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Moulin mechanism design for freight consolidation

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ABSTRACT

In freight consolidation, a "fair" cost allocation scheme is critical for forming and sustaining horizontal cooperation that leads to reduced transportation cost. We study a cost-sharing problem in a freight consolidation system with one consolidation center and a common destination. In particular, we design a mechanism that collects bids from a set of suppliers, and then decides whose demand to ship via the consolidation center and the corresponding cost shares. We use the Moulin mechanism framework to design a truthful mechanism for the cost-sharing problem, and study the mechanism's budget-balance guarantee and economic efficiency. We find that it is generally not possible to obtain a simultaneously truthful and budget-balanced Moulin mechanism under the transportation cost structure we study. For our proposed mechanism, there exists a trade-off between the budget-balance guarantee and the level of incentives that can be given to large suppliers. Additionally, the mechanism has better economic efficiency when there are more bidding suppliers or the destination is farther away. In our setting, either the consolidation center or the suppliers need to be subsidized. The parameters that determine the trade-off between the consolidation center's benefit and suppliers' cost savings should be set based on the specific goals of the consolidation center. Encouraging more suppliers to bid helps to increase the overall social welfare.

1. Introduction

Transportation costs have increased over the last few decades for various reasons, such as the mismatch of supply and demand for freight transportation services (Russell et al., 2014). Competitive transportation costs are especially critical for the success of various industries. For instance, transportation costs are often a large percentage of product costs in the agriculture industry (Nguyen et al., 2013). Furthermore, as the single largest logistics cost element, transportation costs usually account for more than 50% of the total logistics costs (Thomas and Griffin, 1996). As a result, it is important for suppliers to reduce their transportation costs in order to be competitive.

In terms of transportation costs, suppliers with low market share, which we call small suppliers, are at a competitive disadvantage compared to suppliers with high market share, which we call large suppliers, because small suppliers have

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greater difficulty negotiating favorable transportation rates with carriers due to their smaller shipping volumes. Transportation costs for such suppliers can be reduced by freight consolidation, which is the process of assembling smaller shipments together from different locations; the resulting large shipping volumes allow for a reduction in transportation rates. A survey of 53 United States companies revealed that freight consolidation, which takes advantage of economies of scale, has contributed the most to reducing transportation costs (Jackson, 1985). Significant cost savings through freight consolidation have also been reported in various industries (e.g., Cruijssen et al. (2010); Vanovermeire et al. (2014)). Freight consolidation often takes place among businesses that produce similar products or departments within the same company with a central planner to organize and implement the consolidation. Self-interested businesses are often willing to consolidate because third-party carriers usually charge cheaper shipping rates when the shipment volumes are large enough.

One example that shows the importance of freight consolidation is the plight of the California cut flower industry. This industry has been facing increasing competition from cut flower growers in South America, especially Colombia. Recently, this nation alone exports more than 4 billion flowers at lower prices to the United States (Paletta and McClain, 2018). California's share of the United States cut flower market has decreased from 64% to 20% in the last two decades, while South America's share reached approximately 70% in 2007 (Arbeláez et al., 2007). A shared cross-docking and distribution facility located in Miami, Florida has contributed to the competitive prices of South American flowers by reducing their transportation costs. Central planners in Miami organize and consolidate products from South American growers in the distribution facility before sending them by truck to the rest of the United States. The resulting large volume shipments allow them to obtain cheaper full-truckload (FTL) rates and the corresponding cost savings on transportation provide them with a significant competitive advantage. In contrast, most California cut flower growers, who currently send their products individually using more expensive less-than-truckload (LTL) rates, are often of small to medium size and have no power to negotiate favorable transportation rates on their own. Nguyen et al. (2013) evaluated the transportation practices in the California cut flower industry and explored the possibility of building a consolidation center in Oxnard, California. They concluded that a shipping consolidation center could reduce transportation costs by 35%, saving $20 million per year if all the California cut flower growers were to participate in the consolidation.

Although establishing an alliance to consolidate can improve the competitiveness of suppliers, it is essential to know under what circumstances the individual suppliers will have the incentive to participate in the consolidation. A survey based on approximately 1500 representative logistics service providers in Belgium reported that designing a fair cost sharing scheme is a major impediment to horizontal cooperation among logistics service providers, even though the profitability of cooperation is widely believed (Cruijssen et al., 2007). Therefore, providing a way to fairly allocate the cost of consolidation is critical for facilitating cooperation among the suppliers.

Generally, there are two approaches to solve cost allocation problems. The majority of cost allocation schemes developed in the transportation collaboration literature come from cooperative game theory. Cooperative game theory generally assumes that all players can form a coalition through a binding agreement and focuses on studying whether it is possible to coordinate these players to stay in the coalition through an appropriate way of sharing their costs. The binding agreement is agreed to by the entire set of players as an external enforcement of cooperation. For example, the core (Gillies, 1959) – one of the most well-studied solution concepts in cooperative game theory – consists of cost shares that recover the cost incurred by all of the players and ensure that no individual or a group of players can benefit by defecting. The nonemptiness of the core is often used as a proxy for the possibility of cooperation.

The other approach to solving cost-sharing problems, cost-sharing mechanism design, determines who participates in a collaboration based on bids submitted by the players. The resulting collaboration may contain only a subset of players. In the context of freight consolidation, companies that are interested in participating in the consolidation submit their shipping volumes and the maximum costs they are willing to pay for the shipping service at the planning phase of each consolidation. Then the central planner of the consolidation applies the cost-sharing mechanism to decide who participates and how much cost to allocate to each participant. This approach does not rely on an external binding agreement to enforce cooperation. Instead, it is carefully designed to induce desired cooperative behavior and the coordination is self-enforcing.

In this paper, we advance the research on cost allocation for transportation collaborations by designing cost-sharing mechanisms, which have seldom been applied to transportation collaborations. In particular, we show how to handle the complex transportation cost structure in mechanism design through approximations and demonstrate the trade-offs in mechanism design for the central planners in freight consolidation. In the environment we consider, there is a set of suppliers that could cooperate by using a nearby consolidation center to group their demands to ship to a common faraway destination. Our proposed cost-sharing mechanism decides both the set of suppliers who participate in consolidation and their corresponding cost shares.

We design our proposed cost-sharing mechanism to possess certain desirable properties: (i) *truthfulness*, the idea that it is optimal for individual players or groups of players to bid their true valuations for the service. It is important that no individual supplier or a group of suppliers can benefit from submitting false bids (overreporting or underreporting their willingness to pay) in our mechanism. Otherwise, suppliers can take advantage of this flaw to benefit unfairly and this can be harmful to cooperation. (ii) *Budget-balance*, the notion that the mechanism charges the players the cost they incur. We want our mechanism to be as close to budget-balanced as possible by recovering as much of the cost incurred by consolidation as possible with the cost shares or prices charged. (iii) *Economic efficiency*, the idea that the welfare for all the players is maximized. We want the outcome of the proposed cost-sharing mechanism to maximize social welfare as much as possible.