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Supplier-initiated outsourcing: A methodology to exploit synergy in transportation

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ABSTRACT

Over the last decades, transportation has been evolving from a necessary, though low priority function to an important part of business that can enable companies to attain a competitive edge over their competitors. To cut down transportation costs, shippers often outsource their transportation activities to a logistics service provider of their choice. This paper proposes a new procedure that puts the initiative with the service provider instead: *supplier-initiated outsourcing*. This procedure is based on both operations research and game theoretical insights. To stress the contrast between the traditional *push* approach of outsourcing, and the here proposed *pull* approach where the service provider is the initiator of the shift of logistics activities from the shipper to the logistics service provider, we will refer to this phenomenon as *insinking*. Insinking has the advantage that the logistics service provider can proactively select a group of shippers with a strong synergy potential. Moreover, these synergies can be allocated to the participating shippers in a fair and sustainable way by means of a so-called Shapley Monotonic Path of customized tariffs. Insinking is illustrated by means of a practical example based on data from the Dutch grocery transportation sector.

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1. Introduction

A Logistics Service Provider (LSP) is defined as a provider of logistics services that performs logistics functions on behalf of his customers (cf. Coyle et al. (1996)). In recent years, LSPs have had to cope with stricter requirements of customers in terms of speed, quality, flexibility and price. In addition, because of broader product assortments and shorter life cycles, streams through the LSPs' networks became highly fragmented. This causes load factors and, by consequence, profit margins to drop. To cope with these heavy market conditions, LSPs are on a continuous search for opportunities to increase their efficiency and discern themselves from competitors (cf. Langley et al. (2005)). In parallel, manufacturers are outsourcing their non-core competences, which raises the demand for transportation in the LSP market.

1.1. Supplier-initiated outsourcing

Razzaque and Sheng (1998) define logistics outsourcing or *third party logistics* as the provision of a single or multiple logistics services by a vendor on a contractual basis. It has been estimated that about 40% of global logistics is outsourced, and increasing numbers

of shippers consider it an attractive alternative to the traditional logistics service mode (cf. Wong et al. (2000); Hong et al. (2004)).

For their turnover, LSPs heavily depend on the extent to which producers or retailers outsource their logistics activities. In the remainder of this paper, producers and retailers who might outsource their logistics activities to an LSP will be referred to as 'shippers'. Wilding and Juriado (2004) provide a literature review of empirical papers on outsourcing, investigating which activities are typically outsourced and what are the most important reasons for doing so. Table 1 shows the top-5 reasons for outsourcing.

The outsourced activities can be related to Transportation and Shipment, Warehousing and Inventory, Information Systems and Value Added Services. It turns out that the most basic logistics functions of transportation, warehousing and inventory are outsourced most frequently.

The general idea behind outsourcing is a focus of companies on their core businesses. For example, customers of an LSP benefit from the LSP's larger economies of scale that enable him to perform transportation and warehousing more efficiently than his customers. Traditionally, the initiative for outsourcing lies with the shippers: once it is reckoned by management that logistics activities can better be performed by a third party, an invitation to submit a tender is sent out to a number of pre-selected LSPs. Based on this invitation, the LSPs then propose a price for their services.

The subject of this paper is the reverse mode of operation, where the initiative for the contract lies with the LSP. To stress the contrast between the traditional *push* approach of outsourcing,

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Table 1
Reasons for outsourcing logistics activities.

Rank	Reason
1	Cost or revenue related
2	Service related
3	Operational flexibility related
4	Business focus related
5	Asset utilization or efficiency related

and the here proposed *pull* approach where the service provider is the initiator of the shift of logistics activities from the shipper to the LSP, in the remainder of this paper we will refer to supplier-initiated outsourcing as insinking.

The advantage of insinking over outsourcing is that it enables LSPs to gain maximum synergetic effects by tendering for multiple shippers whose distribution networks can be merged very efficiently. We observe that there exist promising business opportunities for insinking in practice. One example is the introduction of the so-called transport-arrangements in the Dutch Randstad metropolis. In this project, a Dutch LSP offers prominent shippers in the fashion sector to perform the distribution to their shops in the city centers against very competitive tariffs. These tariffs are low because of the strong synergies the LSP can benefit from in case it replenishes multiple fashion outlets in the same city center. The Dutch branch organization for fashion companies, actively participates in this project by stimulating their members to accept the offer. Engaging in the transport-arrangements project is beneficial for the individual producers because transportation costs are reduced and customer satisfaction is likely to increase since the number of visits per shop decreases when multiple shippers make use of the transport-arrangements. As a result, trucks interrupt store personnel less frequently. Moreover, congestion in the city center will decrease as a result of the smaller number of vehicle movements. Apart from the time investments that all partners in this project are making, the financial risk rests solely with the LSP. After all, the tariff offers are based on the *expectation* that a certain minimum number of shippers will participate. So when only 1 or 2 shippers accept the offer, the required synergies to break even may not be attained. When the behavior of potential customers is highly unpredictable, this risk might be prohibitive for the LSP. The phenomenon is also a potential reason why initiatives in for example City Logistics, where LSPs also take the lead, sometimes fail. To resolve this issue, this paper offers a methodology for LSPs to apply insinking while eliminating this financial risk.

1.2. Co-opetition

Shippers who are active in the same sector, such as the fashion producers in the transport-arrangements example, will sell products with roughly the same characteristics and ordering dynamics (time windows, order sizes, conditioning, etc.). This opens up possibilities for synergy, because the LSP can operate the same truck types and sometimes even the same routes to service multiple shippers. As discussed in Cuijssen et al. (2007a), the actual synergy potential then depends on the complementarity of order sizes, time windows and the precise demand locations. When such shippers are served on the same route, insinking creates a situation of so-called ‘co-opetition’ (cf. Brandenburger and Nalebuff (1996) and Zineldin (2004)). Although the shippers are competitors on their core businesses, they tacitly cooperate with each other on the non-core domain of transportation, since they agree that their products are distributed in a single shipment with their competitors’ products. Transportation, the area where the cooperation takes place, is not visible to customers. Bengtsson and Kock

(2000) consider visibility for the customer as the most important characteristic for determining whether competition or cooperation should take place on a certain activity. For example, if there is cooperation on transportation activities, competition and differentiation can remain unchanged on other domains such as product prices and product assortments. Particularly in transportation and logistics, where there are almost no unique technologies, companies must often rely on applying innovative concepts such as co-opetition to achieve growth. Whereas co-opetition is already in place for some time in industries where for example Express transport is heavily used and sourced by consortia of multiple (competing) companies, it is now also quickly gaining momentum in the grocery industry. Examples of co-opetition in the consumer goods industry can be found in Bahrami (2003) and LeBlanc et al. (2007).

1.3. Gain sharing

With co-opetition, issues of fairness and stability of the cooperation are important impediments. In particular, guaranteeing a fair allocation is essential. Mistrust about the fairness of the applied allocation rule for the savings has caused many logistics co-opetition initiatives among shippers to marginalize or disintegrate (cf. Cuijssen et al., 2007b).

In practice, a plethora of allocation rules for cooperation among shippers can be observed. Most often these are simple rules of thumb that distribute savings proportionally to a single indicator of either size or contribution to the synergy. Some examples are:

- Proportional to the total load shipped.
- Proportional to the number of customers served.
- Proportional to the transportation costs before the cooperation.
- Proportional to distance traveled for each shipper’s orders
 - based on inter-drop distances of constructed joint routes,
 - based on direct distances from depot to outlet.
- Proportional to the number of orders.

Because these rules are easy and transparent and since each embodies a construct that arguably represents the importance of an individual shipper to the group, they are likely to appeal to practitioners initially. However, in the long run, some participants will inevitably get frustrated since their true contribution to the group’s success is undervalued. For example, if gain sharing takes place according to the number of drop points, a certain customer firm with many end consumers in a small geographical region will get a large share of the benefits, while his *de facto* contribution to the attained synergy is negligible when the other participants serve only few drop points in this area.

To ensure a fair gain sharing mechanism, the true contributions of each shipper to the total gain have to be accurately quantified. The insinking approach uses these true contributions to the group’s synergy to calculate customized prices that fairly distribute the monetary savings that are attained by consolidating flows of multiple shippers. In our approach, the applied methodology is explained to the shippers and the LSP’s cost structure is deliberately made transparent.

It is illustrated above that practical rules of thumb might not always be the best choice for fair gain sharing. Our proposal is to employ solution procedures from cooperative game theory instead. Cooperative game theory models the negotiation process within a group of cooperating agents (in this case shippers) and allocates the generated savings. This field has proved capable of solving fairness issues in many fields. Some logistics related examples are: (Vertical) Supply Chain Coordination (cf. Dawande et al. (2006)), Hub-and-Spoke network formation (cf. Matsubayashi et al. (2005)), Outsourcing (cf. Elitzur and Wensley (1997)), Inventory pooling (cf. Anupindi et al. (2001); Bartholdi and

Kemahlioğlu-Ziya (2004)), and Machine scheduling (Heydenreich et al. (2007)). Other sectors where game theoretical methods have been successfully applied in practice include among others: Automotive (cf. Cachon and Lariviere (2005)), Retail (cf. Sayman et al. (2002)), Telecommunication (cf. van den Nouweland et al. (1996)), Aviation (cf. Adler (2001)), and Health Care (cf. Ford et al. (2004)). Cooperating companies in these sectors benefit from game theoretical methods that objectively take into account each player's impact within the group as a whole and produce compromise allocations that distribute the benefits of cooperation based on clear cut fairness properties. Different fairness properties are represented by well-known allocation rules such as the Shapley value (Shapley (1953)), the nucleolus (Schmeidler (1969)) and the tau-value (Tijs (1981)).

1.4. Price setting

With the insinking procedure, the LSP establishes fair gain sharing by means of customized pricing. This enables the LSP to explicitly incorporate participants' marginal contributions to the group's synergy potential. The business opportunities offered by intelligent pricing strategies are being increasingly recognized in Marketing (cf. Desiraju and Shugan (1999)) and Psychology (cf. Hermann et al. (2004)). The advent of Information and Communication Technology (ICT) in the last decade has opened up a vast array of new pricing possibilities (cf. Dixit et al. (2005)). The most important challenge of such information enhanced pricing strategies is to be perceived by customers as fair. Perceived fairness depends on comparisons to past prices, competitor prices, and perceived cost of the product or service (cf. Bolton et al. (2003)). Although these factors come from a Business-to-Consumer setting, we hypothesize that the same constructs are relevant for the Business-to-Business situation that we consider in this paper.

An important aspect of fair pricing is the principle of dual entitlement (cf. Kahneman et al. (1986)). This means that a profit increase by the selling firm (the LSP) is only accepted when it does not harm the customer's interest. This egalitarian principle sometimes conflicts with the utilitarian principle of cost-based pricing. Under cost-based pricing, an LSP will charge the total costs plus a 'reasonable' percentage. Dixit et al. (2005) argue that dissatisfaction about fairness of prices could be avoided by proper implementation and communication of price composition. Therefore, openness of information is an important aspect of insinking and, as will become clear in the next section, both the egalitarian and utilitarian principles mentioned above are satisfied. In particular, this means that no potential participants will have an incentive to provide false information, since gain sharing is conducted during the operation based on the true contribution of the participant has brought to the group.

Despite its obvious business opportunities, only few firms take full advantage of intelligent pricing. The vast majority still uses pricing strategies based on historical cost benchmarks, whereas more forward-looking and clientele-oriented pricing is likely to be more promising (cf. Noble and Gruca (1999)). Especially in the very competitive and low-margin transportation sector, smart pricing offers LSPs an excellent opportunity to gain a competitive edge.

The remainder of this paper is organized as follows. In the next section the insinking procedure for exploiting synergy in transportation will be explained and illustrated by means of a small hypothetical example. In Section 3, the applicability of the procedure is established by means of a practical example based on real-life data from the Dutch grocery transportation sector. Finally, Section 4 concludes.

2. The insinking procedure

The insinking procedure builds on customized pricing by an LSP. These prices (or: *tariffs*) are induced by the varying claims of shippers' order sets on the LSP's resources. Among other properties, order sets may differ in the number of orders, the geographical spread of the drop points, the location of the shipper's warehouse(s), the tightness of time windows, and the average and standard deviation of the order sizes. In Cruijssen et al. (2007a) it is shown that each of these aspects has a clear influence on the synergy potential when the order sets are combined. In this section we introduce the insinking procedure by describing its three steps:

- (i) Target group selection,
- (ii) Cost reductions, and
- (iii) Negotiation and structure of sequential offers.

These steps will be successively discussed in the three subsections below and necessary notation will be gradually introduced. Then, at the end of Section 2, a comprehensive overview of the insinking procedure will be provided.

2.1. Target group selection

As a first step, the LSP has to select the group of shippers M it wishes to serve from the total set N of potential customers. It was mentioned in the introduction that opting for a group of shippers from the same industry comes at the advantage of having similar product characteristics and ordering dynamics. It also fits in the current trend of (sectoral) specialization in the logistics sector: having multiple customers in e.g. the chemical, consumer electronics, paper or textile sector strengthens the market position of an LSP and offers a safeguard for future survival.¹

Four necessary ingredients of successful market targeting are: information, the LSP's capabilities and capacity, synergy, and a sustainable path towards the end solution. First, the LSP must have enough market information to assess its chances to obtain the required amount of contracts. In some cases this information is publicly available, such as in the grocery case discussed in Section 3, but for other markets obtaining this information will require a more thorough market analysis. The second condition is the good match between the market and the LSP's capabilities. For example, if an LSP's past experience involves predominantly unconditioned palletized transportation, it might not be advisable to target the specialized petrochemical industry. Furthermore, the LSP must have sufficient capacity or the possibility to increase his capacity to the level required to serve the target group. Next, when market information is available and the LSP has the capabilities and capacity to serve the market, the attractiveness of a target group depends on the synergy potential that exists between them. Gupta and Gerchak (2002) have studied operational synergies for mergers and acquisitions, which can be seen as an upper bound for the synergy. In this paper we assume that the LSP is able to make a reliable estimate of the monetary synergy potential, which we define as the sum of the costs that individual shippers make in the present situation minus the costs when the whole set of shippers would be serviced collectively by the LSP. Besides these operational considerations however, often also relational issues play an important role. For example, it may be the case that an LSP already has (informal) contacts with a group of shippers of whom the LSP knows they are interested in the service. Although this group may not be optimal from a synergy perspective, this may be

¹ It should be mentioned that in difficult economic situations, as is currently the case, LSPs will be less strict in getting a coherent client group.

outweighed by the group’s cohesion and their established contacts with the LSP. In fact, applying an innovative concept such as insinking requires a considerable amount of trust between the LSP and the shippers, which will benefit from positive past business experiences. Finally, the existence of a beneficial (i.e., *Shapley monotonic*, see Section 2.3) path towards the end solution is a very important characteristic of beneficial target groups.

2.2. Cost reductions

When the LSP has identified the group of shippers targeted, it is ready to calculate the cost reductions for each of the shippers involved. Since we use cooperative game theory in this step, we first recall some basic notions from game theory. Myerson (1991) defined game theory as “the study of mathematical models of conflict and cooperation between intelligent and rational decision-makers. Game theory provides general mathematical techniques for analyzing situations in which two or more individuals make decisions that will influence one another’s welfare”. Cooperative game theory focuses on cooperative behavior by analyzing the negotiation process within a group of players in establishing a contract or joint plan of activities, including an allocation of collaboratively generated revenues. In particular, the possible levels of cooperation and the revenues of each possible coalition (a subgroup of the cooperating players) are taken into account so as to allow for a better comparison of each player’s role and impact within the group as a whole. In this way, players in a coalition can settle on a compromise allocation in an objectively justifiable way. Having this in mind, the game underlying the insinking methodology is evidently a cooperative game. The problem of allocating the jointly generated synergy savings is critical to any logistics cooperation (cf. Thun (2003)).

Let N be a finite set of players and denote by 2^N the collection of all subsets of N . Elements of 2^N are called *coalitions*, N is the *grand coalition*. The cost savings that a coalition S can jointly generate without the players in $N \setminus S$ is called the *value* of coalition S . The values of all coalitions S are captured in the so-called characteristic function $v : 2^N \rightarrow \mathbb{R}$. The Shapley value (Shapley (1953)) is a well-known solution concept that constructs a vector $\Phi(N, v) \in \mathbb{R}^N$ that allocates the value $v(N)$ of the grand coalition based on the values $v(S)$ of all coalitions S . The Shapley value can be explained as follows. Consider the creation of a coalition S to which i does not belong. First, a set size $|S|$ is chosen at random out of $\{0, 1, 2, \dots, |N| - 1\}$, each having a probability $\frac{1}{|N|}$ to be drawn. Then a subset of $N \setminus \{i\}$ of size $|S|$ is chosen, each with a probability $\frac{|S|!(|N| - 1 - |S|)!}{(|N| - 1)!}$. After S has been drawn, player i is allocated his so-called *marginal contribution* $v(S \cup \{i\}) - v(S)$. Then, the Shapley value is the expected payoff for player i in this random procedure, as indicated in formula (1):

$$\Phi_i(N, v) = \sum_{S \subset N: i \notin S} \frac{|S|!(|N| - 1 - |S|)!}{|N|!} [v(S \cup \{i\}) - v(S)], \quad \forall i \in N. \tag{1}$$

For a coalition S the subgame $(S, v|_S)$ is given by the restriction of v to 2^S , with for all $T \subset S$ $v|_S(T) = v(T)$. In particular, the Shapley value $\Phi(S, v) := \Phi(S, v|_S) \in \mathbb{R}^S$ is defined as follows:

$$\Phi_i(S, v) = \sum_{T \subset S: i \notin T} \frac{|T|!(|S| - 1 - |T|)!}{|S|!} [v(T \cup \{i\}) - v(T)], \quad \forall i \in S. \tag{2}$$

The Shapley value possesses a number of fairness properties. Below we will briefly discuss four of these properties that are useful in our context. First, the *efficiency* property of the Shapley value ensures that the total value of the grand coalition is distributed among the players, i.e., no value is lost. The Shapley value is also *symmetric*, meaning that two players that create the same additional value to any coalition receive the same share of the total

value. The *dummy* property states that players that do not contribute anything to any coalition except their individual value indeed receive exactly their individual value as a final share of the total value. Finally, we mention the Shapley value’s property of *strong monotonicity*. This guarantees that if all of the player’s marginal contributions increase, his payoff will increase. Since these four properties make perfect sense from a practical perspective, we make use of the Shapley value in this paper.

Having introduced the necessary terminology, we are now ready to formulate the cooperative game that forms the basis of the insinking procedure: the *insinking game*. In the current step, the LSP knows his target group of shippers (from now on called the *players*) and faces the problem of distributing the group’s synergy potential, i.e., the value $v(N)$ of the grand coalition.

In order to cover the extra overhead costs needed to service the players and to gain profit, the LSP claims a pre-determined percentage of the savings attained as a result of synergy. This percent claim is called the *synergy claim* and is denoted by $p \in [0, 1]$. In choosing the value of the synergy claim the LSP faces a trade-off between a higher prospected profit by setting p high, and a larger probability that the players will indeed accept by choosing a smaller value. The LSP can make this decision based on a qualitative assessment of his bargaining power in the market.

The value $v(S)$ of a coalition S in the insinking game is determined by means of formula (3):

$$v(S) = (1 - p) \max \left\{ \sum_{i \in S} C_0(i) - C(S), 0 \right\}. \tag{3}$$

Here, $C_0(i)$ are the costs of player i in the status quo situation, i.e., when player i privately performs his transportation orders O_i , while $C(S)$ represents the costs of the LSP to collectively execute the orders $\bigcup_{i \in S} O_i$ of all players in S . Obviously, a coalition S can only be established when the LSP can serve the players in S at a lower cost than the sum of the costs that the players in S incur when they would all perform their own orders individually. Whenever this is not the case, the players in S will not accept the LSP’s service, and this coalition is left out of consideration. $v(S)$ is then set to 0. This explains the use of the maximum with 0 in (3).

We will illustrate the procedure by means of a hypothetical 3-player example, for which the relevant information is summarized in Table 2. For convenience of calculations, we assume that $p = 0$.

The last column of Table 2, which is calculated using formula (2), shows that the coalition consisting of only players 2 and 3 will certainly not occur since in this case both players receive a value that is lower than the value they would be able to get individually.

2.3. Negotiation and structure of sequential offers

Despite the fact that in the example in Table 2 all possible coalitions have a positive value, the LSP still has to select an effective way to establish the grand coalition. The LSP does so by choosing the most suitable sequence in which it proposes offers to players.

Table 2
A hypothetical 3-player example.

S	$\sum_{i \in S} C_0(i)$	$C(S)$	$v(S)$	$\Phi(S, v)$
{1}	350	300	50	(50; .; .)
{2}	300	260	40	(.; 40; .)
{3}	100	120	0	(.; .; 0)
{1,2}	650	500	150	(80; 70; .)
{1,3}	450	390	60	(55; .; 5)
{2,3}	400	370	30	(.; 35; -5)
{1,2,3}	750	570	180	(95; 75; 10)

The total set Π of such paths consists of $|N|!$ different paths π . $\pi(i)$ is used to refer to the rank of player i on path π .

Every time a player from the selected target group is approached with an offer, the method that the LSP will consistently use is clearly explained to this player. By communicating openly, the player's involvement in the project increases and the LSP has better possibilities to crosscheck the assumptions and data used to calculate the proposals. Sequentially, a player i receives an opening offer based on $\Phi_i(S \cup \{i\}, v)$, if S is the coalition of players that have already committed before. Moreover, it is explained to player i that his offer may further improve when more players consign to the LSP's service. The possible cost reductions $g(i, \pi, s)$ are defined as:

$$g(i, \pi, s) = \frac{\Phi_i\left(\bigcup_{\pi(k) \leq s} k, v\right)}{C_0(i)}, \quad s \geq \pi(i). \tag{4}$$

All cost reductions $g(i, \pi^*, s)$ along the chosen path π^* are also announced to player i , together with the accompanying scenarios for commitment of the players j that are not yet contacted (i.e., those players j for which $\pi^*(j) > \pi^*(i)$). Fig. 1 graphically shows the offered percentage cost reductions with respect to the costs of in-house execution by the players. This figure comprises all $g(i, \pi, s)$ values, defined for the three players, the six different paths along which they can be approached, and the steps along these paths where an offer is made to a player. We use the percentage reduction of the current costs of the players rather than the absolute reduction, because the players may differ in size.

In the example, when players are contacted in the sequence $\pi = 123$, during the negotiations player 1 knows that he is sure to save 50 (14.3%), and that his cost reduction will increase to 80 (22.9%) if later on player 2 consigns, and even to 95 (27.1%) if besides player 2 also player 3 commits. Formally, this means that $g(1, 123, 1) = 0.143$, $g(1, 123, 2) = 0.229$, and $g(1, 123, 3) = 0.271$. Together, the opening offer and the prospected future cost reductions should persuade the player to accept the offer.

Based on Fig. 1, the LSP has to decide on the path π^* along which it can best contact the players. Compared to a simultaneous

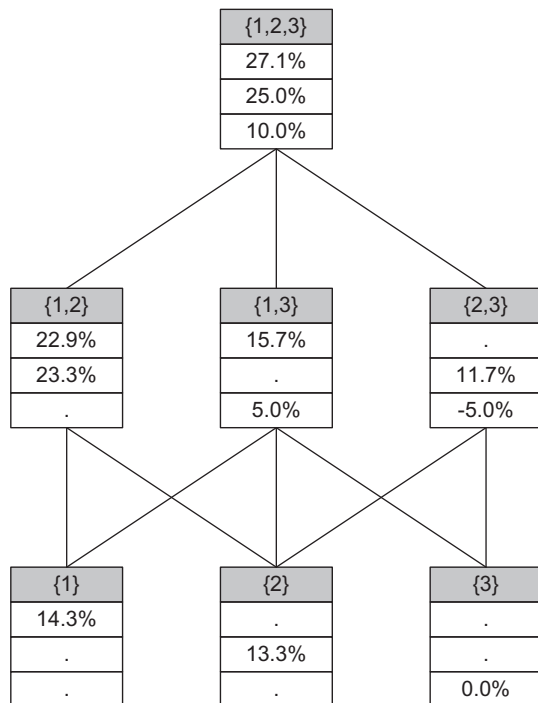


Fig. 1. Percentage cost reductions in the 3-player example.

approach, the one-by-one modus operandi offers the benefit that the obtained commitment of one or more players leverages the value proposition that can be made to the remaining players, since a certain level of scale and synergy is already attained. Moreover, performing $|N|$ one-on-one negotiation rounds based on reliable information about the commitment of other players can be preferred over a single negotiation with all players simultaneously, because of the reduced risk of strategic behavior, and the prevention of mutual envy. Finally, in the sequential procedure the LSP will be better able to preserve anonymity of the targeted players.

The usage of a fixed synergy claim p makes that the LSP's profit is maximized when the grand coalition is attained. Therefore, the LSP is indeed interested in finding the path π^* through Fig. 1 that gives the highest "probability" that all players will accept his insinking offer. To this end, we introduce the notion of a *Shapley (Strictly) Monotonic Path (SMP)*. Along such a path all committed players will be better off when the coalition grows through the decision of the next player to accept the insinking offer:

Definition 1.

π is a Shapley (Strictly) Monotonic Path if and only if $g(i, \pi, j) < -g(i, \pi, k)$, $\forall j < k \leq |N|$, $\forall i \in N$

In the example above, 123, 132, 213 and 312 are SMPs. The others are not because one player's offer worsens during at least one of the steps.

Games (N, v) do not in general possess an SMP. Loosely speaking, an insinking game will have an SMP if the target group is carefully selected based on a high synergy potential among the players. The problem of finding conditions for the existence of SMPs in general games is however hard, as is the problem of finding conditions for uniqueness of an SMP, may it exist (Borm et al., 2006).

On the one hand, it is easy to construct games where none of the paths $\pi \in \Pi$ is an SMP. On the other extreme, if it holds that the savings allocated to a committed player i are consistently higher in case more companies accept the insinking offer, all paths $\pi \in \Pi$ will be an SMP. In game theoretic terms this condition means that the game is *strictly convex*: for all $S, T, U \subseteq N$ such that $S \subset T \subset N \setminus U$ it holds that $v(S \cup U) - v(S) < v(T \cup U) - v(T)$.

Theorem 1. (N, v) is strictly convex if and only if every $\pi \in \Pi$ is an SMP.

A proof of this theorem is provided in Appendix A. In our setting, strict convexity means that the more players have already accepted the insinking offer, the more efficient the LSP can combine the order set of a not yet committed player with the current order base. This is in line with the findings of Cruijssen et al. (2007a) who state that synergy increases when the number of combined orders grows. This is a direct result of the enlarged search space of the planning problem. However, these results are based on situations where the pickup location is identical for all flows. When this is not true (like in the example in Section 3), strict convexity of the insinking game is not obvious. Therefore, the LSP should always check beforehand if the insinking game based on a target group N indeed possesses an SMP. Because in practical cases, $|N|$ will be small, this can easily be done by complete enumeration.² Finally, note that the value of p does not affect the existence of SMPs.

If there are more SMPs, the next question becomes how to choose between them. For the hypothetical 3-player example, the four SMPs together with the offered percentage cost reductions $g(i, \pi, s)$ are displayed in Table 3.

Although all four paths described in Table 3 are SMPs, path 312 does not seem to be a reasonable choice for the LSP. This is because

² In cases where $|N|$ is bigger, a branch and bound type of search procedure can provide a workable solution, but lies beyond the scope of this paper.

Table 3
Example of possible sequential offers according to SMPs.

$\pi_1 = 123$				$\pi_2 = 132$			
Player i	1	2	3	Player i	1	3	2
$C_0(i)$	350	300	100	$C_0(i)$	350	100	300
$g(i, \pi_1, 1)$	14.3%	.	.	$g(i, \pi_2, 1)$	14.3%	.	.
$g(i, \pi_1, 2)$	22.9%	23.3%	.	$g(i, \pi_2, 2)$	15.7%	5.0%	.
$g(i, \pi_1, 3)$	27.1%	25.0%	10.0%	$g(i, \pi_2, 3)$	27.1%	10.0%	25.0%
$\pi_3 = 213$				$\pi_4 = 312$			
player i	2	1	3	player i	3	1	2
$C_0(i)$	300	350	100	$C_0(i)$	100	350	300
$g(i, \pi_3, 1)$	13.3%	.	.	$g(i, \pi_4, 1)$	0.0%	.	.
$g(i, \pi_3, 2)$	23.3%	22.9%	.	$g(i, \pi_4, 2)$	5.0%	15.7%	.
$g(i, \pi_3, 3)$	25.0%	27.1%	10.0%	$g(i, \pi_4, 3)$	10.0%	27.1%	25.0%

in the first step, player 3 is not offered a cost reduction, $g(3, 123, 1) = 0$, because he can perform his own orders more efficiently individually than the LSP can. This is captured in the concept of *first offer rationality*: the first offer of the LSP to an entering player indeed represents a cost reduction compared to player's status quo situation of performing the orders individually.³ SMPs that satisfy this criterion are referred to as *Rational Shapley Monotonic Paths (RSMPs)*:

Definition 2.

π is an RSMP if and only if π is an SMP and $g(i, \pi, 1) > 0 \forall i \in N$.

In the remainder, we will restrict attention to RSMPs and the set of all RSMPs will be referred to as $\widehat{\Pi} \subseteq \Pi$. It should be noted that for a path to retain its property of Rational Shapley Monotonicity, the order sets O_i of the customers should be more or less stable. This is e.g. true in the Dutch grocery retail sector example discussed in the next section. The demand locations are supermarkets that are visited according to a fixed delivery schedule (e.g. daily delivery). If, in the long run, considerable changes occur in the order set of one or more customers, tariffs need to be recalculated. This of course holds true for any general contract between LSP and customer: if the terms of a contract change, the contract itself will change.

There might be various ways to judge which RSMP is best from the LSP's perspective of achieving the grand coalition. In other words: there exist various sensible functions $f: \widehat{\Pi} \rightarrow \mathbb{R}$ that denote the quality of an RSMP. It seems reasonable however that the reductions on the diagonal and bottom rows in Table 3 are relevant considerations for players. The first correspond to the cost reductions that player i is guaranteed to achieve when accepting the offer (*certain gain*, $g(i, \pi^*, \pi(i))$), and the second are the maximum possible cost reductions that are attained when the grand coalition is indeed achieved (*top gain*, $g(i, \pi^*, |N|)$).

Here, for the purpose of illustration, we assume that the best RSMP is selected on the basis of the certain gains. Table 4 shows the certain gains for the three RSMPs. Consequently, we propose to select the "best" RSMP in the following way: first select those RSMPs that have the maximal lowest cost reduction. In our example, these are 123 and 213 with a lowest certain gain of 10%. Then, from those RSMPs, select the one that has the maximal second-lowest certain gain, etc. In our hypothetical example $\pi^* = 123$ will be selected with a second-lowest certain gain of 14.3%. This RSMP solution procedure can be referred to as an iterative maximin procedure, as players pursue to the maximum savings, but a maximization of their certain (i.e., minimum) savings.

³ Depending on the context, in some cases it might be argued that in order to attract a new customer, the savings in the first step might even have to be bigger than some positive (industry-specific) lowerbound in order to compose and RSMP.

As stated above, many other quality criteria for RSMPs can be thought of. In any case, the choice of $f: \widehat{\Pi} \rightarrow \mathbb{R}$ is open for the LSP, and may depend on characteristics of the targeted market and the LSP's own preference.

To summarize this section, we now recapitulate the introduced notation. Using this notation, the three steps are formalized in Fig. 2 to represent a comprehensive description of the insinking procedure.

M	set of all potential customers
N	set of targeted customers
2^N	collection of all subsets of N (collection of all possible coalitions)
O_i	set of transportation orders belonging to customer $i \in N$
$C_0(i)$	costs of executing O_i by customer i in the status quo situation
$C(S)$	cost of executing $\cup_{i \in S} O_i$ by the LSP
p	the LSP's synergy claim
$v(S)$	value of coalition $S \in 2^N$ as determined by (3)
Π	set of permutations of N . These give the possible paths along the customers
$\pi(i)$	rank of customer i in π
$\Phi_i(S, v)$	Shapley value allocated to player i in the subgame defined on $S \in 2^N$
$g(i, \pi, s)$	(sequential) gains offered to player i on step s along path π as determined by (4)
$\widehat{\Pi}$	the set of RSMPs
$f: \widehat{\Pi} \rightarrow \mathbb{R}$	additional selection criterion function to choose the best RSMP
π^*	the RSMP chosen to approach the targeted shippers

This finishes our discussion of the insinking procedure. In the next section we illustrate the insinking procedure by means of a practical example based on real-life data from the Dutch grocery transportation sector.

3. An example based on real-life data

Many grocery retailers are not performing well and have been facing a loss of profitability in recent years. Together with the complexity and dynamism inherent to the grocery industry, this has made it difficult for retailers to survive in isolation of their competitors (cf. Ballou et al. (2000)). There is growing empirical evidence that retailers as a result turn to co-opetive behavior to construct win-win situations together with their competitors. For example, Kotzab and Teller (2003), present a case study in which the largest Austrian retailers cooperate in their logistics processes by introducing uniform load units and performing joint replenishment. This cooperation runs parallel to fierce price competition and heavy promotional spending. In this section we present a practical example of insinking that results in considerable efficiency gains for retailers in the Dutch grocery transportation sector. For reasons of confidentiality, the company names are not disclosed.

3.1. Background

The case focuses around an LSP that has a large temperature controlled distribution center for frozen goods (FDC) in the geographical center of the Netherlands. Taking advantage of its established position in ambient food retail, the LSP's goal is to fill this FDC with the frozen food products of grocery retailers, and perform the transportation from the FDC to their stores. Among other things, this means that in the new situation suppliers of frozen products must only visit the central FDC instead of the multiple FDCs of individual retailers, thereby reducing the number of drops that suppliers make on their delivery routes. As a side effect to the

Table 4
RSMP selection based on certain gains.

RSMP	Certain gain			Sorted certain gain		
	Player 1 (%)	Player 2 (%)	Player 3 (%)	Lowest (%)	2nd lowest (%)	3rd lowest (%)
123	14.3	23.3	10.0	10.0	14.3	23.3
213	22.9	13.3	10.0	10.0	13.3	22.9
132	14.3	25.0	5.0	5.0	14.3	25.0

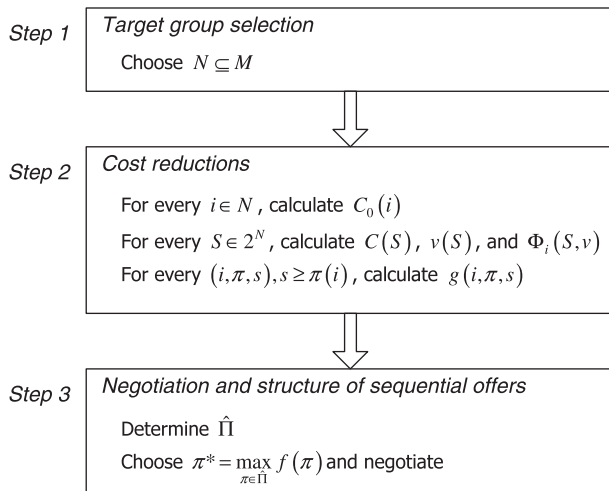


Fig. 2. Three steps of the insinking procedure.

synergy attained in the retailers' distribution process, this will increase the efficiency of the suppliers' transportation process.

The LSP applies the insinking procedure outlined in Section 2 to attract a number of large and medium sized grocery retailers as his customers. Below we discuss how the three steps of the procedure can be applied here.

3.2. Target group selection

Table 5 shows some characteristics of four grocery retailers A, B, C, and D with whom the LSP maintains close contacts.

These retailers have the same (or at least a comparable) customer base and Fig. 3 shows that their distribution networks have considerable geographical overlap. Furthermore, they have not yet outsourced their transportation activities to an LSP. All four retailers use a standardized roll pallet for shop deliveries, which makes it easy to consolidate loads of different retailers in one truck. The encouraging synergy potential, the existing contacts and the fact that the capacity of the FDC is sufficient to fulfill their orders, make that these four retailers form the LSP's target group.

3.3. Cost reductions

In step 2 of the insinking procedure we calculate the value of all subcoalitions of {A, B, C, D}. The cost reduction that the LSP will be able to offer then depends on the synergy among the order sets

Table 5
Characteristics of targeted retailers (2003).

Retailer	# Outlets	Weekly demand (roll pallets)	Yearly turnover (mln EURO)	Symbol in Fig. 3
A	37	17,366	367	●
B	61	25,369	616	■
C	63	18,634	373	▲
D	195	62,857	1187	•

of the retailers. Additionally, the offers are influenced by the LSP's synergy claim. This claim must cover the extra administrative (back office) costs, the costs of storage at the central FDC, and profit. For illustration purposes, the synergy claim is set to 0.2 in this case. In practice, the appropriate value will reflect the respective negotiation power positions of the LSP and the shippers.

Below we comment on the data and the routing problems that form the basis of the calculation of the cost reduction proposals.

3.3.1. Data

Order data of the four retailers are estimated on the basis of the commercial surface of their stores and the average turnover of frozen products per square meter of commercial surface. The daily frequency of delivery per retailer is based on de Koster and Neuteboom (2001) and information from other industry experts. Based on these data five daily order sets are constructed, representing the working days in a typical week.

By assumption, the trucks operated by the retailers and by the LSP all have a capacity of 57 roll pallets and a uniform cost structure. This cost structure is based on the published market averages for the Netherlands and consists of a fixed cost per truck per day of EURO 120 and a cost of EURO 0.33 per minute that a truck is driving or unloading at the store. The fixed costs are incorporated in the cost structure, because the retailers can dispose of the specialized temperature controlled trucks when the transportation of the frozen products is taken over by the LSP.

Besides transportation costs, also the costs of operating an FDC are incorporated. In the Netherlands, storage of one roll pallet of frozen goods costs on average EURO 2.79 per week. These costs include handling, depreciation and cooling. Whereas they are fixed for the LSP, the retailers can eliminate these costs by accepting the LSP's insinking offer. We assume that the FDCs of each retailer have a capacity equal to a week's throughput of pallets.

3.3.2. Routing problems

To calculate the costs for all coalitions we have to solve 95 vehicle routing problems with time windows. This is because for each of the five working days in the planning period, there are $2^4 - 1$ routing problems representing the non-empty coalitions that can be served by the LSP and four extra routing problems because for the 1-player coalitions also the scenario exists that the player rejects the insinking offer and performs the transportation himself.

Orders are to be delivered to the stores between 8:00 am and 6:00 pm. The dataset shows that the number of deliveries per store per day is either 1 or 2. When stores are delivered twice a day, there is a morning delivery between 8:00 am and 1:00 pm and an afternoon delivery between 1:00 pm and 6:00 pm. To solve the 95 vehicle routing problems with time windows (VRPTW) we use the heuristic of Bräysy et al. (2004). Details of the solutions to the routing problems can be found in Table 6. Please note that calculating the coalitional values is an exercise that might differ based on the exact case at hand.

The first four rows of Table 6 represent the cases where the retailers perform the transportation individually from their private FDCs, while for the other rows the service of the LSP is used. The location costs and the transportation costs form the necessary

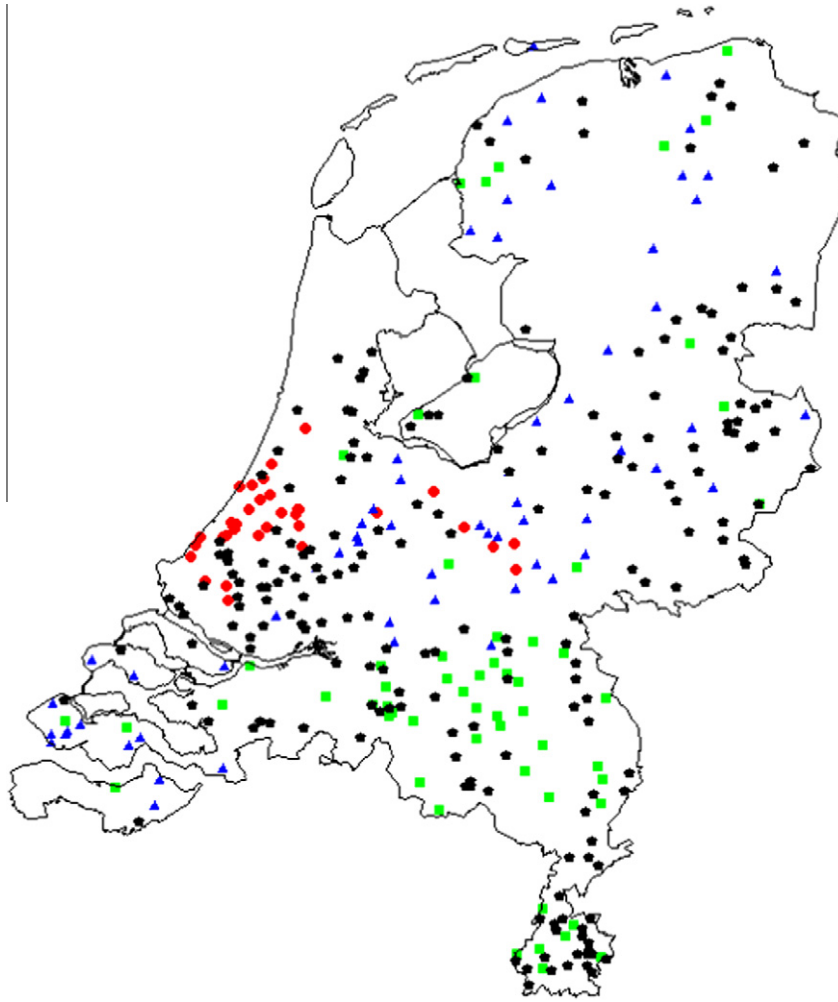


Fig. 3. Geographical overlap of stores of retailers.

input to calculate the coalitional values from Eq. (3). Table 7 displays the structure of all coalitional values and the allocation over the retailers according to the Shapley value. Fig. 4 depicts all paths from the 1-retailer coalitions to the grand coalition. Note that the percentage cost reductions in this figure are the quotient of the allocations given in Table 7 and the individual location and trans-

portation costs of the retailers provided in the first four rows of Table 6. As mentioned earlier, a synergy claim of 0.2 is incorporated in the coalitional values.

In practice the LSP will transfer the cost reductions to player i by means of a lower tariff t_i^S per roll pallet, depending on the coalition S that it serves. This tariff can easily be calculated from the cost

Table 6
Routing results aggregated over five working days.

S	# Roll pallets	# Orders	Location costs	# Trucks	Total time	Transportation costs
{A}-self	580	370	509	20	5,251	4,133
{B}-self	716	244	743	28	11,161	7,043
{C}-self	513	189	546	23	8,852	5,681
{D}-self	1,758	585	1,841	45	16,345	10,794
{A}	580	370	.	20	5,254	5,558
{B}	716	244	.	28	11,519	7,161
{C}	513	189	.	20	8,954	5,354
{D}	1,758	585	.	44	16,114	10,597
{A, B}	1,296	614	.	48	17,997	11,699
{A, C}	1,093	559	.	45	16,314	10,783
{A, D}	2,338	955	.	62	23,025	15,038
{B, C}	1,229	433	.	44	17,630	11,097
{B, D}	2,474	829	.	63	23,686	15,376
{C, D}	2,271	774	.	51	20,590	12,914
{A, B, C}	1,809	803	.	60	23,801	15,054
{A, B, D}	3,054	1,199	.	78	29,383	19,056
{A, C, D}	2,851	1,144	.	72	26,826	17,492
{B, C, D}	2,987	1,018	.	74	28,566	18,306
{A, B, C, D}	3,567	1,388	.	89	34,390	22,028

Table 7
Cost reduction offers (rounded to integer values).

S	$\sum_{i \in S} C_0(i)$	C(S)	$v(S)$	$\Phi(S, v)$
{A}	4,642	5,558	0	(0.0; .; .; .)
{B}	7,786	7,161	500	(.; 500.; .)
{C}	6,227	5,354	698	(.; .; 698.; .)
{D}	12,635	10,597	1,630	(.; .; .; 1,630)
{A,B}	12,428	11,699	583	(42; 542; .; .)
{A,C}	10,869	10,783	69	(-315; .; 384; .)
{A,D}	17,277	15,038	1,791	(80; .; .; 1,711)
{B,C}	14,013	11,097	2,333	(.; 1,067; 1,266; .)
{B,D}	20,421	15,376	4,036	(.; 1,453; .; 2,583)
{C,D}	18,862	12,914	4,758	(.; .; 1,913; 2,845)
{A,B,C}	18,655	15,054	2,881	(92; 1,474; 1,316; .)
{A,B,D}	25,063	19,056	4,806	(297; 1,670; .; 2,839)
{A,C,D}	23,504	17,492	4,810	(-61; .; 1,772; 3,099)
{B,C,D}	26,648	18,306	6,674	(.; 1,478; 1,939; 3,256)
{A,B,C,D}	31,290	22,028	7,410	(266; 1,805; 1,908; 3,431)

reductions attributed to player $i \in S$ and his demand $D(i)$ in roll pallets:

$$t_i^S = \frac{C_0(i) - \Phi_i(S, v)}{D(i)} \tag{5}$$

The development of these tariffs along all possible paths is shown in Fig. 5. This shows that player D has by far the lowest tariff, representing the cost effectiveness of operating his dense nation-wide network of stores.

3.4. Negotiation and structure of sequential offers

Negotiation takes place on a bilateral basis between the LSP and the individual retailers. Only the LSP has perfect information because it has calculated all coalitional values and knows the tariffs to offer to each individual retailer. The retailers on the other side only know their own current and future tariff offers and have to make their accept/reject decision based on only these data.

Fig. 4 clearly shows that there are many paths along which retailers get a positive cost reduction at every step. It is however readily verified that the only three RSMPs are CBAD, BCAD, and BACD. Table 8 shows that, according to the criterion proposed in Section 2.3 (“certain gain”), CBAD is the best RSMP.

3.5. Discussion

Table 7 shows that all coalitions, except {A}, have a positive value. This means that for almost every coalition the LSP can perform the orders more efficiently than the corresponding players can if they reject the offer and perform the orders individually. In particular, all retailers benefit when the grand coalition is reached, i.e., if all retailers accept the LSP’s insinking offer. In that case, the monetary savings attained from the synergy between the four retailers, are distributed as presented in Table 9.

The LSP reserves 20% of the total savings, which provides him with a gain of 1852 EURO per week. This gain is used to cover the extra administrative (back office) costs and the costs of storage

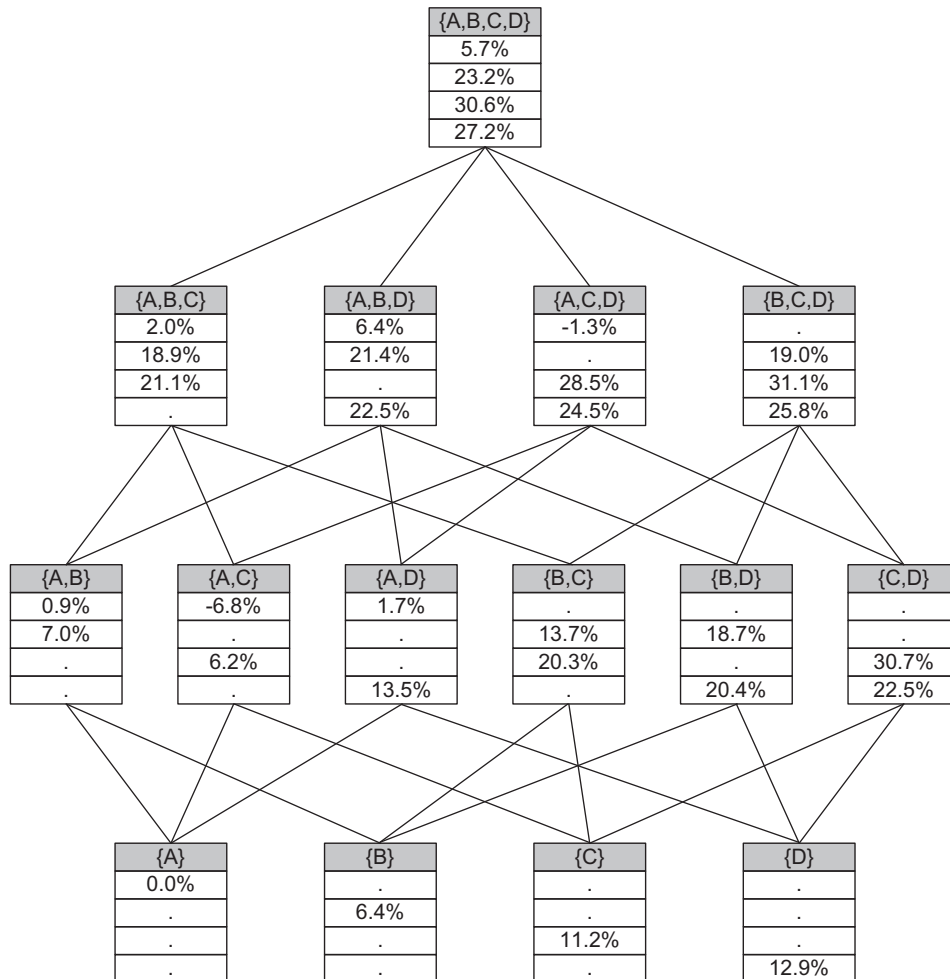


Fig. 4. Percentage cost reduction paths.

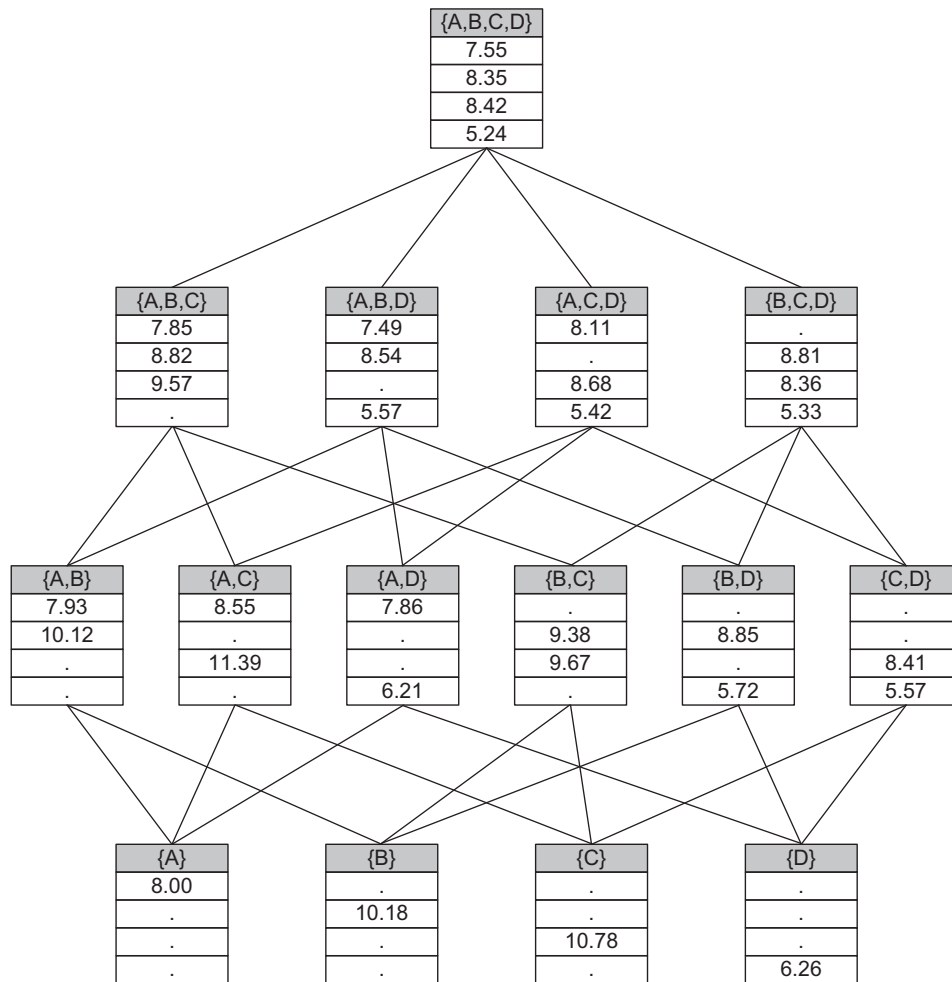


Fig. 5. Tariff paths.

Table 8
RSMPs sorted lexicographically according to the certain gains.

Path	Certain gain				Sorted certain gain			
	A	B	C	D	Lowest	2nd	3rd	4th
CBAD	2	13.7	11.2	27.2	2	11.2	13.7	27.2
BCAD	2	6.4	20.3	27.2	2	6.4	20.3	27.2
BACD	0.9	6.4	21.1	27.2	0.9	6.4	21.1	27.2

Table 9
Distribution of monetary savings (rounded to integer values).

Retailer	Monetary gain	Percentage gain (%)
A	266	5.7
B	1,805	23.2
C	1,908	30.6
D	3,431	27.2
LSP	1,852	.

at the central FDC. The remainder is profit. Retailer D brings in the most orders and is rewarded for this by getting the largest part of the savings from synergy in absolute terms. Retailer C however gets the largest percentage cost reduction because his orders relatively exhibit most synergy with the other retailers. Fig. 3 indeed shows that the stores of retailer C in a way glue together the geographical locations of the stores of the other retailers.

An important decision is to choose in which of the 24 possible sequences the LSP approaches the retailers. It turns out that in the case at hand there are only three RSMPs: CBAD, BCAD, and

BACD. This implies that Shapley monotonicity is a quite discriminatory property for a path. Of the three RSMPs available, according to the criterion proposed in Section 2.3, path CBAD performs best. This means that the LSP can best contact C first, then B, then A, and finally D. The virtue of an RSMP is that in every step along the path all committed players benefit when another player accepts the offer. This type of monotonicity makes that no committed player is harmed by the event that one of his competitors joins the cooperation. This is a very important condition for companies entering a co-opetive relation.

The small number of RSMPs encourages the insinking LSP to perform extra effort in the target group selection. When the possibility exists to pick shippers from a larger set M than the LSP can effectively handle, it can proactively perform step 2 of the procedure on test grand coalitions of shippers and evaluate the number and quality of the RSMPs present.

By applying insinking, the LSP offers shippers the opportunity to considerably cut down transportation and location costs. In order to reap the maximum benefits, all involved parties depend on each other, which creates a beneficial lock-in that contributes to the probability of lasting success of the project. However, it should be noted that the numbers in Fig. 4 represent the 'ideal' situation in which every player accepts the LSP's offer. Although the clear initiative of the LSP makes his competitors less visible to the shippers, and insinking brings the retailers considerable cost reductions, still the retailers might have the strongest negotiation power. As a result, there is the chance that a retailer will (initially) reject the offer. In this case, the LSP still has some room for

bargaining by decreasing his synergy claim for this specific retailer. When the LSP cannot persuade the retailer to accept the offer by lowering his synergy claim, the rejection is definitive. This retailer then has to be removed from the grand coalition. If for example on the best RSMP CBAD retailer C would reject the offer, the new grand coalition N' becomes {A,B,D} and the insinking game is restricted to the subgame $(N', v|_{N'})$. An identical analysis reveals that the best RSMP in this case would in fact be DBA, instead of the sequence BAD proposed by the original RSMP. If players further up the path reject the offer, no new negotiations with the already committed players will take place, although the negotiation plan with future players will have to be reconsidered.

4. Conclusions

In this paper we have introduced the so-called insinking procedure that LSPs can use to attract new customers and improve their market power. The given format minimizes the LSP’s financial risks, while making sure that it offers very competitive tariffs to each potential customer. These customized prices are based on each shipper’s actual contribution to the total synergy and accomplish a fair allocation of the monetary savings resulting from the cooperation. The procedure uses an operations research algorithm to calculate the value of every possible coalition of shippers, and a game theoretical solution concept to construct the customized tariffs.

Insinking seems to be a viable alternative for the traditional outsourcing paradigm. With outsourcing the initiative for transferring the execution of transportation activities to an LSP lies with the shipper, and the occurrence of strong synergies with other shippers served by the LSP is more or less a matter of chance. With insinking however, the initiative lies with the LSP. The LSP can use his market knowledge and experience, enriched by operations research techniques, to target exactly those shippers that exhibit strong synergies. Therefore, having the LSP in the driving seat seems natural because the LSP is the actor in the supply chain with the best competencies to exploit synergies in transportation systems. Moreover, the LSP has a clear economic incentive to attract as many shippers as possible since this increases his turnover and profit. In this way, the LSP enables himself to take advantage of the information asymmetry present between him and his (potential) customers. Due to the property of Shapley Monotonicity, all parties involved benefit when the LSP attracts additional customers.

From an organizational perspective insinking also has advantages compared to outsourcing, because it facilitates the attainment of synergy without the difficulties arising from the sharing of sensitive information between the cooperating companies. Open communication about the methodology and the consistent usage of an objective and fair game theoretical solution concept to allocate savings to shippers, make the LSP a trustworthy partner. In general, transportation is a hands-on and low-tech sector and practical cases have shown that practitioners often regard the problem of constructing a fair gain sharing mechanism as too difficult or academic. The insinking procedure has the advantage that this complex task now lies with only one actor who performs all necessary calculations and communication to the shippers. This avoids long and difficult rounds of discussion among the cooperating companies. Some important implementation issues have to be taken into account however. The results of the insinking procedure depend on the availability of good market information and consequently on the quality of the match between the targeted companies and the LSP’s capabilities. And also the LSP must be capable of conveying the insinking message in a good way to new clients.

Although the calculation of customized tariffs for new customers based on their actual synergy with existing customers of an LSP seems quite logical from an economical point of view, tariff

proposals by LSPs are often based on static rules of thumb, past prices and (conjectured) competitor prices. Modeling the problem as a cooperative game makes LSPs more aware of the actual value that a new customer creates for his business. The advantageous customer – service provider combinations that will result from applying a more sensible tariff quotation methodology will benefit both individual companies and society as a whole.

An interesting direction for further research around the insinking procedure is to investigate situations where multiple competing LSPs target (partially) overlapping groups of shippers and the consequences this will have on the competitive positions of the various players in the industry. Based on the structure of the industry, competition may take place based on the p value, markets might be divided among a small number of oligopolistic LSPs, or other outcomes might be observed.

Acknowledgements

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Appendix A

Proof of Theorem 1. Let (N, v) be strictly convex and consider two coalitions T and S for which there exists a single $j \in N \setminus T$ such that $S = T \cup \{j\}$. Then for all $i \in T$:

$$\begin{aligned} \Phi_i(T, v) &= \sum_{U \subset T, i \notin U} \frac{|U|!(|T| - 1 - |U|)!}{|T|!} (v(U \cup \{i\}) - v(U)) \\ &= \sum_{U \subset T, i \notin U} \frac{(|T| + 1)|U|!(|T| - 1 - |U|)!}{(|T| + 1)!} (v(U \cup \{i\}) - v(U)) \\ &= \sum_{U \subset T, i \notin U} \frac{[(|T| - |U|) + (|U| + 1)]|U|!(|T| - 1 - |U|)!}{(|T| + 1)!} \\ &\quad \times (v(U \cup \{i\}) - v(U)) \\ &= \sum_{U \subset T, i \notin U} \left[\frac{(|T| - |U|)|U|!(|T| - 1 - |U|)!}{(|T| + 1)!} \right. \\ &\quad \left. + \frac{(|U| + 1)|U|!(|T| - 1 - |U|)!}{(|T| + 1)!} \right] (v(U \cup \{i\}) - v(U)) \\ &= \sum_{U \subset T, i \notin U} \left[\frac{|U|!(|T| - |U|)!}{(|T| + 1)!} + \frac{(|U| + 1)! (|T| - 1 - |U|)!}{(|T| + 1)!} \right] \\ &\quad \times (v(U \cup \{i\}) - v(U)) \\ &= \sum_{U \subset T, i \notin U} \left[\frac{|U|!(|S| - 1 - |U|)!}{|S|!} + \frac{(|U| + 1)! (|S| - 2 - |U|)!}{|S|!} \right] \\ &\quad \times (v(U \cup \{i\}) - v(U)) \\ &= \sum_{U \subset T, i \notin U} \left[\frac{|U|!(|S| - 1 - |U|)!}{|S|!} \right] (v(U \cup \{i\}) - v(U)) \\ &\quad + \sum_{U \subset T, i \notin U} \left[\frac{(|U| + 1)! (|S| - 1 - (|U| + 1))!}{|S|!} \right] (v(U \cup \{i\}) - v(U)) \\ &< \sum_{U \subset T, i \notin U} \left[\frac{|U|!(|S| - 1 - |U|)!}{|S|!} \right] (v(U \cup \{i\}) - v(U)) \\ &\quad + \sum_{U \subset T, i \notin U} \left[\frac{(|U| + 1)! (|S| - 1 - (|U| + 1))!}{|S|!} \right] (v(U \cup \{i, j\}) - v(U \cup \{j\})) \\ &= \sum_{U \subset S, i \notin U} \frac{|U|!(|S| - 1 - |U|)!}{|S|!} [v(U \cup \{i\}) - v(U)] = \Phi_i(S, v), \end{aligned}$$

where the strict inequality follows from strict convexity. This shows that every path $\pi \in \Pi$ will be an SMP. It will be obvious that, by the same argument, the converse also holds. □

References

Adler, N., 2001. Competition in a deregulated air transportation market. *European Journal of Operational Research* 129 (2), 337–345.

- Anupindi, R., Bassok, Y., Zemel, E., 2001. A general framework for the study of decentralized distribution systems. *Manufacturing & Service Operations Management* 3 (4), 349–368.
- Bahrami, K., 2003. Horizontale Transportlogistik-Kooperationen: Synergiepotenzial für Hersteller kurzlebiger Konsumgüter. Deutscher Universitäts-Verlag, Köln.
- Ballou, R., Gilbert, S., Mukherjee, A., 2000. New managerial challenges from supply chain opportunities. *Industrial Marketing Management* 29, 7–18.
- Bartholdi III, J., Kemahlioglu-Ziya, E., 2004. Using Shapley value to allocate savings in a supply chain. In: Pardalos, P., Geunes, J. (Eds.), *Supply Chain Optimization*. Kluwer, Amsterdam, The Netherlands.
- Bengtsson, M., Kock, S., 2000. Co-opetition in business networks – to cooperate and compete simultaneously. *Industrial Marketing Management* 29 (5), 411–426.
- Bolton, L., Warlop, L., Alba, J., 2003. Consumer perceptions of price (un)fairness. *Journal of Consumer Research* 29 (4), 474–491.
- Borm, P., Çiftçi, B., Hamers, H., 2006. Population Monotonic Path Schemes for Simple TU-games. Tilburg University. Working paper.
- Brandenburger, A., Nalebuff, B., 1996. *Co-opetition*. Doubleday, New York.
- Bräysy, O., Hasle, G., Dullaert, W., 2004. A multi-start local search algorithm for the vehicle routing problem with time windows. *European Journal of Operational Research* 159 (3), 586–605.
- Cachon, G., Larivière, M., 2005. Supply chain coordination with revenue-sharing contracts: Strengths and limitations. *Management Science* 51 (1), 30–44.
- Coyle, J., Bardi, E., Langley Jr., J., 1996. *The Management of Business Logistics*, sixth ed. West Publishing Company, New York.
- Cuijssen, F., Bräysy, O., Dullaert, W., Fleuren, H., Salomon, M., 2007a. Joint route planning under varying market conditions. *International Journal of Physical Distribution & Logistics Management* 37 (4), 287–304.
- Cuijssen, F., Cools, M., Dullaert, W., 2007b. Horizontal cooperation in logistics: Opportunities and impediments. *Transportation Research E: Logistics and Transportation Review* 43 (2), 129–142.
- Dawande, M., Geismar, H., Hall, N., Srikandarajah, C., 2006. Supply chain scheduling: Distribution systems. *Production and Operations Management* 15, 243–261.
- Desiraju, R., Shugan, S., 1999. Strategic service pricing and yield management. *Journal of Marketing* 63 (1), 44–56.
- Dixit, A., Braunsberger, K., Zinkhana, G., Pan, Y., 2005. Information technology-enhanced pricing strategies: Managerial and public policy implications. *Journal of Business Research* 58, 1169–1177.
- Elitzur, R., Wensley, A., 1997. Game theory as a tool for understanding information services outsourcing. *Journal of Information Technology* 12 (1), 45–60.
- 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 (2), 159–169.
- Gupta, D., Gerchak, Y., 2002. Quantifying operational synergies in a merger/acquisition. *Management Science* 48 (4), 517–533.
- Hermann, A., Huber, F., Sivakumar, K., Wricke, M., 2004. An empirical analysis of the determinants of price tolerance. *Psychology & Marketing* 21 (7), 533–551.
- Heydenreich, B., Müller, R., Uetz, M., 2007. Games and mechanism design in machine scheduling – An introduction. *Production and Operations Management* 16 (4), 437–454.
- Hong, J., Chin, A., Liu, B., 2004. Logistics outsourcing by manufacturers in China: A survey of the industry. *Transportation Journal* 43 (1), 17–25.
- Kahneman, D., Knetsch, J., Thaler, R., 1986. Fairness constraints on profit seeking: Entitlements in the market. *American Economic Review* 76, 728–741.
- Koster, M., Neuteboom, deA., 2001. *The Logistics of Supermarket Chains*. Elsevier, Doetinchem.
- Kotzab, H., Teller, C., 2003. Value-adding partnerships and co-opetition models in the grocery industry. *International Journal of Physical Distribution & Logistics Management* 33 (3), 268–281.
- Langley Jr., J., van Dort, E., Ang, A., Sykes, S., 2005. *Third-party logistics – Results and Findings of the 10th Annual Study*.
- LeBlanc, H., Cuijssen, F., Fleuren, H., de Koster, M., 2007. Factory gate pricing, An analysis of the Dutch Retail Distribution. *European Journal of Operational Research* 174 (3), 1950–1967.
- Matsubayashi, N., Umezawa, M., Masuda, Y., Nishimo, H., 2005. A cost allocation problem arising in hub-spoke network systems. *European Journal of Operational Research* 160 (3), 821–838.
- Myerson, R., 1991. *Game Theory – Analysis of Conflict*. Harvard University Press, Cambridge.
- Noble, P., Gruca, T., 1999. Industrial pricing: Theory and managerial practice. *Marketing Science* 18 (3), 435–454.
- Nouweland, A., van den, Borm, P., van Golstein Brouwers, W., Groot Bruinderink, R., Tijs, S., 1996. A game theoretic approach to problems in telecommunication. *Management Science* 42 (2), 294–303.
- Razzaque, M., Sheng, C., 1998. Outsourcing of logistics functions: A literature survey. *International Journal of Physical Distribution & Logistics Management* 28 (2), 89–107.
- Sayman, S., Hoch, S., Raju, J., 2002. Positioning of store brands. *Marketing Science* 21 (4), 378–397.
- Schmeidler, D., 1969. The nucleolus of a characteristic function game. *SIAM Journal of Applied Mathematics* 17, 1163–1170.
- Shapley, L., 1953. A value for n -person games. In: Kuhn, H., Tucker, A. (Eds.), *Contributions to the Theory of Games*, vol. 2. Princeton University Press, Princeton, pp. 307–317.
- Thun, J.-H., 2003. Analysis of cooperation in supply chains using game theory. In: Spina, G., Vinelli, A., Cagliano, R., Kalchschmidt, M., Romano, P., Salvador, F. (Eds.), *One World – One View of OM? The Challenges of Integrating Research & Practice*, vol. II. SGE, Padova, pp. 323–332.
- Tijs, S., 1981. Bounds for the core and the tau value. In: Moeschlin, O., Pallaschke, D. (Eds.), *Game Theory and Economics*. North Holland, Amsterdam, pp. 123–132.
- Wilding, R., Jurjado, R., 2004. Customer perceptions on logistics outsourcing in the European consumer goods industry. *International Journal of Physical Distribution & Logistics Management* 34 (7/8), 628–644.
- Wong, Y., Maher, T., Nicholson, J., Gurney, N., 2000. Strategic alliances in logistics outsourcing. *Asia Pacific Journal of Logistics and Marketing* 12 (4), 3–21.
- Zineldin, M., 2004. Co-opetition: The organization of the future. *Marketing Intelligence & Planning* 22 (7), 780–789.