Benefit allocations of the strategic alliance in a logistics industry

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Abstract

This study investigates a logistics alliance in terms of various sharing rules in a cooperative game theory. Through high efficiency of resource utilization with collective market demand, carriers gain extra profits. In our study, the model conceptualizes the characteristic function of cost savings by coalitions considering the hub-spoke network. To share the improved profits fairly between members, we use different allocation schemes of a cooperative game theory. Analytical results with a numerical example demonstrate when coalitions can be formed measuring the satisfaction. Our interesting results with respect to fair allocation schemes provide a practical and academic intuition for further research.

Keywords: Cooperative game theory, Strategic alliance, Cost allocation

Introduction

The intense competition due to the needs for cost reduction and speed of delivery has forced logistics companies into improving competitiveness by cooperating with competitors. A strategic alliance as a strategy for strengthening competitiveness has risen in prominence over the last few decades, allowing carriers to obtain greater efficiency and firms in other industries to enhance the competitiveness potentially by reducing costs. Economies of scale and economies of scope are well known ways for generating profits in logistics industry, which is based on infrastructures such as roads, ports or airports. However, individual companies are limited by high initial investment costs and regulations, thus they expand networks through cooperation in order to achieve economic benefits.

Coopetition, a portmanteau describing cooperative competition, is no longer a novel concept and the strategic alliance is a representative type of it. Firms have chosen forming a strategic alliance, which is an agreement between separate firms to cooperate in terms of sharing resources to achieve a particular goal (Oster, 1999) as an alternative of collaborating with their competitors. The fact that strategic alliances strengthen competitiveness of collaborating firms (Crawford and Haller, 1990; Harrigan, 1988) is supported by numerous research; reducing costs or sharing resource capabilities (Gibson et al., 2002; Kogut, 1988; Li et al., 2013; Roels and Tang, 2016), hedging against risks (Das and Teng, 2001; Hihara, 2014; Li et al., 2013), transferring knowledge and technologies (Chan et al., 1997; Kogut, 1988) ,and enabling to enter new markets (Doz, 1987; Hamel, 1991). Despite of those advantages and substantial influences, strategic alliances may not always be the best way (Aloysius, 2002) and lead to failure in many cases (Gomes-Casseres, 1987; Harrigan, 1988; Kogut, 1989; Park and Russo, 1996). There is a substantial literature analyzing on significant barriers to have a successful alliance, for example, imbalances in power or unequal capacities among partners could be the problem (Harrigan, 1988; Kumar, 2010; Lin and Germain, 1998). Thus, in order to have a successful alliance, firms need to precisely identify their strength (Lei and Slocum, 1992). In addition, the goal of the alliance should be defined clearly (Dyer et al., 2001; Elmuti and Kathawala, 2001; Parkhe, 1993; Todeva and Knoke, 2005).

There are studies in the area of the logistics alliance that apply cooperative game configuration to investigate benefit allocations from cooperation. There are topics related to a vehicle routing game (Engevall et al., 2004; Krajewska et al., 2008), a joint distribution problem of bundling and procurement (Audy et al., 2011; Ö zener and Ergun, 2008), distribution the usage fee of logistics facilities such as airports or railways (Hamidi et al., 2016; Littlechild and Owen, 1973), and so on. Due to most transportation collaboration models' objective is to minimize the total cost, the characteristic function for cooperation is set by the amount of cost reduction. Lozano et al. (2013) explored the synergy from horizontal cooperation of truck delivery which is assumed direct shipment with full truck load. In our paper, we extend the Lozano's model to capture the transshipment in a hub-spoke network, which is more general in practice. Thus, in our model, the shipment is assumed to be consolidated and transshiped as well. We apply a mixed integer programming to investigate the optimization problem, considering a balanced network, where outbound volumes are in sync with the inbound volumes (Caplice and Sheffi, 2003), as well as efficient use of the vehicle.

The key to create and maintain the strategic alliance is that all members should agree the rules of sharing profit gained from cooperation. Depending on extra profit supposed to be derived from the collaboration, firms contract the distribution method in advance. In this context, a balanced and fair distribution of the outcome from the collaboration is prerequisite for ensuring a contract. Here, we apply cooperative game theory to figure out how to distribute benefits between alliance members by a cost allocation problem. Cooperative game theory states several solution schemes, for instance, the core. As a set of feasible payoff profiles for which there is no other coalitions with better payoff, the core is a clearly defined concept. Previous studies have proved the non-emptiness of the core (Owen, 1975; Shapley and Shubik, 1969). The Shapley value which assigns to each member its marginal contribution is the most well-known solution (Shapley, 1953). Due to the uniqueness of the value, numerous studies have applied it, while it could not be in the core. On the other hand, the τ-value is a unique feasible payoff for alliance members satisfied with both the minimal right and marginal contribution. By analyzing and comparing different solution concepts of cooperative game theory, we provide new insights into the strategic alliance in transportation services.

Model

We set a mixed integer programming model to present our network and calculate the total minimized cost. Using the model, the aggregated network reflects the economies of scale and the economies of scope in transportation services. Several research applied cooperative game configuration at alliances sharing network and pooling resources in logistics and transportations. One previous study that has explored the synergy from horizontal cooperation of trucking is by Lozano et al.(2013). They consider direct delivery trips with full truck load, however, in our model, we extend the model for a hub-spoke network and consider less-than-truckload. So, freights could be consolidated and the transshipment is premised. Both studies assume horizontal cooperation in trucking with aggregation of known demand.

The objective function is to minimize the total cost for each coalition. We assume that the demand and the cost are known. While the demand for a certain time period is given based on each origin-destination pair, the cost is calculated by sum of each travelled route, which composes the origin-destination pair. The decision variable is the amount of shipment of each origin-destination pair travelled from location i to j using each type of vehicle. The total cost comprises operating costs on routes depending on the vehicle type, penalty costs for unmatched return trips, and penalty costs for empty space. Note that the penalty term about unmatched return trips is from Lozano (2013)'s and we extend to adding another penalty about unfilled space inside vehicle. Those penalties are reasonable as opportunity costs if the carriers charge for unmatched return trips or if they charge for quick shipping with no consolidation. To be specific, we could consider all possible situations like deadheading (trip of an empty truck) or dwell time (time the driver has to wait for loading or unloading).

All of the sets, parameters and decision variables used in this paper are given as follows.

Sets and index

i, j	:	node index	
k	:	vehicle type index	
N	:	set of nodes	
A	:	set of arcs	
L	:	set of O-D(origin-destination) paths	
A_l	:	set of arcs on path l,	$\forall l \in L$
L_{ij}	:	set of O-D paths including an arc (i, j),	$\forall (i, j) \in A$
K	:	set of vehicle types	
K_i	:	set of vehicle types leaving or arriving on node i,	$\forall i \in N$
K_{ij}	:	set of vehicle types available on arc (i, j),	$\forall (i, j) \in A$
S	:	set of collaborating companies (coalition)	
p	:	index of collaborating companies in coalition S	$\forall p \in S$

Parameters

t_{ij}^k	:	cost of vehicle type k on arc (i, j),	$\forall (i, j) \in A, k \in K_{ij}$
α	:	level of loading (minimum capacity), $\alpha \in [0,1]$	
b^k	:	capacity of vehicle type k,	$\forall k \in K$
β^k	:	penalty cost of empty space in a vehicle type k,	$\forall k \in K$
γ^k	:	penalty cost of unmatched trips of vehicle type k,	$\forall k \in K$
d_l	:	amount of freight (demand) on path l,	$\forall l \in L$

Decision variables

x_{ijl}^k	:	amount of shipment carried by vehicle type k on arc (i,j) in path l,

$\forall(i, j) \in A, l \in L_{ij}, k \in K_{ij}$

y_{ij}^k : 1 if vehicle type k is used on arc (i, j), 0 otherwise, $\forall(i, j) \in A, k \in K_{ij}$

Δ_i^k : Number of unmatched trips of vehicle type k, at node i, $\forall i \in N, k \in K_i$

The formulated mixed integer programming model for coalition S is presented as follows:

$$\text{Minimize} \quad \sum_{(i,j)\in A} \sum_{k\in K_{ij}} t_{ij}^k y_{ij}^k + \sum_{(i,j)\in A} \sum_{k\in K_{ij}} \beta^k \left(b^k y_{ij}^k - \sum_{l\in L_{ij}} x_{ijl}^k \right) + \sum_{i\in N} \sum_{k} \gamma^k \Delta_i^k \quad (1)$$

$$\text{Subject to} \quad \alpha b^k y_{ij}^k \le \sum_{l\in L_{ij}} x_{ijl}^k \le b^k y_{ij}^k, \quad \forall(i,j) \in A, k \in K_{ij} \quad (2)$$

$$\sum_{k\in K_{ij}} x_{ijl}^k = d_l, \quad \forall(i,j) \in A, l \in L \quad (3)$$

$$-\sum_{j:(i,j)\in A} y_{ij}^{kc} + \sum_{j:(j,i)\in A} y_{ij}^{kc} \le \Delta_i^k, \quad \forall i \in N, k \in K_i \quad (4)$$

$$\Delta_i^k \ge 0, \quad \forall i \in N, k \in K_i \quad (5)$$

Then, we let *TC(S)* be the total minimum cost (i.e., minimum value of the objective function in the above model) of coalition *S*. Shipments are bounded at constraint (2) with the lower and the upper capacity levels of each vehicle type. The required demands for each origin-destination path *l* are satisfied from constraint (3). Because our model assumes that each origin-destination pair travels the shortest path, if two other demands have the same origin-destination, they travel the same path connected with same routes. We calculate the number of unmatched return trips to impose penalties from constraint (4) and (5).

We require the characteristic value function of cooperation as the cost savings of coalition *S*, *CS(S)*, to be the difference between the total minimum costs of each carrier and the total minimum cost of coalition. Of course, these cost savings are greater than zero by definition. Through intensive resource utilization by the use of larger trucks, cooperation between logistics companies derives cost savings. With an experiment in the next section, we develop to analyse how to distribute benefits among members of the alliance.

The experiment

In order to find a potential sharing rule which can be satisfied with all alliance members, we demonstrate an experiment of a transportation alliance in a hub-spoke network. An illustration of an alliance between three possible carriers, which operate less-than-truckload delivery in a two-hub system, is suggested. Each carrier has two or three main hubs as a transhipment node and two local hubs as demand nodes for each main hub. For the sake of brevity, there are three types of trucks with different capacities; two lower-capacity types are travelled between a main hub and a local hub and the highest-capacity type is only allowed to travel in between main hubs. All carriers have homogeneous costs in the same distance with the same vehicle type. Merged demands from collaborating are aggregated by each demand before cooperation. Both costs and demands are known. From our mixed integer programming, we find the optimized minimal cost and calculate cost savings in seven possible coalitions. The results are shown in Table 1.

Table 1 – Optimal transportation cost for each of the possible coalitions

Coalition *S*	*TC(S)*	*CS(S)*
{A}	497	0
{B}	642	0
{C}	930	0
{AB}	1,100	39
{AC}	1,330	97
{BC}	1,369	203
{ABC}	1,812	257

Using three different cooperative game solutions, i.e., the Shapley value, the core centre, and the τ–value, we show the allocation of cost savings in Table 2. The results show that allocations by the core centre and the τ-value have similar values, while the Shapley value assigns relatively lower distribution to carrier C and higher distribution to carrier A and B.

Table 2 – Allocation of the cost savings CS({ABC})=257 according to the Shapley value, the core centre, and the τ-value

carrier	Shapley	Core centre	τ -value
A	40.6667	28.3512	29.7069
B	93.6667	86.4666	88.0206
C	122.6667	142.1822	139.2725

With above allocations, we suggest the satisfaction ($F_S(CS)$) of each coalition S to the grand coalition {ABC}. The satisfaction is calculated as the excess of the sum of distributed value of all coalition members in case of the grand coalition compared to the cost savings of that coalition. In Table 3, we compare the satisfaction values of each coalition scenario as the absolute term $F_S(CS)$ and the relative term $F_S(CS)/TC(S)$, which is a percentage of total costs *TC(S)* in the corresponding coalition. Interestingly, in our example, the maximum values exist in the biggest carrier C, except the maximum relative satisfaction of the Shapley value exists in carrier B. This implies that carrier C is willing to create the grand coalition to have the benefit. However, all the case of the minimum satisfaction is presented in a coalition of carrier B with carrier C ({BC}). This means that once a coalition {BC} is formed and then they do have little incentive to invite carrier A, because carrier B and carrier C have enough cost savings through the coalition {BC}. For example, sum of distributed values to carrier B and carrier C in a case of the grand coalition would be 216.3334(=93.6667+122.6667) based on the Shapley value, and this is bigger by 6.57% than the cost saving of coalition {BC} (i.e., 203).

Suppose that a carrier consider creating an alliance with others. In practice, if anticipated advantage from joining of a specific player is not sufficient, other members of an alliance might not invite the player. In this context, we could infer the bargaining game situation. For example, carrier C weighs an alliance with carrier B and the grand coalition with carrier A and carrier B. The maximum value it is expected to obtain from the grand coalition is 142.1822 of the core centre. However, if carrier C cooperates with carrier B, it has to negotiate how to share the total cost savings of coalition {BC} (i.e., 203). As carrier B's view, the maximum expected value is 93.6667 of the Shapley value, which is bigger than 86.4666 of the core centre. Thus, how to distribute 203 is a new game between carrier B and carrier C depending on the bargaining power.

Table 3 – Coalition satisfactions for the Shapley value, the core centre, and the τ-value

Coalition S	Shapley	Core centre	τ -value
{A}	40.7	28.4	29.7
	8.2%	5.7%	6.0%
{B}	93.7	86.5	88.0
	14.6%	13.5%	13.7%
{C}	122.7	142.2	139.3
	13.2%	15.3%	15.0%
{AB}	95.3	75.8	78.7
	8.7%	6.9%	7.2%
{AC}	66.3	73.5	72.0
	4.8%	5.4%	5.3%
{BC}	13.3	25.6	24.3
	1.0%	1.9%	1.8%
Min $F_S(CS)$	13.3	25.6	24.3
Min $F_S(CS)/TC(S)$,	1.0%	1.9%	1.8%
Max $F_S(CS)$	122.7	142.2	139.3
Max $F_S(CS)/TC(S)$,	14.6%	15.3%	15.0%

In our example, carrier C is assumed the biggest firm with three main hubs. Although our example is limiting in homogenous marginal cost between carriers and limiting the networks, the result shows that the big company might have more benefits than the small companies. When this occurs, an oligopoly environment could be generated because big firms strengthen its competitiveness more in the long period. This supports needs of specific rules or regulations imposed by the market or government, which are asserted by the antitrust law or studies about the negative impact of coalitions on social welfare.

Conclusion

In this paper, we attempt to analyze the fair allocation of benefits from trucking alliances by comparing different solutions using cooperative game theory. We model a horizontal cooperation between carriers to reduce costs by efficient utilization of the resources, based on transshipment and less-than-truckload shipments. The minimum costs of all possible coalitions in a numerical example are derived through a mixed integer programming model and calculate the cost savings, which are the benefits gained from cooperation. Then, we investigate allocation solutions in a cooperative game of splitting the cost savings among the alliance members. In particular, we apply the Shapley value, the core centre, and the τ-value for the allocation scheme. In our numerical example, satisfactions of all possible coalitions show that the biggest carrier is the most satisfied member in the grand coalition, whereas the minimum satisfactions exist in its coalition with the second biggest carrier. This observation highlights an important potential impact of cooperation between big ones and an oligopoly could be a desirable structure for the big firms having no restrictions.

Cooperative game theoretic approach is still a relatively untapped research topic. Our paper only addressed the feasibility of a logistics alliance, which is quite limited research area. The experimental evidence provides practical guidance to logistics managers on how to mediate the distribution of joint profits. As further research, we recommend a model considering scheduling, the extension of the network, or the relaxation of assumptions such as the demand and the cost. Indeed, our assumptions on the demand ignore any influence on demand growth based on increased customer utility caused by cooperation. In this sense, benefits seem to be undervalued compared to admissible extra profits. Besides, our model takes into account a limited number of vehicle types and network structures, thus it does not cover all possible cases resulting from alliances between logistics companies.

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