Analysing collaborative performance and cost allocation for the joint route planning problem

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ABSTRACT

Although organisations become increasingly aware of the inevitable character of horizontal collaboration, surveys report failure rates up to 70 percent for starting strategic partnerships. While a growing body of research acknowledges the importance of the partner selection and cost allocation process, no extensive study has been performed on the numerical relationship between specific company traits, applied allocation mechanisms and collaborative performance. This paper investigates the impact of coalition characteristics on attainable collaborative savings and cost allocation values in a joint route planning context. Results indicate that collaborative order sharing provides significant operational benefits and can be based on intuitively appealing cost allocation techniques, which may reduce alliance complexity and enforce the strength of mutual partner relationships.

Keywords: horizontal carrier collaboration, joint route planning, partner selection, cost allocation

1. INTRODUCTION

Horizontal collaboration between transport companies has become an important research area, since severe competition in global markets, rising costs, a growing body of transport legislation and heightened customer expectations have caused profit margins of organisations to shrink. (Cruijssen et al. 2007b). Horizontal logistics cooperation may be defined as collaboration between two or more firms that are active at the same level of the supply chain and perform comparable logistics functions (Cruijssen et al. 2007c). Through partnering with fellow transport organisations, carriers may extend their resource portfolio, reinforce their market position, enhance their service levels and create a more efficient transport planning (Hernández et al. 2011).

Although transport companies become increasingly aware of the inevitable character of collaboration, surveys report failure rates from 50 to 70 percent for starting partnerships (Schmoltzi and Wallenburg 2011). The success of achieving collaborative benefits strongly depends on the degree of fit between cooperation participants (Verstrepen et al. 2009). While a growing body of collaboration research acknowledges the importance of partner characteristics (Cruijssen et al. 2007a, Lozano et al. 2013, Guajardo and Rönnqvist 2015, Guajardo et al. 2016), no extensive study has been performed on the numerical relationship between specific company traits and the performance of the alliances in which these carriers are involved. The first goal of this paper is thus to provide practical recommendations on which partnership structures may provide the highest collaborative benefits.

Although selecting the right partners is crucial for the success of any horizontal alliance, it is not sufficient to guarantee long-term coalition stability. Dividing the collaborative gains in a fair manner constitutes a key issue, since the proposed allocation mechanism should induce partners to behave according to the collaborative goal and may improve cooperation stability. However, a wide range of possible allocation mechanisms have been developed in recent literature, each with its specific benefits, drawbacks and fairness properties. In this context, the second goal of this paper is to perform an extensive comparative analysis examining the applicability and suitability of different cost allocation methods in varying cooperation scenarios.

Based on the literature review on collaborative logistics described in Verdonck et al. (2013), the impact of coalition characteristics on attainable collaborative savings and cost allocation values will be investigated in a joint route planning context. In the majority of carrier alliances customer orders from all participating carriers are combined and collected in a central pool and efficient route schemes are set up for all requests simultaneously using appropriate vehicle routing techniques (Cruijssen et al. 2007a). Since existing studies mainly focus on demonstrating the benefits associated with joint route planning, an empirical analysis of the influence of cooperation structure on partnership performance and the impact of cost allocation mechanisms on coalition stability could provide useful insights for carriers considering collaboration.

The novelty of this paper lies in the application and empirical analysis of an existing routing problem in a practical context with the aim of providing guidelines to practitioners. Using a well-known statistical research method, recommendations can be made to transport organisations considering joint route planning on how they should tackle the partner selection and gain sharing process.

The remainder of this paper is organised as follows. First, current research on joint route planning, partner selection and cost allocation is summarised. Second, the research methodology is described. Third, results of a factorial ANOVA on the impact of coalition characteristics and cost allocation mechanisms are presented and discussed. Finally, conclusions and possible directions for future research are formulated.

2. STATE OF THE ART

2.1. Joint Route Planning

Scientific research on horizontal carrier collaboration can be divided into two main research streams: order sharing and capacity sharing (Verdonck et al. 2013). The majority of carrier cooperation literature focuses on carrier alliances in which customer requests are exchanged between the participating organisations through various techniques. A mechanism which has been generally accepted in a horizontal carrier cooperation context is joint route planning. Creating a joint route plan for all requests simultaneously may lead to reductions in travel distance, empty vehicle movements and number of required trucks (Cruijssen et al. 2007a).

Cruijssen and Salomon (2004) use a simulation study to demonstrate that joint route planning may lead to reductions in transport costs up to 15%. Similarly, Cruijssen et al. (2007a) define a framework based on the VRP with time windows (VRPTW) to determine the synergy value of horizontal carrier cooperation through joint route planning. Case study results show that joint route planning between three frozen food distributors saves about 30% in distance travelled. Nadarajah and Bookbinder (2013) study horizontal carrier collaboration within urban regions. Computational experiments indicate distance savings up to 15% when collaborating at the entrance of the city and additional reductions in kilometres driven up to 15% when carriers are involved in intra-city collaboration. Pérez-Bernabeu et al. (2015) compare a cooperative route planning scenario with various non-cooperative scenarios, differing in geographical customer distribution, in terms of distance-based and environmental costs. Another variant of the traditional VRP used to model the collaborative carrier order sharing problem is the multi-depot pickup and delivery problem (MDPDP), as described in Krajewska et al. (2008) under time windows. The authors test their approach both on artificial instances and real-life data from a German freight forwarder. Dahl and Derigs (2011) examine the order sharing problem in a collaborative network of carriers performing express customer orders. Based on a simulation study using real data from 50 European express carriers, the authors demonstrate that cost reductions up to 13% may be achieved when applying dynamic joint route planning. Contrary to the previous articles considering the entire transport network for collaboration, Bailey et al. (2011) and Juan et al. (2014) focus on order sharing opportunities for the backhaul routes of partnering companies.

The existing research work described above mainly focuses on demonstrating the cost reduction potential of order sharing between logistics service providers. Following this observation, the main contribution of this paper is to provide decision support on the partner selection and cost allocation process within a joint route planning context. The next sections provide relevant details on both collaboration challenges.

2.2. Partner Selection

Selecting the right partners constitutes a crucial phase in the development of a horizontal collaboration. According to Brouthers et al. (1995) cooperating with an unsuitable partner is more damaging to an organisation than not collaborating at all. Carriers also seem to be aware of the crucial importance of partner selection, as indicated in a survey by Cruijssen et al. (2007b).

Van Breedam et al. (2005) distinguish four key factors that should be considered when selecting possible collaboration partners: trust and engagement, operational fit, strategic fit and cultural fit. Trust refers to each company's conviction that the other partners will refrain from opportunistic behaviour. Engagement reflects the preparedness of each alliance partner to make a contribution to the collaboration, evoking a mutual sense of responsibility towards alliance success (Schmoltzi and Wallenburg 2012). Other focal points are the operational, strategic and cultural fit with a potential partner. Operational fit concerns organisational characteristics on a financial and operational level such as company size, proprietary structure and profitability. In order for strategic fit to be present, the organisational strategies of the partners need to be compatible and mutually strengthen each other. A final key factor in partner selection is cultural fit. Compatibility between organisational cultures is crucial when a stable collaboration is aspired. In line with these four factors, Schmoltzi and Wallenburg (2011) define six dimensions associated with the structure of the cooperation that may impact its performance. First, the contractual scope defines the formality of the cooperation project. Second, the organisational scope refers to the number of companies taking part in the alliance. Third, the functional scope is associated with the activity domains in which organisations join forces. A cooperation might be limited to non-core activities or may involve core business' operations. Fourth, the geographical scope is related to the markets that are covered by the alliance. In line with this geographical dimension, the service scope defines the products or services offered by the collaboration. Finally, the resource scope refers to the degree of resource overlaps between the cooperation participants. A distinction is made between overlaps in business activities, customer base and company size. Based on the partner selection criteria discussed above, the effect of five measurable coalition characteristics on alliance performance and stability is investigated and statistically analysed in this paper: number of partners, carrier size, geographical coverage, order time windows and order size. In section 3.2 the studied hypotheses are discussed in detail.

2.3. Cost Allocation

Although selecting the right partners is crucial for the success of any horizontal alliance, it is not sufficient to guarantee long-term coalition stability. Dividing the collaborative gains in a fair manner constitutes a key issue.

Verdonck et al. (2016) provide a structured review of allocation mechanisms applied in horizontal logistics collaborations distinguishing between (1) proportional sharing mechanisms, (2) allocation mechanisms using game theory concepts and (3) allocation techniques designed to cope with additional cooperation properties. First, the most commonly used profit or cost division mechanism in practice is the proportional allocation method (Liu et al. 2010). In this case, the collaborative profit is allocated to the cooperating organisations equally, on the basis of, among others, their individual cost level or the volume they have to transport as a consequence of their engagement in the cooperation (Verdonck et al. 2016). Second, a logistics cooperation clearly matches the structure of a cooperative game. Collaborating partners share and consolidate freight and receive or make payments in return. This cooperation process results in an allocation of benefits or costs to each participant that may be considered equivalent to the outcome of a cooperative game. A well-known allocation method based on the foundations of game theory is the Shapley (1953) value. This value allocates to each participant the weighted average of his contributions to all (sub)coalitions, assuming the grand coalition is formed one company at a time. A more complex allocation mechanism supported by game theory is the nucleolus. This profit or cost sharing procedure, developed by Schmeidler (1969), has the distinct property of minimising the maximal excess, which constitutes the difference between the total cost of a coalition and the sum of the costs allocated to its participants. Finally, several authors have developed distinct, more intuitively clear allocation mechanisms that account for certain specific cooperation characteristics, some of them partly based on game theory ideas (Verdonck et al. 2016). Tijs and Driessen (1986) discuss three allocation techniques based on the division of the total collaborative costs in separable and non-separable costs. Frisk et al. (2010) create profit sharing mechanisms with the goal of finding a stable allocation that minimises the largest relative difference in cost savings between any pair of cooperating partners. Özener and Ergun (2008) develop allocation mechanisms ensuring that existing partners do not loose savings when an additional company joins the collaboration, while Hezarkhani et al. (2016) define allocations preserving the competitive positions of cooperation participants.

The overview provided in the previous paragraph demonstrates that a wide range of possible allocation mechanisms exists. As each method has its specific benefits and drawbacks, it remains ambiguous which technique(s) could guarantee stability and sustainability in a joint route planning setting. In order for partners to make an informed decision on the allocation mechanism that suits their collaborative needs, an extensive comparative analysis examining the applicability and suitability of three different cost allocation methods in varying cooperation scenarios is performed in this paper. The three allocation methods selected for their application are the Shapley value, the Alternative Cost Avoided Method (Tijs and Driessen 1986) and the Equal Profit Method (Frisk et al. 2010). Details on their theoretical foundation and mathematical formulas can be found in Appendix A.

3. RESEARCH METHODOLOGY

To investigate the impact of coalition characteristics on collaborative performance and cost allocation values the statistical approach of experimental design is used. Using factorial ANOVA, the value of the performance measure associated with various levels of the independent parameters or factors can be statistically derived. Based on the partner selection criteria discussed in section 2.2, the effect of five measurable coalition characteristics on alliance and cost allocation performance is investigated within a joint route planning context. Section 3.1 briefly describes the joint route planning problem faced by the collaborating carriers. In section 3.2 the research hypotheses are discussed in detail. Since no test instances are available for the specific collaboration problem investigated here, the method used to generate artificial instances is described in section 3.3, together with a presentation of the experimental factors coinciding with the relevant cooperation characteristics.

3.1. Problem Statement

The joint route planning problem of collaborating carriers studied in this paper can be defined as follows. Carriers receive pickup and delivery requests from different types of customers. In a static context, it is assumed that customer demand is known and fixed at the start and no additional requests are acquired during the execution of already determined transport schedules. Each route has to satisfy coupling and precedence constraints, meaning that for each order, the origin must precede the destination and both locations need to be visited by the same vehicle. In addition, hard time windows are associated with each request. In a non-cooperative environment, the routing problem associated with each individual carrier, may be classified as a single depot PDPTW. The objective of the PDPTW is to identify an optimal set of routes for a fleet of vehicles to serve all customers without violating vehicle capacity, time windows, precedence and coupling constraints. The optimality characteristic coincides with an objective function that minimises total customer service time, distance travelled, number of used vehicles or a weighted combination of these goals (Li and Lim 2003, Krajewska et al. 2008, Parragh et al. 2008, Ropke and Cordeau 2009).

If carriers cooperate horizontally, pooling all their customer orders together to achieve potential savings, additional constraints have to be added to the PDPTW in order to optimally solve the joint route planning problem. The most important modification that needs to be made, is the adoption of a multi-depot perspective. As requests from all carriers are considered simultaneously, vehicles may depart from multiple depots. The joint route planning problem may thus be defined as a multi-depot PDPTW with the general purpose of identifying optimal routes for all customer requests simultaneously. This set of routes minimises total cost, guarantees that all requests are served within their time windows, all vehicles return to their respective depots and vehicle capacities are never exceeded (Krajewska et al. 2008).

3.2. Research Hypotheses

In the first part of the numerical experiment, the effect of specific coalition characteristics on alliance performance is investigated. For this purpose, the following five relationships based on theoretical, qualitative collaboration literature are analysed. First, the influence of the **number of partners** on cooperation performance is examined. Based on statements made by Park and Russo (1996), Griffith et al. (1998) and Lozano et al. (2013) it is investigated whether the number of collaborating partners has a positive impact on coalition performance. Second, in line with the operational fit concept described by Van Breedam et al. (2005), the impact of similarity in **size of the collaborating companies** is studied. Size of a carrier is measured in terms of the amount of customer requests it initially needs to serve before considering the cooperation. In accordance with experimental results of Cruijssen et al. (2007a) and Vanovermeire et al. (2013), it is examined whether coalition performance is higher for cooperations established between equally sized carriers compared to collaborations between organisations differing in size. Third, the effect of resource overlaps between alliance partners is analysed in three ways. The resource scope is first defined as the **degree of overlapping geographical coverage** between cooperating carriers. Here, it is studied whether coalition performance is higher for cooperations established between carriers operating within the same geographical area compared to collaborations between companies active in unrelated customer markets. Next, the effect of similarities and differences in customer base characteristics is investigated. This concept is translated in two partner characteristics. On the one hand, it is studied whether overlap between cooperation participants in terms of **customer order time windows** has a positive effect on coalition performance. On the other hand, it is investigated whether coalition performance is higher for cooperations formed by partners with differing **order sizes** compared to collaborations established between carriers serving orders of similar size. Throughout all these hypotheses the dependent variable, coalition performance (CP), is defined as the difference between the total distance-dependent cost of the coalition after applying joint route planning and the sum of the stand-alone distance-dependent costs of the companies considering operating independently.

The goal of the second part of the numerical experiment is to examine the applicability and suitability of **the Shapley value, the ACAM and the EPM** in varying cooperation scenarios. First, the influence of the five coalition characteristics described above on cooperation stability is examined. Second, it is analysed whether significant differences exist between allocation solutions defined by the three applied mechanisms. Third, the relationship between the cooperation structure and the cost share allocated to the different alliance partners is studied.

3.3. Instance Generation

First, test instances are created for individual carriers differing in terms of the partner characteristics presented in the previous section. Table 1 provides an overview of the characteristics associated with these individual carrier instances together with their implementation details. Regarding the chosen implementation values, experienced practitioners were consulted in order to create realistic partnership structures fitting in a joint route planning setting. Second, the individual carrier instances are combined in a factorial experiment to represent horizontal alliances with varying structures.

Considering the individual carrier instances (Table 1), organisations of three different sizes are created. ’Small’ carriers have to serve between 15 and 25 customer requests, ’medium’ carriers are responsible for 60 to 70 customer orders and ’large’ carriers are assigned 100 to 120 requests. This implementation is in line with the European logistics environment comprised of a significant amount of SMEs (small and medium-sized enterprises). To examine the impact of resource overlaps between alliance partners, within each of the three carrier categories just described, distinct carrier profiles are created. First, the Li and Lim (2003) distinction between LR (random customer locations) and LC (clustered customer locations) instances is used to cope with the geographical coverage associated with individual carriers. Second, a distinction is made between carriers serving customers with broad time windows and carriers performing orders with narrow time windows. The average time window width of customer orders characterised by ‘broad’ time windows is two to three times larger than that of orders with ‘narrow’ time windows. Third, carrier instances may differ in terms of the average size of the orders that need to be served. A ’small’ order takes up 5% to 15% of vehicle capacity, while a ’large’ order occupies 30% to 40% of vehicle space. Transported goods and used vehicles are considered to have homogeneous characteristics among participating transport organisations.

Table 1: Characteristics of Individual Carrier Instances

Characteristic	Levels	Implementation
Carrier size	Small Medium Large	*U*(15, 25) orders *U*(60, 70) orders *U*(100, 120) orders
Geographical coverage	R C	Random Clustered
Order time windows	1 2	Narrow Broad
Order size	Small Large	U(0.05, 0.15) * cap. U(0.30, 0.40) * cap.

The five experimental factors and their associated factor levels are listed in Table 2. Horizontal carrier alliances with different coalition characteristics are generated by combining the individual carrier instances as follows. Regarding the number of partners in a coalition, two-carrier, three-carrier, four-carrier and five-carrier partnerships are considered. Next, due to the stated importance of operational fit between coalition partners (e.g. Van Breedam et al. 2005), a distinction is made between alliances consisting of equally sized organisations and alliances comprised of companies differing in size for each of the studied coalition sizes. As such, 'equal size' coalitions are established either between small carriers, medium-sized carriers or large carriers. In order to get a balanced experimental design, for the 'different size' coalitions a random selection is made of three coalition structures containing a mix of small, medium and large carriers. As a consequence, the experimental design can be considered fractional instead of full since not all factor level combinations are included. Within each of these 24 alliance classes, coalitions are then created between carriers operating in the same geographical area (combination of LR instances) and carriers serving customers in different regions (combination of LC instances). In addition, a distinction is made between coalitions established between carriers who are similar in terms of average order time windows (combination of all 'narrow time windows' or all 'broad time windows' instances, each representing half of the number of instances) and carriers responsible for customers with different time window widths (mix of 'narrow time windows' and 'broad time windows' instances, divided equally within every instance). Finally, both alliance structures with only small or large average order sizes and coalitions servicing a mix of small and large orders are created. For comparison and analysis purposes, three instances are generated for each of the described coalition profiles, leading to a total of 1152 test instances.

Table 2: Experimental Factors and Factor Levels

Factors	Factor levels (number of levels)
Number of partners	Two, three, four, five (4)
Carrier size	Small, medium, large, mix_1, mix_2, mix_3 (6)
Geographical coverage	Random, clustered (2)
Order time windows	Equal, mix (2)
Order size	Small, large, mix_1, mix_2 (4)

4. RESULTS AND DISCUSSION

This section is devoted to the presentation and discussion of the joint route planning outcomes, both in terms of collaborative savings and allocation values. The effects of coalition characteristics on collaborative performance are analysed by factorial ANOVA. In the cost allocation analyses paired *t*-tests are used. All statistical experiments are performed using SPSS for Windows Release 24 and are carried out on a Xeon CPU at 2.8 GHz with 64GB of RAM. Coalition performance of all considered cooperation structures is determined using a metaheuristic framework based on Adaptive Large Neighbourhood Search (Pisinger and Ropke 2007).

4.1. Collaborative Savings Results

The savings level associated with joint route planning ranges from 1.64% to 38.57% over all experiments, with an average savings level of 17.14%. Horizontal collaboration through order sharing can hence produce large operational benefits to carriers. However, because of the wide spread in possible savings and because 1.64% may not be a sufficient gain to compensate for additional overhead of collaboration, a further investigation of the main effects of the five factors on the savings attained by the collaboration is in order.

Table 3 presents the ANOVA based significance values for the main effects of the considered alliance characteristics on coalition performance. For each of the studied characteristics the ω^2 value (Olejnik and Algina 2000) is also reported, indicating their respective effect size. The mean coalition performance (CP) for the studied factor levels are displayed in Tables 4, 5 and 6 in Appendix B. Bonferroni and Games-Howell post hoc *t*-tests were used to define the statistical significance of the different factor levels (Field 2013).

Table 3: Main Effects of Coalition Characteristics

Factor	p	ω^2
Number of partners	0.0000*	0.242
Carrier size	0.0000*	0.281
Geographical coverage	0.0000*	0.052
Order time windows	0.0096*	0.005
Order size	0.0000*	0.039

Note: * Significant at α of 0.01

Table 3 indicates that all of the main effects exhibit a statistical significance of less than 0.01. As such, each of the five studied coalition characteristics has a significant impact on coalition performance. The next paragraph will discuss the experimental factors and the proposed hypotheses (section 3.2) independently.

Reviewing the ω^2 values reveals that the size of the carriers involved in the coalition has the most profound impact on its performance. In accordance with experimental results of Cruijssen et al. (2007a) and Vanovermeire et al. (2013), coalitions with the largest profits are achieved when a lot of orders are combined. The larger the pool of joint orders, the larger the potential to find a more profitable route plan for the collaboration. While large transport organisations thus best seek for partners that are equal in size, small companies best join forces with a significant amount of equal-sized organisations and/or attract a large partner in order to enjoy savings levels associated with large order pools. Next, the hypothesis which states that the number of partners in a collaboration influences its performance in a positive way, can be confirmed in a joint route planning context. Increasing the coalition size from two to five partners leads to a more than tripled profit level. However, companies need to be aware that coalition size cannot be enlarged infinitely. Collaborating with a large number of partners also increases alliance complexity and may dilute the strength of mutual partner relationships. In this context, Lozano et al. (2013) proof that there exists a limit above which the synergy increase generated by adding another company to the collaboration is negligible. Then, results demonstrate that coalitions between partners operating within the same geographical service area gain on average 45% more compared to collaborations between companies active in completely unrelated customer markets. Increased geographical coverage may provide more cooperation opportunities and could thus lead to larger cost reductions. Overlapping customer markets seem to constitute an important aspect of coalition sustainability, as was also stated by Van Breedam et al. (2005), Cruijssen et al. (2007a), Schmoltzi and Wallenburg (2011) and Guajardo and Rönnqvist (2015). In terms of order sizes, transport organisations involved in joint route planning best seek for partners that serve requests differing in size. A company with large orders may experience difficulties combining them in a single trip. As such, small orders can be useful to fill the remaining vehicle capacity. Moreover, organisations with small orders could avoid performing a multitude of routes, possibly with many detours, to deliver all its orders by combining them with larger ones. Following these statements, coalitions formed by partners with differing order sizes may achieve on average 26% more compared to collaborations established between carriers serving orders of similar size. Similar results were found by Vanovermeire et al. (2013) and Palhazi Cuervo et al. (2016) for two-partner shipper coalitions. Finally, differences in order time windows seem to complement each other and increase the number of possible improvement opportunities for the joint route plan. This result is supported by Schmoltzi and Wallenburg (2011) who found that, in practice, the majority of multi-lateral horizontal cooperations between logistics service providers are characterised by complementary customer portfolios of partners. However, the remark needs to be made here that, although the main effect of the time window width is significant, its explaining power is rather limited as shown by its low ω^2 value.

4.2. Cost allocation results

In order to ensure sustainability of the joint route planning project, incurred costs need to be divided in a fair way among the participants. For this reason, the collaborative costs are now allocated to the carriers applying the Shapley value, the ACAM and the EPM.

To identify whether the cost allocations defined for the studied experiments guarantee cooperation **stability**, compliance of the Shapley and ACAM solutions with individual, subgroup and group rationality needs to be verified. A cost allocation satisfying the individual rationality property guarantees that no carrier pays more than his stand-alone cost. Subgroup rationality avoids that players leave the grand coalition to form a subgroup because they could be better off excluding certain partners. Group rationality, also labelled efficiency, ensures that the total cooperative cost is shared as the grand coalition forms. Since core constraints are included in the EPM linear program, feasibility of the EPM solution indicates whether the grand coalition is stable. In case of a non-stable grand coalition, additional allocations are calculated for comparison purposes, namely the 'Stability relaxation EPM' and 'ϵ-EPM'. Regarding the calculation of these cost allocations for non-stable collaborations, two modifications are applied to the EPM in order to find a feasible solution. First, allocation values are calculated while relaxing core constraints that could not be satisfied for the respective cooperative game. Second, EPM is combined with the ϵ-core concept, as suggested by Frisk et al. (2010). Applying the ϵ-core, cooperation participants are penalised with a cost $\epsilon > 0$ for quitting the grand coalition. In this way, stable cost allocations may be calculated for cooperative games with an empty core (Shapley and Shubik 1966).

Analysing cost allocations over all instances reveals that stability of the grand coalition is guaranteed in 73% of the studied experiments. In the remaining 27% the core of the cooperative game is empty. If the grand coalition is stable, then no subgroup of partner companies has the incentive to leave the grand coalition and be better off acting alone. Results demonstrate that in the experimental design stability either holds or not, that is, that this outcome is independent of the allocation technique used. The non-stable coalition instances demonstrate the influence of cooperation structure on the longevity of joint route planning projects. The analysis reveals that increasing the number of coalition participants has a negative impact on its long-term sustainability. While two-carrier cooperations are always related with stable outcomes, only 45% of the five-carrier cooperations are associated with stability. Although increasing the coalition size from two to five partners leads to a more than tripled profit level, companies need to be aware that collaborating with a large number of partners also increases alliance complexity and may dilute the strength of mutual partner relationships. Regarding the other experimental factors, the influence on coalition stability is not so clear. When cooperations with varying levels of partner size, order size, geographical coverage or order time windows are compared the number of stable versus unstable experiments is divided almost equally.

Investigating the **allocation values** defined by means of the Shapley value, the ACAM and the EPM variations over all instances, the following observations can be made. First, when comparing over the division mechanisms using paired *t*-tests, no significant differences exist in the allocation values. The share of logistics costs allocated to the cooperation participants is thus fairly similar with respect to the used allocation technique. On average, the smallest differences are associated with coalitions of limited size between equal partners. For all two-partner coalitions, Shapley and ACAM even lead to identical cost allocations. Second, examining the cost share allocated to the different cooperation participants reveals that the division of cost savings is related to the collaborative efforts made by the participants, regardless of the used sharing mechanism. As such, organisations that contribute more to the partnership receive a higher share of the collaborative savings. For example, consider a coalition of three partners A, B and C joining their orders. When partner A has to serve significantly more shared orders than partner B and C when executing the joint route plan, partner A is rewarded for this effort with a higher share in the collaborative gains. Third, the original EPM and the EPM with relaxed stability constraints provide the most equally spread cost savings among the partners of the coalition. Although the ϵ-EPM also aims to minimise maximal pair wise differences between allocated savings, increased variation in carrier savings is caused by adding ϵ-core constraints. Finally, the Shapley value benefits small carriers in case of a coalition comprised of participants of different size. On average, collaborative savings of companies with a smaller amount of customer orders are highest when costs are divided by means of the Shapley value.

5. CONCLUSIONS AND FUTURE RESEARCH

Although transport companies become increasingly aware of the inevitable character of horizontal collaboration, surveys report failure rates up to 70 percent for starting strategic partnerships. While a growing body of collaboration research acknowledges the importance of partner characteristics, no extensive study has been performed on the numerical relationship between specific company traits and the performance of the alliances these organisations are involved in. The first contribution of this paper is thus to provide practical recommendations on which partnership structures may provide the highest collaborative benefits by means of analysing the results of an experimental design. Although selecting the right partners is crucial for the success of any horizontal alliance, it is not sufficient to guarantee long-term coalition stability. Dividing the collaborative gains in a fair manner constitutes a key issue. In this context, the second contribution of this paper is to perform a comparative analysis examining the applicability and suitability of three different cost allocation methods in varying cooperation scenarios.

Based on extensive numerical experiments analysing the influence of alliance characteristics on the amount of attainable collaborative savings using factorial ANOVA, the following managerial insights may be formulated. First, results reveal that coalitions with the largest profits are achieved when a lot of orders are combined. The larger the pool of joint orders, the larger the potential to find a more profitable route plan for the collaboration. While large transport organisations best seek for partners that are equal in size, small companies best join forces with a significant amount of equal-sized organisations and/or attract a large partner in order to enjoy savings levels associated with large order pools. Second, considering the positive influence of the number of partners on collaborative performance, the importance of the total number of orders is confirmed. However, companies need to be aware that coalition size cannot be enlarged infinitely. Collaborating with a large number of partners also increases alliance complexity and may dilute the strength of mutual partner relationships. Third, broad geographic coverage and/or overlapping customer markets seem to constitute an important aspect of coalition sustainability. The larger the service region of the coalition, the more possibilities for efficient order sharing there are. Moreover, when the supply areas of the companies overlap each other the average transport distances decrease. Finally, transport organisations involved in joint route planning best seek for partners that serve requests differing in size. In this way, the coalition can take full advantage of unused vehicle capacity.

When participants have to decide on the mechanism of how to share collaborative savings, the following observations can be made. Regardless of the used sharing mechanism, allocation techniques account for differences in partner contributions to the collaborative goal. Participants that make notable efforts to execute the joint route plan are rewarded with a higher share of the collaborative savings. The original EPM and the EPM with relaxed stability constraints may be most useful in collaborations between carriers with similar characteristics as they provide the most equally spread cost savings. In addition, both allocation techniques may also be valuable in the early phases of a growing horizontal cooperation, in which having an initial allocation with similar benefits for all participating organisations may suit communication and negotiation purposes. Small carriers may prefer costs to be allocated by means of the Shapley value. This division mechanism favours companies with a smaller share in customer demand by allocating them a higher percentage of collaborative savings in comparison with the ACAM and the EPM. Next, results show that although increasing the coalition size from two to five partners leads to a more than tripled profit level, increasing the size of the alliance has a negative impact on its long-term sustainability. Companies need to be aware that collaborating with a large number of partners increases alliance complexity and may dilute the strength of mutual partner relationships. Finally, the most striking finding is that no significant differences were observed in the allocation values when comparing over the division mechanisms.

To conclude, the following relevant suggestions for future research can be made. First, when exploring joint route planning, the focus may be expanded from considering cost minimisation exclusively to account for customer service effects. Besides its impact on cost and efficiency levels, cooperation with fellow transport companies may also have an influence on the service that can be provided by each participating carrier. Second, considering the overview of collaboration strategies in Verdonck et al. (2013), a similar impact study of cooperation characteristics and allocation mechanisms could be done in other collaborative logistics environments. Third, another natural avenue of research is to examine the efficacy of other cost allocation techniques in a joint route planning setting. Finally, the consideration of specific factors and factor levels may influence the general validity of the findings. As such, an adapted experimental design with other experimental factors and/or factor levels could be the subject of future research work.

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APPENDIX

Appendix A

Shapley value

The Shapley value (Shapley 1953) allocates to each participant the weighted average of his contributions to all (sub)coalitions, assuming the grand coalition is formed one company at a time. The Shapley allocation to participant *i* can be mathematically expressed as:

$$y_i = \sum_{S \subset N:\, i \in S} \frac{(|S|-1)!(|N|-|S|)!}{|N|!} [c(S) - c(S \setminus \{i\})] \qquad (1)$$

With |.| denoting the number of participants in the considered (sub)coalition, $c(.)$ the cost of the respective (sub)coalition, *N* the grand coalition and *S* a cooperation of a subset of partners of the grand coalition.

Alternative Cost Avoided Method

The ACAM (Tijs and Driessen 1986) allocation to participant *i* can be mathematically expressed as:

$$y_i = m_i + \frac{c(i) - m_i}{\sum_{j=1}^{n}[c(j) - m_j]} * (c(N) - \sum_{j=1}^{n} m_j) \qquad (2)$$

With m_i, denoting the separable or marginal cost of company *i*, which may be calculated as *c(N) – c(N \ i)*, and $j \in N$ representing all other coalition partners.

Equal Profit Method

The EPM (Frisk et al. 2010) guarantees stable allocations that minimise the maximum difference between the cost savings allocated to the cooperating partners. In order to find the EPM allocations to all participants, the following linear pro- gram needs to be solved to optimality:

$$Min\ f \qquad (3)$$

Subject to

$$f \geq \frac{y_i}{c(i)} - \frac{y_j}{c(j)} \qquad \forall\, i,j \in N \qquad (4)$$

$$\sum_{j \in S} y_j \leq c(S) \qquad \forall\, S \subseteq N \qquad (5)$$

$$\sum_{j \in N} y_j = c(N) \qquad (6)$$

The first constraint set (4) measures the pair wise difference between the relative savings of the participants. The objective function (3) minimises the largest difference using variable *f*. Constraint sets (5) and (6) ensure that the allocation is stable and belongs to the core. As such, the cost allocation guarantees that no subcoalition *S* exists in which a set of partners would be better off (5) and that the total collaborative cost is shared as the grand coalition forms (6).

Appendix B

Table 4: Mean Coalition Performance for Factor Levels

Number of partners	Mean CP	Carrier size	Mean CP
2	3892.209	Small	3187.501
3	7232.228	Medium	9015.907
4	10950.386	Large	14797.365
5	13511.741	Mix	8882.020

Tale 5: Mean Coalition Performance for Factor Levels

Geographical coverage	Mean CP	Order time windows	Mean CP
Random	10725.29	Equal	8494.768
Clustered	7390.856	Mix	9621.381

Table 6: Mean Coalition Performance for Factor Levels

Order size	Mean CP
Small	8243.017
Large	6890.533
Mix	10233.673

REFERENCES

Bailey E., Unnikrishnan A., Lin D.Y., 2011. Models for minimizing backhaul costs through freight collaboration. Transportation Research Record 2224(1):51-60.

Brouthers K., Brouthers L., Wilkinson T., 1995. Strategic alliances: Choose your partners. Long Range Planning 28(3):18-25.

Cruijssen F., Bräysy O., Dullaert W., Fleuren H., Salomon M., 2007a. Joint route planning under varying market conditions. International Journal of Physical Distribution and Logistics Management 37(4):287-304.

Cruijssen F., Cools M., Dullaert W., 2007b. Horizontal cooperation in logistics: Opportunities and impediments. Transportation Research Part E: Logistics and Transportation Review 43(2):129-142.

Cruijssen F., Dullaert W., Fleuren H., 2007c. Horizontal cooperation in transport and logistics: A literature review. Transportation Journal 46(3):22-39.

Cruijssen F., Salomon M., 2004. Empirical study: Order sharing between transportation companies may result in cost reductions between 5 to 15 percent. CentER discussion paper. Available from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=607062 [Accessed 5 April 2017].

Dahl S., Derigs U., 2011. Cooperative planning in express carrier networks - An empirical study on the effectiveness of a real-time decision support system. Decision Support Systems 51(3):620-626.

Field A., 2013. Discovering statistics using IBM SPSS Statistics. London: SAGE Publications Ltd.

Frisk M., Göthe-Lundgren M., Jörnsten K., Rönnqvist M., 2010. Cost allocation in collaborative forest transportation. European Journal of Operational Research 205(2):448-458.

Griffith D.A., Hu M.Y., Chen H., 1998. Formation and performance of multi-partner joint ventures: A Sino-foreign illustration. International Marketing Review 15(3):171-187.

Guajardo M., Rönnqvist M., 2015. Operations research models for coalition structure in collaborative logistics. European Journal of Operational Research 240(1):147-159.

Guajardo M., Jörnsten K., Rönnqvist M., 2016. Constructive and blocking power in collaborative transportation. OR Spectrum 38(1):25-50.

Hernández S., Peeta S., Kalafatas G., 2011. A less-than-truckload carrier collaboration planning problem under dynamic capacities. Transportation Research Part E: Logistics and Transportation Review 47(6):933-946.

Hezarkhani B., Slikker M., Van Woensel T., 2016. A competitive solution for cooperative truckload delivery. OR Spectrum 38(1):51-80.

Juan A., Faulin J., Pérez-Bernabeu E., Jozefowiez N., 2014. Horizontal cooperation in vehicle routing problems with backhauling and environmental criteria. Procedia - Social and Behavioral Sciences 111:1133-1141.

Krajewska M., Kopfer H., Laporte G., Ropke S., Zaccour G., 2008. Horizontal cooperation among freight carriers: Request allocation and profit sharing. Journal of the Operational Research Society 59(11):1483-1491.

Li H., Lim A., 2003. A metaheuristic for the pickup and delivery problem with time windows. International Journal on Artificial Intelligence Tools 12(2):173-186.

Liu P., Wu Y., Xu N., 2010. Allocating collaborative profit in less-than-truckload carrier alliance. Journal of Service Science and Management 3(1):143-149.

Lozano S., Moreno P., Adenso-Díaz B., Algaba E., 2013. Cooperative game theory approach to allocating benefits of horizontal cooperation. European Journal of Operational Research 229(2):444-452.

Nadarajah S., Bookbinder J.H., 2013. Less-Than-Truckload carrier collaboration problem: modeling framework and solution approach. Journal of Heuristics 19(6):917-942.

Olejnik S., Algina J., 2000. Measures of effect size for comparative studies: Applications, interpretations and limitations. Contemporary Educational Psychology 25(3):241-286.

Özener O.Ö., Ergun Ö, 2008. Allocating costs in a collaborative transportation procurement network. Transportation Science 42(2):146-165.

Palhazi Cuervo D., Vanovermeire C., Sörensen K., 2016. Determining collaborative profits in coalitions formed by two partners with varying characteristics. Transportation Research Part C: Emerging Technologies 70:171-184.

Park S.H., Russo M.V., 1996. When competition eclipses cooperation: An event history analysis of joint venture failure. Management Science 42(6):875-890.

Parragh S., Doerner K., Hartl R., 2008. A survey on pickup and delivery problems, part II: Transportation between pickup and delivery locations. Journal für Betriebswirtschaft 58(2):81-117.

Pérez-Bernabeu E., Juan A.A., Faulin J., Barrios B.B., 2015. Horizontal cooperation in road transportation: a case illustrating savings in distances and greenhouse gas emissions. International Transactions in Operational Research 22(3):585-606.

Pisinger D., Ropke S., 2007. A general heuristic for vehicle routing problems. Computers & Operations Research 34(8):2403-2435.

Ropke S., Cordeau J.F., 2009. Branch-and-cut-and price for the pickup and delivery problem with time windows. Transportation Science 43(3):267-286.

Schmeidler D., 1969. Nucleolus of a characteristic function game. Siam Journal on Applied Mathematics 17(6):1163-1170.

Schmoltzi C., Wallenburg C.M., 2011. Horizontal cooperations between logistics service providers: Motives, structure, performance. International Journal of Physical Distribution and Logistics Management 41(6):552-575.
Schmoltzi C., Wallenburg C.M., 2012. Operational governance in horizontal cooperations of logistics service providers: Performance effects and the moderating role of cooperation complexity. Journal of Supply Chain Management 48(2):53-74.
Shapley L.S., 1953. Contributions to the Theory of Games. Princeton: Princeton University Press.
Shapley L.S, Shubik M., 1966. Quasi-cores in a monetary economy with nonconvex preferences. Econometrica 34(4):805-827.
Tijs S.H., Driessen T.S.H., 1986. Game theory and cost allocation problems. Management Science 32(8):1015-1028.
Van Breedam A., Krols K., Verstrepen S., 2005. Logistiek samenwerken praktisch bekeken. Flanders Institute for Logistics (VIL). Available from: anet.uantwerpen.be/link/irua/57584 [Accessed 5 April 2017].
Vanovermeire C., Palhazi Cuervo D., Sörensen K., 2013. Estimating collaborative profits under varying partner characteristics and strategies. Antwerp University. Available from: http://antor.uantwerpen.be/members/christine-vanovermeire/ [Accessed 5 April 2017].
Verdonck L., Beullens P., Caris A., Ramaekers K., Janssens G.K., 2016. Analysis of collaborative savings and cost allocation techniques for the cooperative carrier facility location problem. Journal of the Operational Research Society 67(6):853-871.
Verdonck L., Caris A., Ramaekers K., Janssens G.K., 2013. Collaborative logistics from the perspective of road transportation companies. Transport Reviews 33(6):700-719.
Verstrepen S., Cools M., Cruijssen F., Dullaert W., 2009. A dynamic framework for managing horizontal cooperation in logistics. International Journal of Logistics Systems and Management 5(3-4):228-248.

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