the biggest challenges of implementing a freight cost sharing transportation system is how to fairly allocate the cost to each participant in the cooperation. Yet, this problem remains rarely studied in the literature. Also, lean manufacturing and just-in time (JIT) delivery constraints challenge us to consider the cost sharing transportation system in a dynamic environment, where new customers request service in real time. Indeed, the problem of allocating costs in a real-time cost sharing transportation system is highly nontrivial and is ranked among the top impediments for successful horizontal cooperation. Therefore, an online cost allocation mechanism addressing dynamic vehicle routing problem is studied in this research.

Research Methodology

We focus on studying a category of the dynamic vehicle routing problem where only part of the customers are known in advance, and the rest become known in real time. Based on a dynamic routing framework, we develop an online cost-sharing mechanism referred to as Hybrid Proportional Online Cost Sharing (HPOCS) that is capable of dynamically allocating cost to each customer as it is realized. Our approach combines two cost-sharing mechanisms (proportional and marginal costs) originally designed for the static environment, respectively. With specially designed cost functions and routing schedules, the hybrid mechanism is shown to possess several desired properties, namely online fairness, immediate response, individual rationality, budget balance, and ex-post incentive compatibility. The individual rationality property states that the shared cost value for any customer never exceeds its willingness-to-pay level once the customer has been accepted into the cooperation. The online fairness property requires that players who join the cooperation late should never receive a lower shared cost than those that join early. The immediate response property requires that when a new customer becomes realized, it should be provided with an initial quote for the service immediately, so that the customer can make the decision on whether to participate in the cooperation or not. The quotes have to be offered without knowledge on future customer realizations and the final total cost of service. The ex-post incentive compatibility property states that the optimal strategy for each player is to make its request known at the earliest time possible. The budget balance property states that at any time during the planning horizon, the sum of the shared costs of all customers equals to the total travel cost of the current routing schedule. Although HPOCS does satisfy the desirable properties, it has certain drawbacks when the number of dynamic customers is small and does not give sufficient incentive for customers to request early. The latter is important since it provides the transportation provider ample time to optimize their routes. Therefore, we make two extensions to HPOCS: 1) we extend it to introduce the idea of discounts to encourage customers to submit their request in advance to better facilitate efficient vehicle routing; 2) we extend it to incorporate a dynamic vehicle routing framework that periodically re-optimizes the current vehicle routes. Both extensions include analysis on the tradeoff between the performance and the loss of certain desirable properties.

Results

We test the proposed HPOCS mechanism on well-established data sets in the academic literature for the vehicle routing problem with time windows (VRPTW) where deterministic information on customer locations, demands, service time windows, and fleet capacity are given. Figure 1 illustrates the series of shared cost per alpha values for selected customers for one of the studied demand scenarios. The alpha value is the direct distance in miles from the origin to the destination. "Dynamic 1" corresponds to the first dynamic customer while all other series correspond to the 1st, 2nd and 3rd 3-quantiles of the total expected number of realized dynamic customers. Clearly, the shared cost of any customer is non-decreasing over the request order. Figure 2 illustrate the initial quotes and final shared cost per alpha value of all customers, two important shared cost values for a cost-sharing mechanism. The final shared cost per alpha values of all customers tend to be the same, suggesting the formation of one single coalition by the customers in the end. The initial quotes provided for all advance customers are the same which is designed by the mechanism and the ones for all realized dynamic customers drop quickly as more customers become realized with some of them even lower than that of advance customers.