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Draft Paper

Efficient supply chains through flexible horizontal collaboration

Empirical evidence supporting the need for supply chain orchestration

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Abstract

Recently, a trend towards horizontal collaboration in the supply chain has been gaining ground. Collaborative supply chains promise to improve sustainability and reduce transportation costs at the same time. This paper examines the possibility of collaboration and its implementation through a description of the current situation and a case study of three large companies in Belgium who have expressed their willingness to collaborate. As collaboration assumes a long-term relationship that needs to be built, this paper investigates the advantages of moving beyond mere bundling of logistics streams and assumes that partners are willing to explore further optimization opportunities that arise from collaboration. Most notably, this paper evaluates the effects of increased flexible with respect to delivery dates, as well as allowing large orders to be split into several deliveries.

The case study developed in this paper shows that a decrease in distribution costs of 25.83% can be achieved. Distributing these gains to the partners by using the recommended *Shapley value*, the individual gains range from 19.01% to 37.56%. By adopting a flexible attitude with respect to delivery dates and order splitting, the partners in the coalition can further increase their individual gains, as well as the total coalition gain. Interestingly, the Shapley value is found to encourage companies to relinquish a rigid attitude with respect to delivery dates and order splitting, by allocating a larger share of the gains to flexible companies.

1. Introduction

Companies trying to optimize their supply chain face important trade-offs between cost, service level and sustainability. More stringent demands of customers, more competition and increasing pressure of governments to be more sustainable are issues to be handled in the future.

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A study of IFEU (2008) shows that on average a truck that rides on the European road network is only half-full. A more efficient use of the available means of transportation can cause large sustainability and cost improvements for supply chains. However, many companies have optimized their own supply chains up to a level where improvements on the level of an individual company level are not able to yield substantial savings. *Horizontal collaboration*, on the other hand, holds promise of far larger efficiency and sustainability improvements. Horizontal logistical collaboration can be defined as *bundling transport of companies operating on the same level of the supply chain, who have similar or complementary transportation needs*. To this end, more and more companies have recently formed horizontal alliances or coalitions, in which they bundle their orders and use a common transportation channel to ship them. Many companies go further than the purely operational aspects and share each others assets (e.g., warehouses), make supply chain decisions together according to a common strategy, use the increased bargaining power of the coalition to obtain lower prices from logistics providers, . . . , effectively creating one large supply chain. This trend is most likely to continue, as pressure grows and increasing support is found for collaborative supply chains (Initiative and Capgemini, 2008).

This paper examines the viability of implementing such horizontal alliances in practice. Previous case studies are discussed, and a new case study is presented. In this case study, it is hypothesised that horizontal alliances, as they provide the necessary trust and long-term commitment, will enable the search for more optimization possibilities. More transparency about the cost structure of each partner will, for example, allow to better decide which orders to postpone and which not. Therefore, not only will evaluate the consolidation of orders be evaluated, we will also assume scenarios in which companies are more flexible with respect to their deliveries, i.e., they allow changes to their deliveries in order to create more profit for the coalition.

In order to properly evaluate the concepts of collaboration and flexibility, it is vital to determine not only the total gain, but also the individual gains for each of the partners in the coalition. To this end, a cost allocation method from the field of game theory, the *Shapley value*, is investigated and found to be preferable over gain sharing methods traditionally used in collaborative supply chains.

2. The first horizontal logistical alliances

As mentioned, truck load factors on European road are very low(IFEU, 2008). As a result of strict delivery demands made by their customers, individual companies have few degrees of freedom to improve their truck load factors, especially if they do not want their service levels to suffer (Skjoett-Larsen, 2000). By integrating the transportation operations of different companies, however, efficiency and sustainability can be increased without touching existing service levels. It is clear that such an integration requires considerable collaboration.

Although many examples of successful supply chain collaborations exist in practice, and the advantages of such alliances have been documented in the literature (e.g., Li et al., 2006; Maloni and Benton, 1997; Perry et al., 1999; Poirier, 1999), a large majority of research on supply chain alliances deals with *vertical* alliances, in which partnerships are created between firms operating on different levels of the supply chain. *Horizontal* collaboration, in which companies collaborate that operate on the same level of the supply chain, is

Nevertheless, such collaboration also prove to be beneficial in a horizontal level. The long-term nature and the commitment demanded of alliances allow for continuous improvement (Slone et al., 2010). More specifically, building a trust-relationship allows better insight into the cost structure of each partner which in turn facilitates additional improvements, based on a better understanding of the effects that transportation decisions have on the entire supply chain. Finally, the stability that the long-term commitment guarantees will create an environment in which these improvements will be more willingly adopted.

A recent survey (EyeforTransport, 2010-2011) conducted on the European level and that involved shippers, carriers, 3PLs (third-party logistics providers) as well as consultants revealed that the majority of the respondents are convinced of the improvement potential of horizontal cooperation (e.g., cost cutting, enhancing customer service, improving overall efficiency and lowering carbon emissions) and hence expect a widespread implementation of horizontal cooperation within the next five years. However, a large number of hurdles still need to be taken in order to translate this idea into practice. The challenges faced are diverse in nature and range from the risk of information disclosure, the difficulty of establishing relations of trust and the absence of case studies to the lack of IT-support and gain sharing models.

A lot of examples of successful horizontal alliances can be found in both air and maritime transportation. Carriers have experienced the advantages that such collaborations may bring in terms of economies of scale and the increase of customer service levels. As the cost of transportation and transportation means are relatively high in the air and maritime transportation sector, large savings can be achieved if the capacity is more fully used (Cruijssen et al., 2007c)

The fragmented competitive landscape of the road transport sector and the fact that trucks are a lot less capital-intensive has slowed down the implementation of horizontal alliances in this sector. In addition, the shorter distances and number of orders to be scheduled add significant complexity to the operational planning process. However, Initiative and Capgemini (2008) state that, in order to respond to the challenge of reducing the impact on the environment, the future supply chain is a collaborative supply chain. The first horizontal alliances in road transportation are indeed already emerging. Table 4 in Appendix A shows a number of horizontal alliances and case studies that have been published, starting with a case study dating back to 2001 and up to three implemented cases presented at the 2nd Horizontal Collaboration Summit in 2011.

As stated in the introduction, by forming strategic alliances, the coalition is able to search for larger improvements in efficiency and sustainability. In collaborative forest transportation in Sweden for example (Frisk et al., 2010), some of the 8 partners agreed to transport their own wood to the other partner's clients whenever their warehouse was located closer to that particular client. Such agreements cannot be reached if there is no trust concerning the quality of the wood, the service, etc.

The case of UCB and Baxter, shipping both to Romania, provides an even better example (Menedeme, 2011). Baxter was already able to ship a large part of its orders using full-truckload (FTL) shipments and therefore already operated efficiently. Still, as their products need to be transported chilled, they decided to start a test case to attempt to reduce the high transportation cost of chilled goods. This test case showed that not only could the load rate of the less-than-truckload (LTL) shipments of Baxter and UCB be decreased, upon further investigation, they discovered that also their FTL shipments could be improved by allowing double-stacking with the often lighter products of UCB. If they would allow their FTL shipments to be split to be able to contain the order of their partner, even more benefits could be created. Finally, as they also included the logistics provider H. Essers in the coalition — guaranteeing this transportation company a significant transportation volume — they were able to use multimodal solutions. The benefits thus not only comprised significant double-digit savings, but also CO_2 savings of about 50% (Menedeme, 2011; Van Breedam et al., 2011).

Horizontal collaboration clearly holds an enormous potential for improvement. The cases in Table 4 show that the cost of transportation is not the only thing that can improve as a result of horizontal collaboration. Additional benefits include a decreased handling cost, increased service levels, better branding, accomplishing a modal shift, etc. These case studies can be considered as the first movers, and more initiatives are expected to follow. Especially in the Netherlands and in Belgium the number of pilot project seems to be growing. Dutch initiatives such as "Doorbraak Bundelen Goederenstromen" ("breakthrough bundling flows of goods"), which invests in collaboration projects in all fields and sectors in the Netherlands and Belgium, will certainly accelerate the adoption of collaborative supply chains.

The European Union is supporting and investing in collaborative supply chains as well. EIRAC, or the European Intermodal Research Advisory Council, is facilitating the implementation by creating a framework for horizontal collaboration. It has started the project COllaboration COncepts for CO-modality (CO^3). A workgroup and a dissemination group are addressing the legal issues (e.g., contractual agreements, exit and entry strategies...) as well as analyzing the rule of costs and benefits sharing (Labrosse, 2010).

The issue of gain-sharing is indeed singled out by academics (Cruijssen et al., 2007c) as well as practitioners (EyeforTransport, 2010-2011) as being one of the main impediments of horizontal collaboration. This will be further discussed in the next section.

3. Allocating profits in horizontal logistic alliances

The previous section clearly showed that establishing horizontal alliances demands a lot of effort. In order to convince individual companies to overcome the hurdles associated with forming strategic coalitions, the alliance should generate enough profits to compensate for the increase in complexity and risk. However, the coalition partners are generally not interested in the profits generated by the entire coalition, but in the impact of the cooperation on their own P& L instead. The availability of a transparent and fair gainor cost sharing mechanism is therefore key in the translation of the ideas behind horizontal logistic alliances into practice.

A wide range of possible profit (or cost) allocation methods have been developed. We refer to Frisk et al. (2010); Heijboer (2002); Ozener and Ergun (2008); Vos et al. (2002) for analyses of allocation methods that can be used in horizontal collaborative alliances. These methods have their own specific (dis)advantages and each partner or coalition may prefer another method. Unsurprisingly, choosing an appropriate allocation method is identified as one of the main hurdles to collaboration in the surveys of EyeforTransport (2010-2011) and Cruijssen et al. (2006).

Cruijssen et al. (2007c) warn that mistrust about the fairness of the chosen allocation rule has already caused many alliances to fail. According to these authors, the transparency and simplicity of uncomplicated rules of thumb have proven to be more likely to be adopted by horizontal alliances. However, they warn that such simple rules can systematically undervalue a participant's true share in the success of the alliance. In the long run, such a participant will become frustrated and leave the coalition. Fairness — although a subjective matter — needs a definition.

Game theory, a field of research that provides decision support in situations in which players act out of self-interest but depend on the behavior of the other players for the achievement of their objectives, provides theoretical support for these specific problems. More specifically, the concepts and techniques stemming from the field of *cooperative* game theory are relevant for the problem of determining a fair profit/cost allocation method. This branch of game theory deals with those situations in which the players can achieve a total benefit together that is greater than the sum of the individual gains. Thus — rather than focusing solely on the maximization of their own profit — players are also concerned with the total gains achieved by the coalition. Co-operative game theory therefore focuses on how to *create benefits* for the total coalition and on the issue of *sharing these benefits* among the players (Shubik, 2006).

Examples of companies that have used co-operative game theory to allocate the benefits produced by their collaboration can be found in Cachon and Lariviere (1999) (automotive), Sayman et al. (2002) (retail), van den Nouweland et al. (1996) (telecommunication), Adler (2001) (aviation) and Ford et al. (2004) (healthcare). According to Cruijssen et al. (2007b), the advantage of using game-theoretic models in these cases is that they "*objectively take into account each player's impact and produce compromise allocations that distribute the benefits of cooperation based on clear cut fairness properties*". The authors further suggest to develop similar approaches for the logistics sector.

When translating the gain sharing problem in a logistics context to the language of game theory, the *game* being played is the bundling of orders, in which *players* (the companies belonging to the coalition), can choose which orders they want to send out and which restrictions on the delivery they want to enforce. Together, these players form a *coalition*. If one player or more is omitted from this (grand) coalition, we refer to the resulting game as a *subcoalition*. The possible *gains* of a (sub)coalition that need to be distributed are in this case the reduction in transportation cost and/or in greenhouse gasses.

The most prevalent concepts for profit/cost allocation in cooperative game theory are the Shapley value and the Nucleolus (Moulin, 1988). The Nucleolus (Schmeidler, 1969) tries to minimize for each player the "excess" or the gain that a partner can achieve by leaving the grand coalition and entering a subcoalition. Calculating the nucleolus is however quite involved and requires solving several linear programming problems.

The Shapley value on the other hand is easy to calculate, and remains the most commonly used in practice (Krajewska et al., 2008). For each player, this value is calculated as the weighted average of the marginal contributions of this player to any possible coalition that can be formed given the game at hand. This implies that the cost *effect* that each player generates when he is added to the coalition as well as the different subcoalitions is used to determine the allocated profit.

Given a player i, a coalition N, which consists of subcoalitions $S \subset N$, that each generate a profit $v(S)$, the Shapley value is

$$v_i^{Shapley} = \sum_{S \subseteq N \setminus i} \frac{|S|!(n - |S| - 1)!}{n!} \times (v(S \cup i) - v(S))$$

A distinction can be made between an allocation of costs and of profits. Generally, profit allocation implies that the situation before collaboration of the partner will be taken into consideration when determining the share of the supply chain cost that needs to be paid (One will need to deduct the allocated profit from its "baseline"). However, note that when we translate the Shapley value into a "cost allocation method" ($c(S)$ is then the cost of a subcoalition S), the resulting cost $c_i^{Shapley}$ or $c_i - v_i^{Shapley}$ that needs to be paid by each partner stays the same. As the Shapley value takes also into account the marginal cost of an empty subcoalition to which the partner is added, it will automaticly consider the stand-alone cost (or baseline). It is also noteworthy that the Shapley value can not only divide costs or profits which are expressed in euros, but also other (measurable) gains such as service level or carbon footprint.

$$c_i^{Shapley} = \sum_{S \subseteq N \setminus i} \frac{|S|!(n - |S| - 1)!}{n!} \times (c(S \cup i) - c(S))$$

A profit or cost allocation based on the Shapley formula will possess four *fairness*-characteristics, namely efficiency, symmetry, additivity and the dummy property. For these reasons, players cannot influence their own or each other profits. For example, there is no excess profit that can be claimed (*efficiency*), nor can the allocated cost be influenced by entering a coalition in a later or earlier stage (*symmetry*), or by making subcoalitions (*additivity*). Finally, if a player does not contribute to the coalition, there is no benefit in joining the coalition (*dummy property*). Loehman and Whinston (1974) state that an agent's *cooperative productivity* is the only thing that should matter in determining his share of the surplus, which can be regarded upon as a very ethical principle. This principle of basing solely on the utility of a player is the basis of the Shapley value.

One of the drawbacks of the Shapley value is that it does not guarantee the property of *stability*. This means that the grand coalition might not be the best possible coalition for each player (a subcoalition might be preferred). However, it is possible that for a certain game there does not exist a cost allocation *in the core*, i.e., there is no stable cost allocation possible. We therefore argue that, rather than looking for a cost allocation in the core, it is better to form stable coalitions. As the Shapley value is, besides *fair*, also *unique*, a company cannot try to influence the cost distribution. It can only decide whether to accept the outcome of the distribution and join the coalition or not. It is important to note that an unstable coalition does not necessarily imply that companies will automatically decide not to enter this coalition. The Shapley value is also *individually rational*. In other words, a player will always do better than or at least as good as he would do when working alone. It is up to the player of the coalition or a neutral third party to decide whether to form a coalition, knowing beforehand the manner in which the total cost will be divided.

Irrespective of its disadvantages, the utilitarian principle of the Shapley value remains very attractive for companies to use as an objective base of their cost allocation. The project CO^3(Barbarino, 2011) as well as the advisors in the project "Doorbraak Bundelen Goederenstromen" in the Netherlands (ArgusI, 2010) are promoting the Shapley value to be used and to base a framework for horizontal collaboration upon.

4. Empirical evidence for increased supply chain efficiency for each partner

In this section the potential gains from horizontal collaboration and the usefulness of the Shapley value for the distribution of the collaborative gains is illustrated by testing these concepts on a real-life data set. Using the orders over a period of one year of three large fast moving consumer goods companies delivering their products in Belgium, we investigate whether and to which degree these companies can each improve their profits by collaborating.

Currently, the three companies deliver their products independently, each using a different 3PL provider, and from their own warehouse. They have, however, a large mutual client base: about 57% of the total number of orders are sent to a client that is shared by two or all three of the companies(these are the warehouses of the large supermarket chains in Belgium).Bundling orders and shipping from a shared warehouse is therefore potentially advantageous. Note that the costs mentioned in the analysis do not include the (fixed) costs of relocating to a joint warehouse or the cost of moving the goods to this shared warehouse on a daily basis. These costs are deemed insignificant by the companies because of the fact that their supply chain setup already requires them to ship the goods to their own 3PL's warehouse.

The cost improvements that can be achieved by horizontal collaboration are determined by starting from the complete list of orders shipped in a year for each of the three companies. Each order line consists of (1) a *destination customer*, (2) a *delivery date* on which the order needs to arrive at the customer, and (3) the *size* of the order in number of pallets. Orders can be bundled (i.e., transported in the same trip) when their delivery date and destination customer are the same. Potential improvements by visiting several different customers in the same trip, are therefore not considered. This is a realistic assumption in this particular problem setting. It is additionally assumed that bundling orders incurs no additional costs, which is also a realistic assumption in the case of a shared warehouse. Each trip (truck) has a maximum capacity of 33 pallets.

To calculate the stand-alone costs for each company, the following procedure is used. First, orders are grouped by customer and delivery date. For each group of orders, a *bin-packing problem* is solved to determine the minimum number of trips necessary to deliver all orders. In general a bin-packing problem consists of finding the minimum number of "bins" of a certain capacity necessary to pack a number of "items" of a certain size.

In both the non-collaborative and the collaborative case, the logistics *costs* are determined based on the pace list, a list that is negotiated between the shipping company and its 3PL provider. A pace list is a two-dimensional matrix that gives the price to ship any number of pallets, up to an FTL shipment (33 pallets). The price of the shipment increases with the number of pallets, but the price per pallet decreases as the number of pallets in a shipment increases.

The solution of the bin packing problem for a given company and a given delivery date/customer pair, the cost can be calculated by looking up the price of each trip in the pace list and adding the resulting costs. The total number of trips in the non-collaborative case is the sum of the number of stand-alone trips necessary to deliver the orders of all three companies individually. The total cost for a company in the non-collaborative case is the sum of the costs needed to deliver all orders for each individual delivery date/customer pair.

To calculate the *collaborative* cost of the coalition the orders of all three companies are joined in a single order list. Then they are grouped by customer and delivery date and allocated to a minimum number of trips by solving a bin-packing problem for each customer/delivery date pair. The total number of trips in the collaborative case is the sum of these numbers. The costs for delivery of each customer/delivery date pair, as well as the total cost of the coalition are calculated as in the stand-alone case. To be able to divide the cost allocation according to the Shapley value, the costs of the subcoalitions are also determined by creating lists that contain orders of the subcoalitions and repeating this calculation. The total cost is then divided over the different companies by using the Shapley value.

Table 1 shows the total and individual logistics costs for different scenarios. The upper block shows the results in the non-consolidated situation (in which each of the companies individually optimizes its own logistics cost). The middle block shows the results of the consolidated situation. The lower block shows the difference between the logistics costs in both situation, and therefore the decrease in logistics cost as a result of collaboration.

In reality, the coalition cost will always be lower than the sum of the individual companies' costs. This is due to two effects. First, the coalition has more options for optimizing: more individual orders that can be grouped and shipped together generally means less (half-empty) trucks to send. Secondly, the coalition has a larger total volume to be shipped and therefore receives a lower price per pallet from the 3PL. In order to be able to distinguish between these different effects, table 1 depicts the logistic costs for the scenario where the prices decrease in function of the total volume shipped (*Decreasing prices* when the total volume increases) and for the scenario where the same prices are maintained in every scenario (*Fixed prices* for increasing total volume).

As can be seen from Table 1 the gains that can be achieved by horizontal collaboration are far greater than can be achieved by optimizing internally. By purely planning each individual company's logistical operation more efficiently, a total improvement of 13.65%can be achieved. When adding the price differences to the consolidation effect (column Decreasing Prices), the total improvement rises up to 25.83%. The total number of trips is even improved by 26.58%.

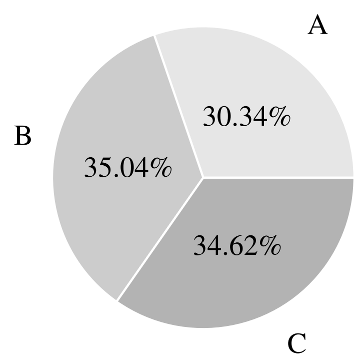

Figure 1: Distribution of profit by the Shapley Value when prices are equal in all subcoalitions

Table 1: Logistics cost in the collaborative and non-collaborative scenarios

	Decreasing prices	Fixed prices	Number of trips
	No collaboration		
Cost of A	189245	161192	2415
Cost of B	545676	470526	4408
Cost of C	307445	263638	4316
Total cost	*1042366* (∗)	*895356*	*11139*
	Collaboration		
Cost assigned to A	118158	124112	1488
Cost assigned to B	441956	427710	3367
Cost assigned to C	213042	221334	3323
Total cost	*773156*	*773156*	*8178*
	Improvement as percentage of (∗)		
Improvement A	37.56%	23.00%	38.39%
Improvement B	19.01%	9.10%	23.62%
Improvement C	30.71%	16.05%	23.00%
Total improvement	*25.83%*	*13.65%*	*26.58%*

The gains are distributed by the Shapley value in such a way that each partner notices a significant reduction in its transportation costs. The gains in the scenario ”Fixed prices” are distributed fairly evenly (see Figure 1), giving a slight advantage to the partners with a larger volume (which is fair, as they offer more opportunities to optimize than a smaller company). Moreover, companies with a large shipped volume contribute more to the better prices negotiated with the logistics service provider (column Decreasing prices). This is also reflected in the share of the cost allocated to each partner of the coalition. It follows that the Shapley value rewards the *impact* that a company has on the total cost of the coalition, without requiring information on where this effect stems cost.

The experiment in this section clearly shows that collaboration can result in far more considerable cost reductions than those that individual companies can achieve. Moreover, not only the entire coalition benefits, each individual company in the coalition will also see its costs reduced significantly. The gains are not confined to merely financial benefits: a positive impact on the environment is a result of the reduced number of trucks sent by the coalition. By facilitating a better use of truck capacity, horizontal collaboration is able to reduces the emission of greenhouse gases and other pollutants, congestion and noise pollution.

In order to more fully exploit the potential of the coalition, however, the collaboration can be further intensified. By adapting terms of delivery and hence adopting a more flexible attitude, the coalition can further increase its gains. This concept will be investigated in the next section.

5. The importance of flexibility

This research investigates how and to which extent an increased orchestration of the collaborative supply chain can positively influence the advantages that come with such alliances. Orchestration implies going further than an ad-hoc or reactive bundling of orders that happen to have the same delivery date and customer, and can fit together in one truck. By allowing changes to the attributes of a delivery (e.g., by allowing it to be postponed), collaborative gains can be further enlarged. The environment created by a strategic alliance will promote an active search for such flexibility opportunities.

To allow further improvements of the collaborative gains, the partners of the coalition should thus take a more flexible attitude with respect to the characteristics of their orders. However, as companies still behave mainly out of self-interest, the main motive for allowing such flexibility will generally be the profit that can be made. In other words, the attributed gain should be large enough to compensate the (invisible) costs related to flexibility, while still distributing enough profits to the other partners so that the incentive to collaborate remains maintained.

More specifically, we suggest that the gain sharing method should have the following characteristics:

1. *The cost allocated to each partner when collaborating should be lower than its stand-alone cost.* In order to increase the incentive to collaborate, each partner should experience a significant reduction in its logistic cost, independent of the type of flexibility that this partner and the other partners allow.
2. *An increase in flexibility by a partner should always result in more gains for that partner.* There should always exist an incentive to behave in a more flexible way and — vice versa — a rigid attitude should be penalized. In order to be perceived as fair, the profit that is allocated to the partner should be greater than the profit it can achieve on its own by being more flexible. Evidently, as flexibility not only lowers the cost of that specific partner but also increases the synergy in the coalition, the rewards for that partner should take into account the increased positive consolidation effect.
3. *The greater the impact of a partner's flexibility, the greater the rewards for that partner should be.* If the flexible attitude of one partner results in a larger increase in the profit for the coalition than the flexible attitude of another partner, this partner should receive a larger incentive to assume that flexibility. This appears to be fair. Moreover, a partner has an incentive to be as flexible as possible.

6. Testing the effects of flexibility

This section investigates — using the data of the case study described in section 4 — to which extent flexibility can improve the supply chain cost and sustainability. Flexibility is defined as *the extent to which a company allows changes to the attributes of a delivery with the aim to reduce the total supply chain cost*.

Using the same data as in section 4, the effects on the logistic cost of two different types of flexibility are investigated. A first type is allowing orders to be split. In other words, the pallets of an order do not have to be delivered all at once (in the same trip), but can be delivered by different trucks (but still on the same day). In this way, for a given customer/delivery date pair all trucks but one can be fully loaded without any loss of capacity. A second strategy allows orders to be synchronized in time. More specifically, it is assumed in this strategy that an order does not have to be delivered on its delivery date, but can be delivered on any day of the week in which its delivery date lies[1]. By relaxing this constraint, delivery dates can be changed so that all orders that happen in the same week and are delivered to the same customer can be bundled.

In order to determine the cost, the algorithm as described in section 4 is used. However, when creating a list of orders, a distinction is made between orders that can be split and orders that can not. After the optimization of the bundling of orders that can not be split, the splittable orders are then distributed over the trips that have unused capacity and are delivered to the same customer and the same date. If the remaining capacity is not sufficient, additional trips are created.

In Table 2, the situation with rigid constraints (column 1, no order splitting allowed) is first compared to a fully flexible situation in which all companies allow order splitting (column 2). In column 3–5, the situation is depicted in which one partner assumes allows order splitting whereas the other partners do not. In Table 3,

Table 2: Determining the gains of order splitting

	No order splitting	Order splitting			
		All	A	B	C
	No collaboration				
Cost of A	189245	189245	189245	189245	189245
Cost of B	545676	543743	545676	543743	545676
Cost of C	307445	306174	307445	307445	306174
Total cost	*1042366* ($*$)	*1039162*	*1042366*	*1040433*	*1041095*
	Collaboration				
Cost assigned to A	118158	115748	112076	116394	117856
Cost assigned to B	441956	433759	437546	432652	436959
Cost assigned to C	213042	208767	211903	210159	205547
Total cost	*773156*	*758274*	*761525*	*759205*	*760362*
	Improvement as percentage of ($*$)				
Improvement A	37.56%	38.84%	40.78%	38.50%	37.72%
Improvement B	19.01%	20.51%	19.82%	20.71%	19.92%
Improvement C	30.71%	32.10%	31.08%	31.64%	33.14%
Total improvement	*25.83%*	*27.25%*	*26.94%*	*27.17%*	*27.05%*

the same comparison is made, but now it is assumed that all partners have flexible constraints (allow order splitting) and one partner behaves in a rigid way (does not allow order splitting).

The simple strategy to allow order splitting can enlarge the total cost improvement from 25.83% to 27.25%. The possible gains however need to be balanced against the cost of this strategy, which is often more difficult to determine. Although a client will find its order to arrive on time and in the right quantity, a number of changes still need to be managed under this strategy. More drops per order can be confusing on the client's side as well as for the shipper himself (e.g., how is this managed in the IT-system?). Also, more handling costs can occur in the goods reception area.

Table 3 shows the results for the time synchronization strategy (in which orders are allowed to be delivered on every day in the week of their delivery date). In order to calculate these costs, the algorithm in section 4 is again adapted. In this case, the bundling is based on the destination and the delivery *week* rather than the delivery day. To be able to capture that some companies remain rigid and prefer their actual delivery day, constraints are added to the original bin packing problem. For each pair of orders i and j that cannot be bundled because they need to be delivered on a different day, we need to add the constraints $\forall t x_{it} + x_{jt} \leq 1$, where $x_{it} = 1$ implies that trip t contains order i and $x_{it} = 0$ that it does not.

Table 3 shows the gains that can be achieved when time synchronization is applied. In the first column, the situation as seen in section 1 is repeated. In the next column, all partners are flexible. The last columns show each time the generated and allocated costs when two companies allow time synchronization and one remains rigid. As can be seen, the extra gains that this strategy allows are considerable: when all companies allow time synchronization, total logistics cost decreases by 41.81% when compared to the situation in which no time synchronization is allowed and all companies individually optimize their trips. In this case, however, the additional costs of reduced service level (clients can no longer count on their initially requested delivery date and thus on a strict delivery time window), more stock at the client as well as at the shipper, etc, should also be considered. A shipper should ensure that he is aware of these (often hidden) costs before adopting such

[1] These are just easy examples to show that flexibility increases the consolidation gain. We can imagine for example that a more realistic scenario encompasses a combination of both scenarios: A part of a delivery (split an order) is allowed to arrive a day later (i.e. time synchronization)

Table 3: Determining the gains of time synchronization

	No time synchronization	Time synchronization			
		All	B & C	A & C	A & B
	No collaboration				
Cost of A	189245	129911	189245	129911	129911
Cost of B	545676	439823	439823	545676	439823
Cost of C	307445	224742	224742	224742	307445
Total cost	*1042366* (∗)	*794476*	*853810*	*900298*	*877154*
	Collaboration				
Cost assigned to A	118158	82356	123789	75698	76355
Cost assigned to B	441956	363825	351581	453267	349710
Cost assigned to C	213042	160349	154761	151597	224963
Total cost	*773156*	*606530*	*630131*	*680562*	*651028*
	Improvement as percentage of (∗)				
Improvement A	37.56%	56.48%	34.59%	60.00%	41.22%
Improvement B	19.01%	33.33%	35.57%	16.93%	20.49%
Improvement C	30.71%	47.84%	49.66%	50.69%	26.82%
Total improvement	*25.83%*	*41.81%*	*39.55%*	*34.71%*	*37.54%*

strategies. A trade-off between the number of days that can be moved and the costs related to such a move should be made and an optimal number of days that an order can be moved should be found.

Moreover, not only the flexibility strategy *time synchronization* can be optimized, the total set of flexibility strategies can be optimized. Backordering, e.g., is essentially a combination of order splitting and time synchronization (in which an order shipment is partitioned and a part of the delivery is postponed). If backordering is allowed, a decision needs to be made on the possible size of the backorder, as well as the possible number of days of delay.

For both strategies, the cost allocation based on the Shapley value gives a proper incentives to be more flexible and collaborative.

1. *The cost allocated to each partner when collaborating should be lower than its stand-alone cost.* As seen in Figure 2, in which the first bar of each strategy depicts the costs in the non-collaborative situation and the second in the collaborative situation, the cost allocated to each company in the latter is always lower than the stand-alone cost. Moreover, this is true for both the coalition and for each partner individually. Even the smallest improvement that is achieved by a partner is still 19.01%. As stated in Section 3, the Shapley value possesses *individual rationality*, and therefore this behavior is always guaranteed.

2. *An increase in flexibility by a partner should always result in more gains for that partner.* For a given partner, the allocated cost when this partner is rigid is always higher than the costs allocated when it is flexible. Therefore, independent of the strategies of the other coalition partners, each company will always see its allocated costs reduced by being more flexible. This is depicted in Figure 3. This behavior is a direct consequence of the *individual rationality* property and can therefore be generalized: the cost of any (sub)coalition will always decrease whenever this (sub)coalition adopts a flexible attitude.

3. *The greater the impact of a partner's flexibility, the greater the rewards for that partner should be.* The Shapley value is able not only to reward flexibility, but also to distinguish the differences in impact and compensate accordingly. There is no need to investigate *why* the total cost has changed, only that it has changed, as the Shapley value only uses the resulting costs. This is advantageous, as it is difficult to

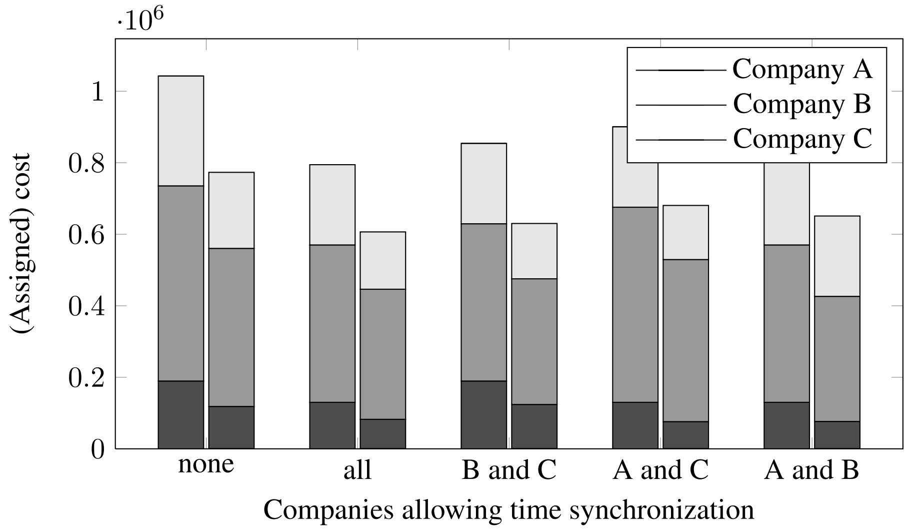

Figure 2: Comparison of the stand-alone costs (left bar) to the assigned collaborative coalition cost (right bar) for several time synchronization scenarios

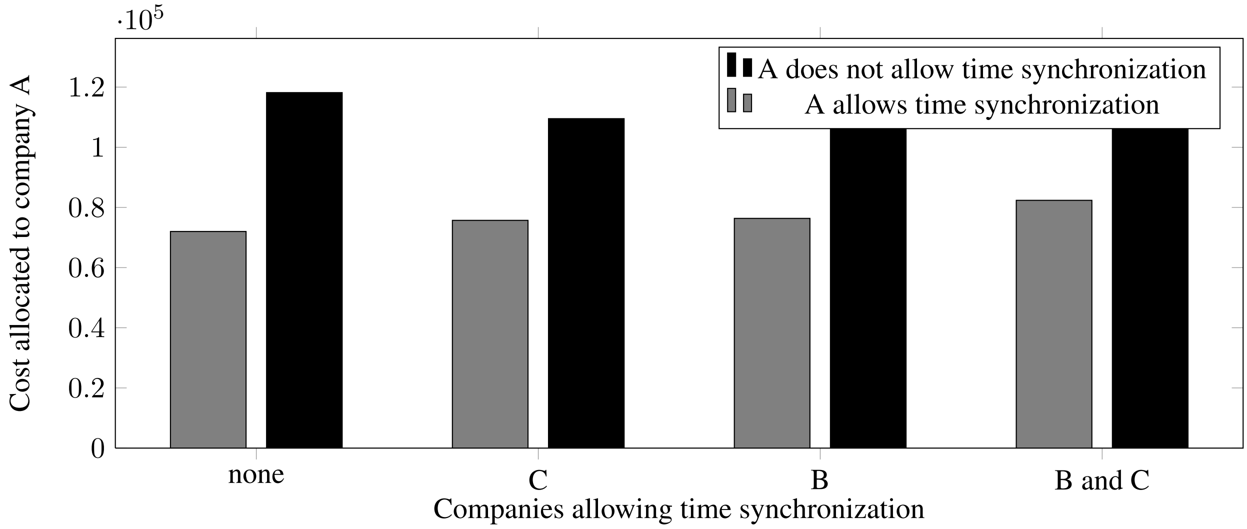

Figure 3: Comparison of costs for company A when adopting rigid vs. flexible attitude

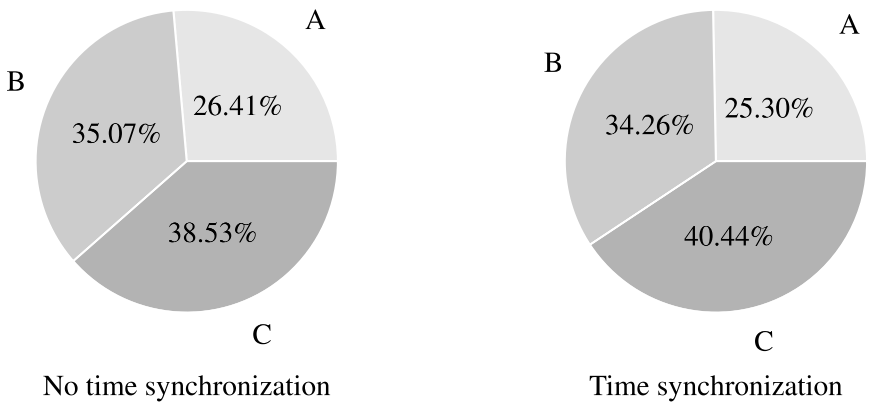

Figure 4: Division of profits when all companies are rigid (no time synchronization allowed) vs. all companies are flexible (time synchronization allowed)

determine all factors that influence the compatibility of a partner with the others in the coalition, and to which degree this will aid the total coalition.

Table 3 shows, e.g., that the impact of the flexibility of company B is than that of the other companies (the total supply chain costs when company B is flexible decreases to 630131, versus 680562 for company A and 651028 for company C). There could be many explanatory factors: the number of orders, very incompatible delivery dates in the rigid situation, order sizes that will lead more quickly to optimal truckloads, and so on. Most likely, it is a combination of all of them. Without measuring the size, comparing dates or using other metrics, the Shapley value has attributed a bigger share of the total collaborative gains (or a smaller share of the cost) to partner B when he is flexible than when he is rigid. Figure 4 shows that company B receives 39% of the profits when all partners are rigid, which climbs up to 2% when it is flexible, although each partner has adopted the same strategy. Thus, company B has a bigger incentive to be flexible than the other partners, which is desirable as the most profit will be generated if that partner would assume a flexible attitude.

We have mentioned in Section 3 that the Shapley value does not guarantee stability. In Table 3 for example, company A would prefer company B and C to be rigid instead of flexible as its costs will increase from 118158 euros to 123789 euros. Although this might be perceived as unfair, the incentive to collaborate still exists (achieving a cost reduction of 34.59%). Moreover, partners are still encouraged to be more flexible. Indeed, in order to reduce its costs again, company A should also assume a more flexible attitude, reducing its costs to 82356 euros. However, this can still cause dissatisfaction. Clear rules negotiated in advance (or derived from a framework) and a relationship of trust are still key to resolving such issues.

7. Conclusion and future work

The main future challenge in supply chain management is to reduce the environmental impact of transporting goods, while still remaining cost efficient and respecting service levels. Horizontal collaboration has already showed to be able to increase efficiency between 10% and 30%. Moreover, the environmental benefits that arise from horizontal collaborations can even exceed the cost reductions, as the larger volumes also allow a modal shift. It is expected that horizontal collaboration will be increasingly adopted to improve supply chain efficiency. The creation of a standard European legal framework for such alliances, as well as the rising number of successful case studies is an excellent facilitator.

This paper investigated the advantages of horizontal collaboration in a case study of three large fast moving consumer good companies in Belgium, 57% of the orders of which are delivered to shared clients. Even without exploring further opportunities for supply chain improvement, collaboration can achieve a 25.83% decrease in transportation costs.

In a second part of this research, the assumption that horizontal alliances provide the necessary trust and long-term commitment to adopt flexibility strategies was investigated. Such strategies allow a further increase of the positive consolidation effects. Because partners of the coalition allow changes to be made to their deliveries, the coalition's supply chain cost, as well as their own cost, can continue to decrease. It was shown that flexibility can be encouraged through an adequate and fair profit allocation method such as the Shapley value, that is designed to reward the *impact* each partner has on the coalition. The Shapley value gives incentives (i.e., allocates more profit) to partners to behave in a manner that is beneficial for the total coalition, i.e., to flexible partners.

Two flexibility scenarios were tested using the case study mentioned: time synchronization and order splitting. Although (hidden) costs are probably incurred when these strategies are introduced, the gains that can be obtained are significant. Further research will focus on determining the impact of other flexibility scenarios (e.g., in which the order size can vary), variations on the scenarios discussed in this paper (e.g., an order can be postponed one day) or combinations of them (e.g., backordering allows a part of an order to be delivered a day later).

The more flexibility however, the more possibilities should be taken into account by the dispatcher, and the more difficult the planning process becomes. Moreover, the operational planning should not only be optimal considering the total supply chain cost, but the profits that are allocated to each partner are also important factors that need to be kept in mind. Therefore, the next challenge will be to develop an operational planning tool that can support horizontal collaboration by integrating flexibility as well as profit allocation.

Finally, we will look into more simple rules of thumb to divide the costs. Comparing their output to more theoretically fair cost allcoaiton mechanisms will give insight which cost allocation mechanisms can be used in a given situation (e.g. can we use a cost allocation mechanisms based on volume when one of the partners has small orders that are currently shipped very inefficiently?).

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A. Horizontal collaboration case studies

Table 4: List of horizontal collaboration case studies

Reference	Description	Results
Boerema and Groothedde (2001) Wiegmans (2005)	Analysis of the shipments of FMCG-manufacturers Albert Heijn, Laurus, Schuitema & Aldi, and implementation of inland barges	22% reduction in transportation costs 48 mil. less kilometers
Bahrami (2002)	Collaboration of 2 German producers (Henkel and Scharzkopf) when distributing their products.	Total distribution costs decreases 9.8%.
Hageback and A. (2004)	Researching the possible advantages of co-distribution of 20 suppliers to a sparsely populated area in Sweden	Cost reductions are estimated on 33% or more.
Cruijssen and Salomon (2004)	The advantages of order sharing in the case of transportation of flowers in the Netherlands are investigated. Then, additional tests are executed on simulated data.	A cost decrease ranging from 5% to 15% is obtained.
Palander and Väätäinen (2005)	4 case studies where the transportation systems of the wood procurement organization are integrated	20% reduction in costs 2% additional reduction with backhauling

Continued on next page

unit Mobiliteit & Logistiek (2005)	Presentation of 8 small pilots of transport collaboration in different industries of the Netherlands	10-15% cost reduction 30-50% more deliveries per week.
Cruijssen et al. (2007a)	Consolidation of the cold supply chains of Douwe Egberts, Masterfoods, Unipro and C. Van Heezik A sensitivity analysis on the dataset	28.5% less kilometers driven
Le Blanc et al. (2006)	Investigation into the possibility of factory gate pricing applied for 3 retailers, using a consolidation hub and routing and planning inventory collaboratively	22% decrease in supply chain costs 26% if retailers also collaborate
Krajewska et al. (2008)	Horizontal collaboration between small- and medium-sized carriers. Data from the North-German transport company Stute GmbH is used.	Number of trucks decreases 10%, transportation cost with 12.46%
Ergun et al. (2007)	Hypothetical collaboration of shippers in US to reduce repositioning costs	Savings between 5.5% - 13%
Verweij (2009)	Presentation of 2 cases: The manufacturing Consolidation Center of Kimberly-Clark and Unilever HPC and the horizontal collaboration between 15 SME logistics service providers in the Benelux called TRANS-MISSION	increase of 57% in number of delivery days per week and decrease of 31% in number of drops per week for Kimberly-Clark and Unilever. TRANS-MISSION is slowly becoming a brand in the Netherlands
Frisk et al. (2010)	Horizontal collaboration between 8 wood shipping firms in Sweden	Internal optimisation can reduce costs by 5%. Collaboration can further reduce costs by 9%
Jordans (2011); Van der Broeck (2011)	Start of a pilot in Dutch project "Doorbraak Bundelen Goederenstromen" of Philips (shipping lightweight products to England) and Hunter Douglas (heavy weight products), who have found each other thanks to the project that aims to find good synergy partners through a "pond" of possible candidates	Expecting higher service levels and reduced lead times. Possibility of stacking will optimize capacity even further
Pulleman (2011)	In Dutch project "Doorbraak Bundelen Goederenstromen": Creation of a network of shippers of chilled goods, with a resulting pilot of coalition of 3 companies shipping to Spain	Analysis predicts 26% reduction in CO_2 emissions
Valender (2011)	Block train was used to ship goods from Benelux to Eastern Europe and back, with Nestle, Bacardi and Kraft as promotors	Reduction in Greenhouse gasses without loss of service levels

Continued on next page

Table 4 – continued from previous page

Menedeme (2011); Van Breedam et al. (2011)	Collaboration between 2 pharmaceutical companies UCB and Baxter, for their shipments to Romania	More than 50% reduction in greenhouse gasses
Tillemans (2011)	Horizontal collaboration between FMCG- manufacturers Heinz & Friesland Campina and vertical collaboration with co-packer	Improved service levels and efficiency, 5% reduction in CO_2