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Decision Support

Cooperative game theory approach to allocating benefits of horizontal cooperation

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ABSTRACT

Logistics costs in general, and transportation costs in particular, represent a large fraction of the operating costs of many companies. One way to try to reduce these costs is through horizontal cooperation among shippers. Thus, when the transportation needs of two or more companies are merged, their collective transportation requirements can be met at lower cost. The attainable cost savings are due to economies of scale, which translate into cheaper rates due to increased negotiation power, use of larger vehicles and bundling of shipments. In this paper, a linear model is presented and used to study the cost savings that different companies may achieve when they merge their transportation requirements. On the one hand, solving this optimization model for different collaboration scenarios allows testing and quantifying the synergies among different potential partners, thus identifying the most profitable collaboration opportunities. On the other, the problem of allocating the joint cost savings of the cooperation is tackled using cooperative game theory. The proposed approach is illustrated with an example in which different cooperative game solution concepts are compared. Extensive numerical experiments have also been carried out to gain insight into the properties of the corresponding cost savings game and the behavior of the different solution concepts.

1. Introduction

In recent decades, logistics costs have gone up due to increased competition, lower inventory levels and the demands of higher service levels on the part of customers. An effective way of reducing these costs is through horizontal cooperation among companies. Horizontal cooperation corresponds to identifying and exploiting win–win situations among companies at the same level of the supply chain in order to improve performance (Cruijssen et al., 2007a). It is not surprising that collaborative practices (such as group purchasing, capacity and inventory information sharing, and resource pooling) have increased. As a result, the field of collaborative logistics has grown and is attracting the interest of researchers. An added benefit of horizontal cooperation is that not only cost savings can be obtained but also reduced CO_2 emissions (e.g. Ballot and Fontane, 2010).

There are a number of papers reporting on horizontal cooperation case studies within specific industries/contexts, such as grocery distribution (Caputo and Mininno, 1996), distribution in rural areas (Hageback and Segerstedt, 2004), furniture (Audy and D'Amours, 2008; Audy et al., 2010), freight carriers (Krajewska et al., 2008), forest (Frisk et al., 2010), and railway transportation (Sherali and Lunday, 2011). Other researchers have approached the problem from more theoretical points of view, studying coordination mechanisms (e.g. Audy et al., 2010), how to build coalitions and how to share the costs among partners (e.g. D'Amours and Rönnqvist, 2010). Ergun et al. (2007a,b) and Özener and Ergun (2008) have proposed the Lane Covering Problem to bundle lanes from different shippers so as to reduce deadheading. Cruijssen et al. (2007b) have carried out extensive experiments in order to measure the dependence of the synergy (i.e. cost savings) on a number of characteristics of the distribution problem under consideration and found that significant cost savings (up to 30%) are achievable. Cruijssen et al. (2010) present an innovative approach in which the initiative to enter the cooperation lies with the Logistics Service Provider (LSP) which allows it to achieve maximum synergies between shippers whose distribution networks can be merged cost-effectively in a sequential manner.

In this paper, we will consider that the collaboration among shippers takes the form of merging their transportation needs so that their collective transportation demand can be met at lower cost. The cost savings may come from the cheaper rates that would be obtained from carriers due to increased negotiation power, use of larger vehicles and reduced asset repositioning through the in-

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creased number of connected deliveries. In this paper, we will concentrate on the last two aspects. In fact, the shipment consolidation and bundling effects induced by the collaboration are the same that make an LSP operate more cost-effectively than its client companies when they do not merge their shipments. However, precisely because the LSP has to make a profit, just a portion of the cost savings attained is usually passed onto the client companies. With the proposed approach, however, the shippers can retain all the cost savings attainable or, alternatively, if they do not use their own fleet, negotiate better rates with the carrier.

In other words, we are considering a Full-Truck-Load (FTL), which in general could be implemented under different scenarios: using the company's trucking fleet, subcontracting the full truck service to a private transportation company, or using a 3PL company that manages by itself all the company's transportation needs (and will optimize, by itself, its routes). In the two first cases, agreements between the companies will allow the sharing of the benefits derived from horizontal collaboration directly by the companies requiring the transportation. This is the situation we are facing in this paper.

But before companies agree to participate in a horizontal cooperation scheme, both an estimation of the cost savings and a cost savings allocation method must be available. Those issues are the main goal of this paper. On the one hand, we use a simple mathematical programming tool to compute the potential savings of merging the transport needs of a company with those of prospective partners. On the other hand, given that information, we propose an approach to find a fair scheme to allocate the cost savings among the cooperating companies. The proposed cost estimation method is presented in Section 2 while cost savings allocation methods based on Cooperative Game Theory (CGT) are discussed in Section 3. Section 4 presents an illustration, while section 5 reports on the results from extensive numerical experiments. In the last section, conclusions are drawn and further research is outlined. Finally, there are two appendices that, for paper length restrictions, have been included as online supplementary material. In these appendices some CGT definitions and properties (including monotonicity, superadditivity, stability and fairness) as well as relevant solution concepts are presented.

2. Cost estimation model

In this section a Mixed-Integer Linear Program (MILP) is presented to estimate the transportation cost of any coalition of collaborating companies (Adenso-Díaz et al., 2011). This estimation of the benefits of the collaboration will be necessary for the cost saving allocation model that is defined later.

Let us assume that, for each company, the demand of transportation between each origin and destination is known for a certain time period (e.g., a week). The cost of the trip between each pair of locations for different types of vehicles of different capacities is also known. The decision variables of the proposed model are the number of trips between each origin/destination pair using each type of vehicle. The objective function is the minimization of transportation costs. These costs have two components. One is the direct cost of the trip, related to the distance travelled and the time spent. The other is a penalty term that the carrier would charge for the return trip insofar as the trip does not have another leg, i.e., it does not connect with another shipment originating in that same location.

The model to be used is the same, whether a company plans its shipments independently or merges its transportation needs with other companies. What is different in both cases is that in the merged case the transportation demand between each pair of locations is the sum of the individual transportation demands of all collaborating companies.

Let:

Data	
i, j	index of physical locations (origin or destinations of deliveries)
k	index of type of vehicles
S	set of collaborating companies (the grand coalition, formed by all companies is labeled as N)
p	index of collaborating companies in coalition S
Q_{ij}^p	Amount that is shipped weekly between locations i and j by company p
$Q_{ij} = \sum_{p \in S} Q_{ij}^p$	Total amount to be shipped by coalition S between locations i and j
W_k	Capacity of vehicles of type k
t_{ijk}	Basic transportation cost (per trip) between locations i and j using a vehicle type k
α_{ik}	Average penalty cost of unmatched incoming trips to location I, vehicles of type k
Variables	
x_{ijk}	Number of weekly trips between locations i and j using vehicles of type k for coalition S
Δ_{ik}	Number of unmatched trips to/from location i using vehicles of type k
Δ_{ik}^+	Number of unmatched incoming trips to location i using vehicles of type k
Δ_{ik}^-	Negative component of free variable Δ_{ik}

Cost minimization model

$$TC(S) = Min \sum_i \sum_j \sum_k t_{ijk} x_{ijk} + \sum_k \sum_i \alpha_{ik} \Delta_{ik}^+ \tag{1}$$

$$\text{s.t.} \sum_k W_k x_{ijk} \geqslant Q_{ij} \quad \forall i \ \forall j \tag{2}$$

$$\Delta_{ik} = \sum_j x_{jik} - \sum_j x_{ijk} \quad \forall i \ \forall k \tag{3}$$

$$\Delta_{ik} = \Delta_{ik}^+ - \Delta_{ik}^- \quad \forall i \ \forall k \tag{4}$$

$$x_{ijk} \text{ integer} \quad \Delta_{ik} \text{free} \quad \Delta_{ik}^+, \Delta_{ik}^- \geqslant 0. \tag{5}$$

The above model computes the number of trips (using the different types of vehicles) between each pair of locations so that the required transportation demands are met at minimum cost. The objective function $TC(S)$ represents the Transportation Cost of coalition S. Constraints (2) guarantee that the number of trips of different vehicle types between each pair of locations must be sufficient for transporting the required total amount to be shipped by coalition S between locations. Constraints (3) compute the number of unmatched trips from/to a location i as the sum of trips to location i minus the sum of the trips from location i. The number of unmatched trips from/to a location is a free variable that can be decomposed using constraints (4) into a positive and a negative component.

The idea is, firstly, to solve the model considering the transportation demands of each company independently. Secondly, to solve again the model merging the transportation demands of every coalition of two of the companies, then considering the coalitions of three companies, and so on, until reaching the grand coalition. The optimal objective function for any coalitional scenario should be lower than the sum of the individual minimum transportation costs of the members of the coalition, i.e.,