Horizontal cooperation among freight carriers: request allocation and profit sharing

Marta Anna Krajewska[1], Herbert Kopfer[1], Gilbert Laporte[2],
Stefan Ropke[2], Georges Zaccour[3]

June 15, 2007

Abstract

In modern transportation systems, the potential for further decreasing the costs of fulfilling customer requests is severely limited while market competition is constantly reducing revenues. However, increased competitiveness through cost reductions can be achieved if freight carriers cooperate in order to balance their request portfolios. Participation in such coalitions can benefit the entire coalition, as well as each participant individually, thus reinforcing the market position of the partners. The work presented in this paper uniquely combines features of routing and scheduling problems and of cooperative game theory. In the first part, the profit margins resulting from horizontal cooperation among freight carriers are analyzed. It is assumed that the structure of customer requests corresponds to that of a pickup and delivery problem with time windows for each freight carrier. In the second part, the possibilities of sharing these profit margins fairly among the partners are discussed. The Shapley value can be used to determine a fair allocation. Numerical results for real-life and artificial instances are presented.

Key words: horizontal cooperation, coalition, pickup and delivery problem, profit sharing, independent freight carrier, game theory, Shapley value.

[1] Chair of Logistics, University of Bremen, Wilhelm-Herbst-Strasse 5,
Bremen, Germany D-28359

[2] Canada Research Chair in Distribution Management, HEC Montréal,
3000 chemin de la Côte-Sainte-Catherine, Montréal, Canada H3T 2A7

[3] Chair in Game Theory and Management, GERAD, HEC Montréal,
3000 chemin de la Côte-Sainte-Catherine, Montréal, Canada H3T 2A7

Email addresses: makr@logistik.uni-bremen.de, kopfer@uni-bremen.de,
gilbert@crt.umontreal.ca, sropke@crt.umontreal.ca, georges.zaccour@gerad.ca

1 Introduction

With increasing globalization of the economy, large international logistics service providers are more competitive than small companies due to their extensive market power structure. A solution for medium- and small-sized carriers lies in establishing coalitions in order to extend their resource portfolios and to reinforce their market position (Krajewska and Kopfer, 2006). Collaboration among freight carriers can be a powerful approach when it is used to improve operational planning. By cooperating shippers can reduce their "hidden costs" (Ergun et al., 2007), partly due to higher utilization of their less-than-truckload capacity and asset repositioning capabilities.

The purpose of cooperation is to find an equilibrium between the required and available transportation resources of the coalition partners by interchanging their customer requests (Kopfer and Pankratz, 1999). Thus, in the collaborative planning process resources are directly connected, and relevant data are exchanged in order to create a common and mutually agreed plan (Kilger and Reuter, 2002). In supply chain management, horizontal cooperation occurs at the same echelon of the distribution system (e.g., between two shippers), whereas vertical cooperation applies to different echelons (e.g., a manufacturer and a shipper). The additional profit generated through the collaboration process is split among the coalition members according to predetermined rules. To ensure the long-term functioning of collaboration structures among independent freight carriers, positive incentives for the partners should be generated in the collaboration process. In other words, an appropriate profit sharing scheme should guarantee a financial advantage for each freight carrier. The features to be included in the profit sharing scheme depend on the distribution of power among freight carriers, on their level of interdependency and willingness to make compromises, and on the market within which they operate.

We have analysed a medium-sized freight forwarding company using its own vehicles and subcontractors for its operations in several regions of Germany. The company consists of several autonomous profit centres which operate as independent freight carriers and have enterpreneurial responsibility towards the headquarters. Thus, the profit centres treat each other like any other competitor on the market, i.e., they do not normally cooperate. Each of them possesses its own vehicle fleet and makes use of subcontractors hired on a long-term basis. An analysis has shown that a high percentage of truck movements within the profit centres are empty. Moreover, some subcontractors accept orders from several profit centres and bundle these orders themselves, thus achieving substantial cost reductions. Collaboration with other profit centres could substantially reduce the number of empty truck movements and would allow profitable bundling of requests forwarded to subcontractors, as the tariffs are non-linear with respect to the weight of a bundle and distance driven.

The aim of this paper is to show the advantage of collaboration in terms of incremental profit. The paper adopts the formalism of cooperative games to share the profits of collaboration. Section 2 presents an overview of the existing concepts relating to horizontal cooperation. Section 3 briefly describes the routing problem faced by the partners in a coalition. In Section 4 some profit sharing approaches are introduced. Section 5 contains computational results showing the benefits of cooperation. Finally, Section 6 provides conclusions.

2 Literature review

Developments in telecommunications and information technology have created many opportunities to increase cooperation among the entities operating in logistics chains. This has led to the realization that suppliers, consumers and even competitors can be potential collaboration partners in logistics (Ergun et al., 2007). Vertical cooperation, involving suppliers, manufacturers, distribution centers, customers and logistics service providers has been the topic of extensive academic research (Cruijssen et al., 2005). This research mainly focuses on identifying potential benefits (Gentry, 1993), critical success factors (Tate, 1996), and partner selection criteria (Carter and Jennings, 2002; Schönsleben, 2000). Formal logistics models for vertical collaboration have enabled performance improvements for an entire supply chain (Slats et al., 1995), covering the analysis of bottlenecks and the quality of customer service. Furthermore, models have been developed to predict costs and their apportionment when existing logistics chains are adapted to new products and markets (Slats et al., 1995) or when new cooperative logistics networks are designed (Matsubayashi et al., 2005; Fernandez et al., 2004; Krus and Bronisz, 2000). Widely discussed issues include specific types of vertical collaboration such as cooperation models between manufacturers and retailers (Slikker et al., 2005; Yue et al., 2004; Li et al., 2002; Jørgensen et al., 2003; Huang and Li, 2001), or effective cooperation mechanisms for inventory decisions (Fu and Piplani, 2004; Baganha and Cohen, 1998).

In comparison, the literature on horizontal cooperation in logistics (i.e., among competitors) is still at an early stage (Cruijssen et al., 2005). Only a few models of horizontal cooperation have been developed. All assume an equal distribution of power and similar market positions for each of the freight carriers and focus on short-term planning.

Cruijssen and Salomon (2004) analyse the effect of collaboration for an entire coalition and show, using a case study, that cost savings may range from 5 to 15% and can be even higher. Ergun et al. (2007) focus on minimizing execution costs for a coalition of freight forwarders. They assume that the goal of collaborating shippers is to identify a set of routes that can be submitted to a carrier as a bundle, instead of as individual requests, in the hope that this will result in more favourable rates. Reduced rates can be achieved when covering the routes in the bundle, and this involves little or no asset repositioning.

Thus, given a set of requests to serve, it is possible to identify common tours to cover all requests and minimize asset repositioning costs. This shipper collaboration problem is considered as a constrained variant of the lane covering problem defined by Cruijssen and Salomon (2004), which is similar to the cycle covering problem. Using a greedy heuristic as well as set partitioning, sets of cycles are generated which show significant cost reduction in asset repositioning.

Further studies introduce the sharing of collaboration profit among freight carriers. Schönsleben and Hieber (2004) propose apportioning the gains uniformly among the participants. This idea is also included in the approach of Schönberger (2005). However, this author proposes a loss sharing, not a profit sharing model. The main assumption is that it is always unprofitable to use outside carriers at spot market prices, as the cost associated with each request is higher than the corresponding costs for self-fulfilment. Thus, a central entity assigns these unprofitable requests and their bundles in line with the principle of minimizing the negative sum of avoided carrier costs. The costs arising from the use of an external forwarder are distributed uniformly among the partners. Each request that has been assigned to one partner is shifted from the offering to the serving partner together with the entire corresponding revenues. The offering freight carrier receives no payment for the shifting of the request. Such a profit sharing concept is not sustainable as it fails to preserve the interests of individual partners.

In Gomber and Schmidt (1997) profit sharing models based on multi-agent auctions are proposed. These models vary according to the features of the requests. If a single request forwarding is concerned, the Vickrey auction is used as a dominant strategy (de Vries and Vohra, 2003). In order to maximize the probability of obtaining the request, each freight carrier quotes the minimal price for the request that still generates a profit. When a request generates losses, it is assumed that the participants can offer negative bids. The Vickrey auction functions for negative prices in the same way as for the positive prices. For accepting the request, the bidder is paid the amount of the second best bidder price, hence generating profit. The payment comes from the offering freight carrier who has acquired the request. The mechanism of combinatorial auction, called matrix auction is proposed for bundles of requests (de Vries and Vohra, 2003). In principle, it is also based on the Vickrey auction. Each of the m freight carriers offers bids (positive or negative) for all $2^n - 1$ combinations of n requests. In order to find the optimal allocation of the requests, a matrix with $2^n - 1$ columns and n rows is constructed, and only one matrix element can be chosen from each column. The chosen bundles must contain all requests offered to the coalition and must be disjunctive.

Krajewska and Kopfer (2006) propose a collaboration model concept based on operations research game theory and combinatorial auctions. In the preprocessing phase each freight carrier specifies its lowest fulfillment costs, called self-fulfillment costs, for each acquired request offered to the partners. Each partner then defines bundles of requests it can and wishes to fulfill, and evaluates the fulfillment cost of such bundles and of each individual request from each bundle taken separately, thus constructing several one-element bundles. The profit optimization phase generates an assignment of requests to the collaborating partners in such a way that the execution cost for the entire coalition is minimized. Hence, as the price paid by the customers remains constant, the maximal total profit for the fulfillment of all offered requests is achieved. The lowest serving costs are determined by solving an integer program called the combinatorial auction problem (de Vries and Vohra, 2003). In the profit sharing phase the profit resulting from the fulfillment of requests within the collaboration process is divided among the freight carriers in the coalition. For each request, the offering freight carrier holds the payment from the customer and pays the amount of potential self-fulfillment costs to the coalition. For each bundle, the serving freight carrier receives the transfer price for request execution, which corresponds to the sum of the lowest potential (self-) fulfillment costs of all single requests from the bundle. The residual profit from the bundle, which is the difference between the payment of the offering enterprise and the transfer price, is then divided among the coalition members according to so called “collaboration advantage indices”. The allocation corresponds to the benefit that each freight carrier brings to the coalition.

In Krajewska and Kopfer (2006), the allocation of the profit generated by a coalition is determined by exchanging some of the partners’ requests through a matrix auction. The authors present a profit sharing model based on the exchange of single bundles, i.e., the profit is shared for each bundle separately. This model creates an incentive for each partner to share as many bundles as possible. Our approach is different. We solve the routing problems of the coalition partners, and of possible coalitions in which the partners merge all their requests. The total profit is shared between the partners on the basis of their overall contribution to the coalition and not on the basis of single bundles. In addition to new concepts for profit sharing, this paper presents computational results on the profit that can result from coalitions, and on how to share it fairly.

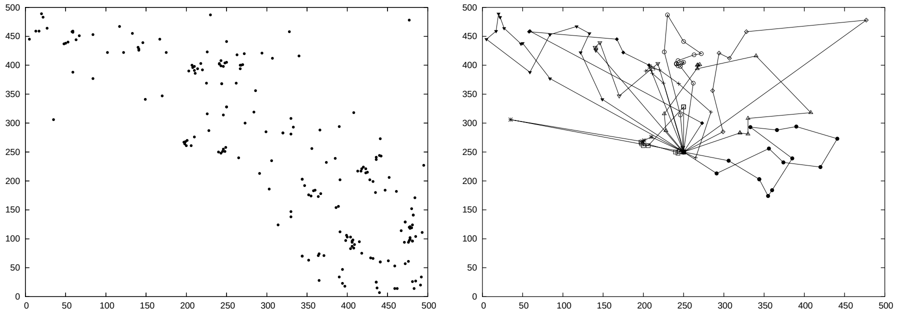
3 The routing problem

Whether the freight carriers cooperate or not, the problem faced by them is to optimally serve a set of pickup and delivery requests with time windows (PDPTW) on which a rich literature exists (see, e.g., Cordeau et al., 2007). In a non-cooperative environment, the set of requests is partitioned between shippers, and each shipper solves a single-depot PDPTW. If shippers cooperate by merging all their requests, the problem is to solve a unique multi-depot PDPTW over the entire customer set, yielding potential savings over the first scenario.

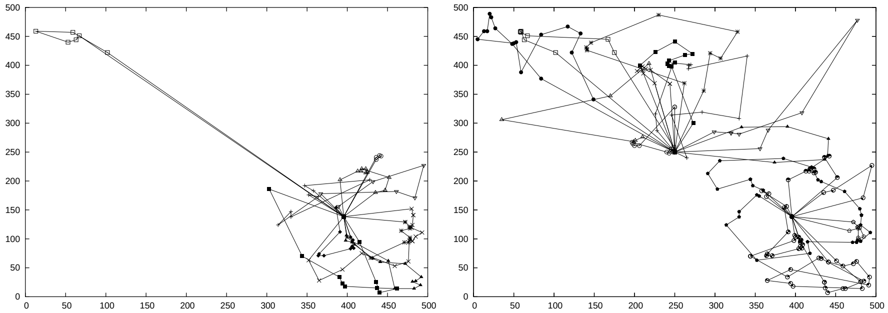
The multi-depot PDPTW is formally defined over a directed graph $G = (V, A)$, where V is the vertex set and A is the arc set. The vertex set is partitioned into $V = \{R, PU, D\}$, where R is the set of depots, PU is the set of pickup locations and D is the set of delivery locations. For each pickup location $i \in PU (i = 1, ..., n)$ there is a corresponding delivery location $n + i \in D$. Each request i has a weight q_i, a service time d_i and a time window $[e_i, l_i]$. When a request is picked up, the vehicle load increases by q_i and it decreases by q_i when it is delivered. A set of identical vehicles of capacity Q are available and each is based at one of the depots. The distance-dependent travel cost between vertices i and j of V is c_{ij} and the corresponding travel time is t_{ij}. The multi-depot PDPTW consists of determining a set of vehicle routes whose total cost is minimized, and such that all requests are served within their time windows, the vehicle capacity is never exceeded, and each vehicle starts and ends its trip at its depot.

Because the PDPTW is NP-hard, it is usually solved by means of a heuristic. Here we use the heuristic proposed by Ropke and Pisinger (2006) which is probably the best available and can be applied to instances involving one or several depots. The method is a local search method which moves from the current solution to another solution in its neighbourhood. The heuristic is based on the large neighbourhood search heuristic proposed by Shaw (1998). A move in the neighbourhood is defined by the removal of up to 100 requests and a subsequent reinsertion of these requests. Several removal and insertion heuristics are defined and the choice of heuristic at a given iteration is randomized. More precisely, the algorithm applies three removal heuristics (Shaw's removal procedure, random removal, worst removal), as well as some insertion heuristics (greedy, and several types of regret-based insertions). The insertion heuristics use the true value of f to evaluate the quality of a solution, or a perturbed value $f + \epsilon$, where ϵ is a randomly generated noise. During the search, the algorithm maintains a score ψ_j which measures how well heuristic j has performed in previous iterations. At a given iteration, it applies a roulette wheel selection principle, i.e., it selects heuristic j with probability $\psi_j / \sum_i \psi_i$. Because of this feature, the authors call their multi-depot PDPTW heuristic an adaptive large neighbourhood search heuristic. This heuristic uses a simulated annealing based acceptance rule for neighbour selection and runs for a preset number of iterations. The heuristic has been intensively tested on benchmark instances and has proved to be superior to other algorithms. It applies without modifications to our problem.

To illustrate the potential of collaboration, consider the case of two shippers who have to serve the requests shown in Figure 1a. If each carrier operates independently, sets of routes are generated which are presented in Figures 1b and 1c. The set of routes obtained under collaboration are shown in Figure 1d. A numerical solution for this instance is given in Table 1. In this particular example, cooperation between the two carriers yields a 10% reduction in the number of vehicles and a 12.46% reduction in routing cost.



a. Pickup and delivery locations of all requests
b. Fulfillment plan for carrier 1



c. Fulfillment plan for carrier 2
d. Fulfillment plan for the coalition

Figure 1: Solution for a coalition of carriers 1 and 2.

4 Profit sharing

Cooperative game theory offers a natural paradigm to deal with profit or cost sharing problems. To define a cooperative game, two ingredients are needed: a set $P = \{1, ..., p\}$ of players (here the carriers) and a *characteristic function* $v(S)$ which assigns to each possible coalition of players S ($S \subseteq P$) a numerical value to be interpreted as a measure of its power (payoff, strength). The characteristic function must satisfy the following two conditions:

$$\begin{aligned} v(\emptyset) &= 0, \\ v(S \cup T) &\geq v(S) + v(T), \qquad \forall S, T \subseteq P, \quad S \cap T = \emptyset. \end{aligned}$$

The first property is a convention by which a void coalition has a zero value, and the second one, called superadditivity, states that when two coalitions join force, they can achieve at least the same payoff as when acting separately. A

Carrier	# Requests	Cost	# Vehicles	Cost reduction
1	50	5603.73	10	
2	50	4156.86	10	
coalition	100	8543.88	18	12.46%

Table 1: Numerical solution for a coalition of carriers 1 and 2

vector $x = (x_1, ..., x_p)$ is an *imputation* if it satisfies

$$x_i \geq v(\{i\}), \forall i \in P$$
$$\sum_{i=1}^{p} x_i = v(P).$$

An imputation is a vector of players' outcomes. Its definition refers to individual and group rationality. Individual rationality means that a player will not accept an outcome which is not at least equal to what he could obtain by acting alone as measured by his characteristic function value. Group rationality states that the total cooperative gain, when the grand coalition forms, is fully shared. From a negotiation perspective, the set of imputations (denoted X) can be seen as the set of feasible agreements. This set is seldom a singleton and therefore one needs other properties to predict the final issue of the game. This is precisely the objective pursued by the different solution concepts of cooperative games. The set of solutions include the *kernel*, the *bargaining set*, the *stable set*, the *core*, the *Shapley value* and the *nucleolus* (see, e.g., Osborne and Rubinstein (1994) or Ordeshook (1986) for an introduction to these concepts). A solution is a sharing mechanism based typically on a series of axioms which correspond to some desirable properties (e.g., fairness, stability). The solutions of a cooperative game can therefore be contrasted in terms of these properties, and also in terms of whether they select a unique imputation or not. We shall retain here the Shapley value as the mechanism to share the dividend of cooperation among the different participant carriers. This solution selects a single imputation, a p-vector denoted $\phi(v) = (\phi_1(v), \ldots, \phi_p(v))$, satisfying three axioms: fairness (similar players are treated equally), efficiency ($\sum_{i=1}^{p} \phi_i(v) = v(P)$) and linearity (a rather technical axiom needed to obtain uniqueness). The Shapley value is defined by

$$\phi_i(v) = \sum_{S \ni i} \frac{(p-s)!\,(s-1)!}{p!} \left(v(S) - v\left(S \backslash \{i\}\right)\right), \qquad \forall i \in P,$$

where s denotes the number of players in coalition S. The factor $v(S) - v(S \backslash \{i\})$ corresponds to the marginal contribution of player i to coalition S. Thus, the Shapley value allocates to each player the weighted sum of his contributions.

The main reasons for choosing the Shapley value are the following:

Uniqueness By selecting only one imputation, this solution is reassuring psychologically for the players in that no hypothetically better deal could have been overlooked. Hence, the Shapley value leaves no room for the players to regret the adopted allocation, and close the door to what could be an endless bargaining process.

Ease of implementation The Shapley value shares with the nucleolus the property of being one-point solutions, i.e., each selects a single imputation. The Shapley value has, however, a major advantage over the nucleolus in terms of implementation . Indeed, the Shapley value is nothing but a "formula" which is easy to implement. In contrast, finding the nucleolus requires solving a sequence of linear programs. Most probably, this explains why the Shapley value has been used in literally hundred of applications of cooperative games in many areas of economics and management science.

Fairness This property is typically claimed by all parties involved in a sharing problem. We believe that a solution which is, or perceived as, unfair has a great potential of being rejected by some of the players.

One potential problem with the Shapley value is that it may not lie in the *core* of the cooperative game[1]. The *core* is the set of undominated imputations. This confers to the core a stability property: there exists no coalition that can pretend to offer a better deal to its members. A drawback is that the core can be empty or contain a large number of imputations. In the former case, the players must adopt another solution concept to share the dividend of their cooperation, and in the latter they will still need to negotiate to choose one imputation in the core to be implemented. It is well known that for an imputation to be in the core it must satisfy

$$\sum_{i \in S} x_i \geq v(S), \forall S \subseteq P.$$

The above condition is somehow a generalization of the concept of individual rationality to group (coalition) rationality.

In the next section we will use the Shapley value as a mean to allocate the total cost among the cooperating partners. We will also check the non-emptiness of the core and eventually whether the Shapley value belongs to it.

---

[1] The nucleolus belongs to the core whenever the latter is non-empty. If the game is convex, that is

$$v(S \cup T) + v(S \cap T) \geq v(S) + v(T), \qquad \forall S, T \subseteq P,$$

then it is well known that the core is non-empty and the Shapley value corresponds to the center of gravity of the core.

5 Computational results

To our knowledge, no test instances are available in the literature for the collaboration problem studied in this paper. We have generated three artificial instances and one instance based on real data.

Based on the existing PDPTW instances of Li and Lim (2001), we have generated three instances (T1, T2 and T3) for five carriers. Each carrier possesses one depot. The vehicle fleet is unlimited and homogenous for all carriers. The instances are different with regard to the number of requests that each carrier has to fulfill. For each instance all 31 possible coalitions, consisting of one, two, three, four and five carriers, are assumed.

We have also tested our approach on real-life data sets provided by Stute GmbH, a German freight forwarder operating mainly in northwestern Germany, between the Niedersachsen province and the Main area. The company consists of 19 profit centres, each using between five and 15 of its own vehicles and up to ten different subcontractors. We have used the data of the Bremen, Schwerte and Neuwied profit centres which are not only the largest, but also the most likely to engage in horizontal cooperation. Figure 2 shows the 19 profit centres in Germany. The three profit centres used in our test instance are marked with black circles while the rest of the profit centres are shown in grey. The number of requests from customers fluctuates daily, but due to the possibility of hiring subcontractors in the short term, the fleet size is always sufficient.

On all instances, for the coalition with one carrier, the PDPTW is solved as if this carrier operated independently and fulfilled the request without assistance. The multi-depot PDPTW is then solved for each coalition using the vehicles of all partners in the coalition. Fulfillment costs for each solution were calculated.

Turning now to the cost sharing problem, we first define the characteristic function values as follows:

$$v(S) = \sum_{i \in S} c(\{i\}) - c(S), \quad \text{for all } S \subseteq P,$$

that is the cost saving realized by the players in the coalition. In this manner, the data are transformed into payoffs instead of costs. Tables 2 to 5 present the results for the instances used in our tests. In these tables, we define

$$\text{Net cost} = \text{cost} - \text{savings (Shapley value)},$$
$$\text{Cost ratio} = (\text{cost} - \text{savings})/\text{cost}\ .$$

These numerical results give rise to the following comments. First, in all instances, the cost reduction is significant. Indeed, the cost ratio can be as low as 0.68 and the highest observed value is 0.84. Although there are some variations between the different instances, the cost ratios are of the same magnitude.

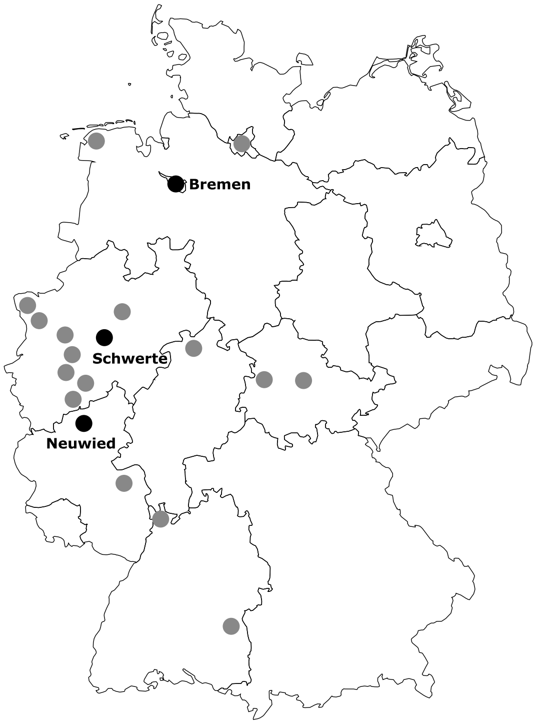


Figure 2: Location of profit centres in Stute GmbH

These results show clearly that it is indeed worth pooling resources to serve customer requests. Second, the real case involves three carriers and 257 requests. The grand coalition needs 38 vehicles to serve these requests. The level of the cost ratio is lower in this case than in the simulated instances, which is probably due to the lower number of players and request types occurring in the real case. In this instance a large number of requests either have their pickup or delivery location at the depot of the player to which they are assigned, while the corresponding delivery or pickup is an arbitrary location. These requests are usually best served by the vehicles originating at the depot in question and consequently fewer requests are exchanged between players, leaving less room for improvement. Still, player 1 (Neuwied) saves almost 20% and the other two players around 10% each, which is far from being negligible and rather higher than the savings reported in Cruijssen and Salomon (2004). Third, in all simulated instances, as well as in the real case, the core of the cooperative game is non-empty and the Shapley value belongs to the core. Therefore, in addition to providing a fair solution of the sharing problem, this solution is stable (no coalition can do better than the Shapley allocation).

Carriers in coalition	# Requests	# Vehicles	Cost	Shapley value	Net cost	Cost ratio
1	50	10	5603.7	1461.6	4142.1	0.74
2	50	10	4156.9	1104.7	3052.1	0.73
3	50	10	4598.4	1421.5	3177.0	0.69
4	50	10	5406.9	1124.3	4282.5	0.79
5	50	8	5236.9	963.5	4273.4	0.82
1 2	100	18	8543.9			
1 3	100	16	8433.8			
1 4	100	18	9836.6			
1 5	100	16	9490.3			
2 3	100	18	7780.0			
2 4	100	19	8934.1			
2 5	100	16	8362.4			
3 4	100	16	8488.4			
3 5	100	18	9004.5			
4 5	100	18	10028.2			
1 2 3	150	25	11588.4			
1 2 4	150	25	12394.6			
1 2 5	150	24	12338.1			
1 3 4	150	23	12485.4			
1 3 5	150	24	12671.6			
1 4 5	150	25	13827.4			
2 3 4	150	25	11281.1			
2 3 5	150	24	11879.7			
2 4 5	150	25	13205.6			
3 4 5	150	24	12910.1			
1 2 3 4	200	33	15238.4			
1 2 3 5	200	31	15262.8			
1 2 4 5	200	32	16587.3			
1 3 4 5	200	30	16573.2			
2 3 4 5	200	30	15427.8			
1 2 3 4 5	250	39	18927.1			

Table 2: Results for instance T1

Carriers in coalition	# Requests	# Vehicles	Cost	Shapley value	Net cost	Cost ratio
1	100	13	7468.5	1711.1	5757.4	0.77
2	100	14	6390.7	1954.9	4435.8	0.69
3	100	15	7275.9	1752.2	5523.7	0.76
4	100	13	7518.7	1265.1	6253.6	0.83
5	100	14	7202.9	1168.1	6034.8	0.84
1 2	200	25	11638.8			
1 3	200	24	12825.7			
1 4	200	25	14236.7			
1 5	200	25	13031.4			
2 3	200	26	11785.7			
2 4	200	28	12884.1			
2 5	200	25	12053.0			
3 4	200	25	13050.3			
3 5	200	28	13771.7			
4 5	200	27	14649.1			
1 2 3	300	36	16910.3			
1 2 4	300	38	17847.8			
1 2 5	300	36	17034.7			
1 3 4	300	36	18807.9			
1 3 5	300	37	18543.9			
1 4 5	300	36	19763.9			
2 3 4	300	36	16989.8			
2 3 5	300	38	17681.8			
2 4 5	300	37	18489.2			
3 4 5	300	38	19450.2			
1 2 3 4	400	47	22731.6			
1 2 3 5	400	48	22738.7			
1 2 4 5	400	48	23298.3			
1 3 4 5	400	49	24597.4			
2 3 4 5	400	48	22830.9			
1 2 3 4 5	500	60	28005.3			

Table 3: Results for instance T2

Carriers in coalition	# Requests	# Vehicles	Cost	Shapley value	Net cost	Cost ratio
1	50	10	5603.7	1534.6	4069.2	0.73
2	75	14	5890.6	1902.7	3987.9	0.68
3	100	15	7275.9	1492.8	5783.1	0.79
4	50	10	5406.9	1120.1	4286.8	0.79
5	75	12	6492.2	1175.6	5316.6	0.82
1 2	125	21	9346.6			
1 3	150	23	11223.9			
1 4	100	18	9836.6			
1 5	125	19	10383.1			
2 3	175	26	11144.1			
2 4	125	23	10537.1			
2 5	150	22	10138.8			
3 4	150	21	11012.8			
3 5	175	26	13066.1			
4 5	125	21	11217.6			
1 2 3	225	33	14774.5			
1 2 4	175	28	13179.9			
1 2 5	200	29	13971.3			
1 3 4	200	28	14984.3			
1 3 5	225	32	16446.3			
1 4 5	175	28	15181.5			
2 3 4	225	31	14628.7			
2 3 5	250	36	16335.2			
2 4 5	200	31	15125.6			
3 4 5	225	32	16768.8			
1 2 3 4	275	38	18775.3			
1 2 3 5	300	43	19755.4			
1 2 4 5	250	38	18276.5			
1 3 4 5	275	39	20337.8			
2 3 4 5	300	41	19774.6			
1 2 3 4 5	350	47	23443.5			

Table 4: Results for instance T3

Carriers in coalition	# Requests	# Vehicles	Cost	Shapley value	Net cost	Cost ratio
1	61	13	16512.6	3087.17	13425.4	0.81
2	96	11	17876.0	1898.97	15977.0	0.89
3	100	28	38585.4	3426.97	35158.4	0.91
1 2	157	24	31961.6			
1 3	161	36	49615.0			
2 3	196	32	53354.8			
1 2 3	257	38	64560.9			

Table 5: Results for the Stute GmbH company case

6 Conclusions

Collaborative freight carrier planning is clearly of high practical significance. However, the literature on the distribution of both costs and savings arising from horizontal cooperation is scarce. Cooperative game theory provides a promising framework for analysis. Cooperating companies in the automotive industry (Cachon and Lariviere, 1999), retail (Sayman et al., 2002), telecommunications (van den Nouweland et al., 1996), aviation (Adler, 2001), and health care (Ford et al., 2004) have already benefited from game theoretical methods that objectively take into account each player's impact within a cooperating group and produce compromise allocations that distribute the benefits of cooperation based on clear-cut fairness properties (Cruijssen et al., 2005). We propose a similar approach for the logistics sector to help freight carriers understand how to share costs and savings. We have demonstrated that collaboration can yield a considerable cost decrease and that efficient profit allocation is possible by using cooperative game theory. However, as opposed to maritime shipping and air transportation, where the concept of alliances between competing companies is quite common, the truck transportation industry has not yet adopted horizontal cooperation on a large scale (Vos et al., 2003).

Acknowledgements

We thank the Stute GmbH company, Germany, for providing the data for the real case instances. This work was supported by Natural Sciences and Engineering Research Council of Canada (NSERC) under grants 39682-05 and 37525-01, and by the Deutsche Forschungsgemeinschaft (DFG) under grant SFB637. The authors thank Ann Langley for her help and two referees for their valuable comments.

References

[1] Adler, N., 2001. Competition in a deregulated air transportation market. European Journal of Operational Research 129, 337-345.

[2] Baganha, M., Cohen, M., 1998. The stabilising effect of inventory in supply chains. Operations Research 46, 572-583.

[3] Cachon, G., Lariviere, M., 1999. Capacity allocation using past sales: When to turn and earn. Management Science 45, 685-703.

[4] Carter, C., Jennings, M., 2002. Social responsibility and supply chain relationships. Transportation Research E 38, 37-52.

[5] Cordeau, J.-F., Laporte, G., Potvin, J.-Y., Savelsbergh, M.W.P., 2007. Transportation on demand, Handbooks in Operations Research and Management Science, Volume 14, C. Barnhart and G. Laporte (Eds.), Elsevier, Amsterdam, pp. 429-466

[6] Cruijssen, F., Cools, M., Dullaert, W., 2005. Horizontal cooperation in logistics: Opportunities and impediments. Transportation Research E 43, 129-142.

[7] Cruijssen, F., Salomon, M., 2004. Empirical study: Order sharing between transportation companies may result in cost reductions between 5 to 15 percent. CentER Discussion Paper 2004-80, Faculty of Economics and Business Administration, Tilburg University, The Netherlands.

[8] Ergun, Ö., Kuyzu, G., Savelsbergh, M.W.P., 2007. Shipper collaboration. Computers & Operations Research 34, 1551-1560.

[9] Fernandez, F., Hinojosa, M., Puerto, J.,2004. Multi-criteria minimum cost spanning tree games. European Journal of Operational Research 158, 339-408.

[10] Ford, E., Wells, R., Bailey, B., 2004. Sustainable network advantages: A game theoretic approach to community-based health care coalitions. Health Care Management Review 29, 159-169.

[11] Fu, Y., Piplani, R., 2004. Supply-side collaboration and its value in supply chains. European Journal of Operational Research 152, 281-288

[12] Gentry, J., 1993. Strategic alliances in purchasing: Transportation is the vital link. International Journal of Purchasing and Materials Management 29, 11-17.

[13] Gomber, P., Schmidt C., 1997. Elektronische Märkte für die dezentrale Transportplanung. Wirtschaftsinformatik 39, 137-145.

[14] Huang, Z., Li, S., 2001. Co-op advertising models in manufacturer-retailer supply chains: A game theory approach. European Journal of Operational Research 135, 527-544.

[15] Jørgensen, S., Taboubi, S., Zaccour, G., 2003. Retail promotions with negative brand image effects: Is cooperation possible? European Journal of Operational Research 150, 395-405.

[16] Kilger, C., Reuter, B., 2002. Collaborative Planning. In: H. Stadtler, C. Kilger, 2002. Supply Chain Management and Advanced Planning, Springer, Berlin-Heidelberg-New York, pp. 223-241.

[17] Kopfer, H., Pankratz, G., 1999. Das Groupage-System kooperierender Verkehrsträger. Operations Research Proceedings 1998, Springer, Berlin-Heidelberg-New York, pp. 453-462.

[18] Krajewska, M., Kopfer, H., 2006. Collaborating freight forwarding enterprises: Request allocation and profit sharing. Operations Research Spectrum 28, 301-317.

[19] Krus, L., Bronisz, P., 2000. Cooperative game solution concepts to a cost allocation problem. European Journal of Operational Research 122, 258-271.

[20] Li, H., Lim, A., 2001. A Metaheuristic for the Pickup and Delivery Problem with Time Windows. Proceedings of the 13th International Conference on Tools with Artificial Intelligence, Dallas, pp. 160-167

[21] Li, S., Huang, Z., Zhu, J., Chau, P., 2002. Cooperative advertising, game theory and manufacturer-retailer supply chains. Omega 30, 347-357.

[22] Matsubayashi, N., Umezawa, M., Masuda, Y., Nishino, H., 2005. A cost allocation problem arising in hub-spoke network systems. European Journal of Operational Research 160, 821-838.

[23] van den Nouweland, A., Borm, P., van Golstein Brouwers, W., Groot Bruinderink, R., Tijs, S., 1996. A game theoretic approach to problems in telecommunication. Management Science 42, 294-303.

[24] Ordeshook, P.C., 1986. Game theory and Political Theory. Cambridge University Press.

[25] Osborne, M.J., Rubinstein, A., 1994. A Course in Game Theory. MIT Press, Cambridge, Massachusetts.

[26] Ropke, S., Pisinger, D., 2006. An adaptive large neighbourhood search heuristic for the pickup and delivery problem with time windows. Transportation Science 40, 455-472.

[27] Sayman, S., Hoch, S., Raju, J., 2002. Positioning of store brands. Marketing Science 21, 378-397.

[28] Schönberger, J., 2005. Operational freight carrier planning. Springer, Berlin-Heidelberg-New York.

[29] Schönsleben, P., Hieber, R., 2004. Gestaltung von effizienten Wertschöpfungspartnerschaften im Supply Chain Management. In: A. Busch, W. Dangelmaier, 2004. Integriertes Supply Chain Management. Gabler, Wiesbaden, pp. 47-65.

[30] Schönsleben, P., 2000. With agility and adequate partnership strategies towards effective logistics networks. Computers in Industry 42, 33-42.

[31] Shaw, P., 1998. Using constraint programming and local search methods to solve vehicle routing problems. In: CP-98 (Fourth International Conference on Principles and Practice of Constraint Programming), vol. 1520 of Lecture Notes in Computer Science, 417-431.

[32] Slats, P., Bhola, B., Evers, J., Dijkhuizen, G., 1995. Logistic chain modelling. European Journal of Operational Research 87, 1-20.

[33] Slikker, M., Fransoo, J., Wouters, M., 2005. Cooperation between multiple news-vendors with transshipments. European Journal of Operational Research 167, 370-380.

[34] Tate, K., 1996. The elements of successful partnership. International Journal of Physical Distribution and Logistics Management 26, 7-13.

[35] Vos, B., Iding, M., Rustenburg, M., Ruijgrok, C, 2003. Synergievoordelen in Logistieke Netwerdek (SYLONET) - deel 1 (Dutch), TNO Inro rapport 033N08832001.

[36] de Vries, S., Vohra, R., 2003. Combinatorial auctions: A Survey. INFORMS Journal of Computing 15, 284-309.

[37] Yue, J., Austin, J., Wang, M., Huang, Z., 2006. Coordination of cooperative advertising in a two-level supply chain when manufacturer offers discount. European Journal of Operational Research 168, 65-85.