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Assessing the Benefits of Horizontal Cooperation using a Location-Inventory Model

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Abstract

Horizontal cooperation consists in the collaboration of companies that work at the same level of the supply chain. The literature discusses several real-life cases and experimental studies of horizontal cooperation, showing that these partnerships generate savings. In this paper, to evaluate these savings, we present a location-inventory model, formulated as a conic quadratic mixed integer program, which minimizes facility opening, transportation, cycle inventory, ordering and safety stock costs. This model enables us to assess the synergy value and the evolution of the cost components, comparing the costs of stand-alone companies and horizontal partnerships. In order to better understand the impact of markets and partners characteristics on the synergy value, we conduct a large set of numerical experiments, varying several key parameters (vehicles' capacity, facility opening cost, inventory holding cost, order cost, demand variability and distances), aiming to offer valuable managerial insights for companies wishing to collaborate. We find that indeed horizontal cooperation can lead to significant savings, with an average coalition gain of 22.5%. Moreover, collaboration is particularly profitable for companies with high facility opening costs and low order costs, carrying small (compared to the vehicle capacity) and inexpensive (low unit holding cost) products in a market with a low demand variability.

Keywords: Horizontal Cooperation; Coalition Gain; Synergy Value; Supply Chain Network Design; Location-Inventory Model.

1. Introduction

Nowadays, companies have to find the right balance between a cost-effective supply chain and a competitive service to their customers. Delivery frequencies are increased to reduce inventory costs and improve customer service, but lead to incomplete loading of vehicles, while the oil price and road taxes are persistently increasing (Lozano et al., 2013;

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Pomponi et al., 2015). In order to improve cost-effectiveness as well as customer service, some companies turn towards cooperation (Juan et al., 2014). In that respect, two major approaches can be identified. First, vertical cooperation consists in the collaboration of companies that work at different levels of the supply chain (e.g. a supplier and a retailer). Second, horizontal cooperation, which is the focus of this paper, is the "*active cooperation between two or more firms that operate on the same level of the supply chain and perform a comparable logistics function on the landside*"(Cruijssen, 2006, p. 12).

Horizontal cooperation brings several benefits regarding cost efficiency, customer service and air pollution, as it allows companies to share resources (vehicles, buildings, knowledge). Customers are delivered by closer warehouses, reducing the distances and thus positively impacting the transportation cost. Vehicles carry products from different companies, improving the loading rates and reducing the total number of vehicles needed. Furthermore, the total number of vehicles delivering a retailer over a given period is reduced, but a specific product is delivered more often. This improves the customer service, and also reduces the inventory cost. Indeed, cycle inventory decreases because shipment quantities are reduced, while safety stocks decrease due to shortened lead times (Cruijssen et al., 2007b). Finally, the reduction of the traveled distances and the more efficient loading of vehicles impact positively the ecological footprint of companies, reducing the CO_2 emissions generated (Ballot and Fontane, 2010).

Horizontal cooperation brings many advantages but also bears some risks and challenges. The failure rate for horizontal cooperation projects is rather high, ranging between 50 and 70% (Schmoltzi and Wallenburg, 2011). Therefore, it is important to assess when the expected savings justify the risks, and to find the best ways to create a successful partnership. Frameworks for a successful transition to cooperation have been proposed with this goal in mind (Das and Teng, 1998; Naesens et al., 2007; Audy et al., 2011). One of the challenges for the partners is to create an atmosphere of trust while being competitors (Bahrami, 2002; Cruijssen et al., 2007b). The success of collaboration depends on the degree of information sharing (Berger and Bierwirth, 2010). Moreover, a sustainable relationship requires a fair allocation of the benefits between partners. There are two main ways to tackle this issue, both based on game theory. On the one hand, some allocation schemes are designed to ensure a fair distribution of the savings, after finding the best cooperative distribution network (Frisk et al., 2010; Dai and Chen, 2012; Cuervo et al., 2016; Defryn et al., 2016). On the other hand, some models directly integrate the cost allocation method in the operational planning problem to ensure the complete satisfaction of all partners (Vanovermeire and Sörensen, 2014).

In this paper, our goal is to assess the benefits of horizontal cooperation, and how they depend on the companies and markets characteristics. For this, we propose a location-inventory model, and we compare the costs of companies when they use independent or joint supply networks. Our model has the form of a conic quadratic mixed integer program, and determines the number and the locations of the distribution centers, the allocation of flows, as well as the inventory decisions regarding cycle inventory and safety stocks. It includes the main logistical costs: transportation, facility opening, ordering, cycle inventory and safety stock costs. The transportation cost is proportional to the number of vehicles required and not to the quantity of products carried, so as to account for the improved loading of vehicles when companies collaborate. We run a large number of experiments (29,100) to determine the impact and the importance of various market and partner characteristics on the coalition gain, e.g. the vehicles' capacity, the facility opening cost, the inventory holding cost, the ordering cost, or the demand variability. Our final goal is to present valuable managerial insights to help companies assessing the potential benefits they can get when cooperating, as a function of their characteristics. This then leads to insights on what are the favorable parameters that could motivate companies to collaborate, or the characteristics they should look for when selecting their partners.

The remainder of the paper is structured as follows. In the next section, we present the existing literature on horizontal cooperation and on the assessment of the synergy value. Then, in Section 3, we detail our problem setting and our location-inventory model. In Section 4, we present the results of our computational experiments and we highlight the impact of some markets and partners characteristics on the coalition gain, analyzing each cost contribution in details. In Section 5, we propose additional analyses with more partners, a limitation in the opening of new distribution centers (DCs) and changes in the geographical repartition of the demands. Finally, we end this paper in Section 6 with a conclusion and propositions for future research.

2. Literature review

The literature on horizontal cooperation in freight transportation is often reported as scarce but clearly acknowledges the benefits of horizontal cooperation (Cruijssen et al., 2007b; Leitner et al., 2011; Adenso-Díaz et al., 2014; Pan et al., 2014; Çömez-Dolgan and Tanyeri, 2015). Notably few real-life cases of horizontal collaborations have been reported. Bahrami (2002) presents the case study of two German consumer goods manufacturers, Henkel Cosmetics and Schwarzkopf which merged their distribution activities. The utilization of the same service provider, joint trucks for deliveries and a unique central warehouse led to a coalition gain of 9.8%. Hageback and Segerstedt (2004) study the benefits of co-distribution (i.e. when suppliers transport their goods in common vehicles) in a rural area through the case of twenty companies located in northern Sweden. The transportation cost reduction was estimated to be around 30%. Frisk et al. (2010) analyzed the horizontal co-operation of eight forest companies from southern Sweden. They showed savings from the collaborative planning ranging between 5 to 15%.

To reach more general results, researchers have proposed experimental studies, which analyze a large number of built-up cases, solved using mathematical models. Most of these studies focus on a routing context. Cruijssen and Salomon (2004) evaluate the profitability of order sharing between multiple carriers when planning delivery routes. They compare the results obtained when companies solve their own vehicle routing problem and when they cooperate and jointly solve the problem. The vehicle routing problem is solved heuristically and cost savings are estimated between 5% and 15% on a set of experiments. Pursuing the same research idea, Ergun et al. (2007) develop and implement an efficient heuristic algorithm minimizing the transportation cost for a coalition of freight forwarders. The main goal is to identify common tours to cover all demands and minimize asset repositioning costs. The algorithm is tested on data obtained from a strategic sourcing consortium for a 14 billion dollar sized US industry.

Cruijssen et al. (2007a) argue that the variability of coalition gains constitute a major obstacle for potential partners, as companies want to be able to estimate potential savings before they engage in a horizontal partnership. To understand the causes of this variability, they solve a vehicle-routing problem with time windows with a common distribution center for all the partners. They estimate savings of 30% in distance traveled for a case study with three Dutch food distributors. The results show that the collaboration is more suitable when partners are of small or medium size with small order sizes compared to the trucks' capacity, and when time windows are narrow. Krajewska et al. (2008) analyze the profit resulting from horizontal cooperation between two freight carriers using a pickup and delivery problem with time windows for each carriers. The problem is solved with a local search heuristic. The number of required vehicles is reduced by 10% and the transportation cost by 12.46%. Cuervo et al. (2016) analyze a periodic vehicle routing problem to assess the gains achieved by coalitions of two partners with various characteristics, and identify the most promising ones. The study shows that the complementarity in the order size of partners, for the filling of trucks, contributes to a fruitful coalition.

The references mentioned here before suppose that the cooperating companies use routes, passing through multiple customers, to deliver their products. In our paper, on the contrary, we suppose that companies use a supply network where a vehicle visits one customer per delivery. To the best of our knowledge, Verdonck et al. (2016) are the only authors to study this configuration, as they develop a cooperative facility location model. The sharing of DCs allows an average savings level of 9.1% of the total cost which is composed of the fixed cost of keeping DCs open and transportation costs between depots, DCs and customer zones. Freight transport is modeled in terms of product flows and multi-sourcing is allowed. However, Verdonck et al. (2016) mainly aim to test three different cost allocation techniques from the literature, and do not include inventory and shipment size decisions. In our paper, we use a location-inventory model with shipment size decisions in order to assess the synergy value through a large set of numerical experiments varying several key parameters (vehicles' capacity, facility opening cost, inventory holding cost, ordering cost, demand variability and distances), and to determine the factors of a promising collaboration. The transportation cost is proportional to the number of vehicles required to better represent the possible economies of scale related to a better vehicle loading rate. To the best of our knowledge, inventory costs and shipment size decisions have never been taken into account in the current horizontal cooperation literature.

3. Location-Inventory Model

In this section, we present our conic quadratic mixed integer program, similar to those proposed in Atamtürk et al. (2012) and Schuster Puga and Tancrez (2017). The advantage of this formulation is that it can be solved using standard optimization softwares. Compared to Atamtürk et al. (2012), our model adds shipment size decisions, transportation cost per vehicle instead of per items, as well as cycle and safety stocks at retailers. The model by Schuster Puga and Tancrez (2017) is expanded to more than one product/company, i.e. to the multi-product case. In our model, we use an integrated approach with a total cost focus in order to concentrate on the assessment of the horizontal cooperation benefits. We suppose non-negative individuals earnings, a Nash equilibrium motivating companies to stay in the partnership and a fair gains allocation (as by Andelman et al. (2009); Dai and Chen (2012); Vanovermeire and Sörensen (2014); Defryn et al. (2017)). In the following, we give the notations used in our model, detail the costs composing its objective function and finally present the complete conic quadratic mixed integer program.

3.1. Notations

In this section, we present the indexes, the parameters and the variables used in our location-inventory model.

Indexes:
$d = \{1, ..., n_d\}$ for DC potential locations;
$r = \{1, ..., n_r\}$ for retailers;
$i = \{1, ..., n_i\}$ for the companies and their products.

Parameters:
O_{dr}: transportation cost for one vehicle from DC d to retailer r, in €/vehicle;
H_r^i: unit inventory holding cost at retailer r for product i, in €/(item·period);
H_d^i: unit inventory holding cost at DC d for product i, in €/(item·period);
C_{dr}: vehicle capacity from DC d to retailer r, in items/vehicle;
F_d: fixed cost for opening DC d, in €/period;
K_d^i: fixed cost for placing an order to the plant producing product i at DC d, in €/order;
α^i: service level at retailers for product i;
z_α^i: standard normal deviation associated with service level α^i;
LT_{dr}: lead time between DC d and retailer r, in periods;
LT_d^i: lead time between the plant producing product i and DC d, in periods;
λ_r^i: mean demand for product i at retailer r, in items/period;
Λ_r: mean demand for all products at retailer r, in items/period, $\Lambda_r = \sum_i \lambda_r^i$;
σ_r^i: standard deviation of the demand for product i at retailer r, in items/period.

Decisions Variables:
y_d =1 if DC d is opened, 0 otherwise;
y_{dr} =1 if DC d serves retailer r, 0 otherwise;
λ_d^i: number of products i leaving DC d, in items/period;
q_{dr}^i: shipment size for product i from DC d to retailer r, in items/vehicle;

Q_{dr}: total shipment size, for all products, from DC d to retailer r, in items/vehicle, $Q_{dr} = \sum_i q^i_{dr}$;
q^i_d: order size for product i to the plant at DC d, in items.

3.2. Cost function

Our location-inventory model aims at minimizing the total cost composed of fixed opening, transportation, ordering, cycle inventory and safety stock costs. The **fixed facility opening cost** of a distribution center is simply computed as the opening cost, F_d, times the binary variable, y_d, determining if DC d is opened: $\sum_d F_d \, y_d$.

The **transportation cost** is proportional to the cost per vehicle, O_{dr}. This is more realistic than supposing a transportation cost per product, as commonly done in the literature. It is also important for our purpose as an important benefit of cooperation is to improve the loading rate of vehicles and gain from economies of scale by sharing the fixed cost of a vehicle. The cost per vehicle, O_{dr}, is multiplied by the number of vehicles shipped per period, which is equal to the total quantity of products to deliver to a retailer, Λ_r, divided by the quantity carried per vehicle, Q_{dr}. This leads to the following equation for the total transportation cost: $\sum_{d,r} O_{dr} \, (\Lambda_r / Q_{dr}) \, y_{dr}$. Note that we assume single sourcing for the retailers. A retailer is served by one DC per company when companies work independently and by one joint DC when they cooperate.

The **cycle inventory cost** at retailers is the unit inventory cost, H^i_r, times the average inventory level, i.e. half the shipment size q^i_{dr}, leading to $\sum_{d,r,i} H^i_r \, (q^i_{dr}/2) \, y_{dr}$. Even if the products of each company are delivered and stored together, each product has its own cycle inventory and safety stock. Each company's product is distinct and non-substitute. As the products are shipped in the same vehicle when a common supply chain network is used for several products, the frequency of this vehicle for each product i, λ^i_r / q^i_{dr}, has to be the same. Moreover, it equals the frequency of the vehicle, $\lambda^i_r / q^i_{dr} = \Lambda_r / Q_{dr}$. The **transportation and cycle inventory costs** are thus given by the following equation, which depends on Q_{dr} only and not on q^i_{dr}.

$$\sum_{d,r} O_{dr} \, \frac{\Lambda_r}{Q_{dr}} \, y_{dr} + \sum_{d,r,i} H^i_r \, \frac{Q_{dr}}{2} \, \frac{\lambda^i_r}{\Lambda_r} \, y_{dr} \tag{1}$$

The shipment size Q_{dr} only impacts these two costs. Deriving Equation (1), equaling it to zero, and accounting for the vehicle capacity, we find the following closed-form formula for Q_{dr}.

$$Q_{dr} = min \left(C_{dr}, \sqrt{\frac{2 \, O_{dr} \, \Lambda_r}{\sum_i H^i_r \, \frac{\lambda^i_r}{\Lambda_r}}} \right) \qquad \forall d, r \tag{2}$$

From this equation, we see that Q_{dr} is only proportional to parameters. It can thus be computed a priori, and is not treated as a variable when solving our model (see Tancrez et al. (2012) for the single product case).

The **cycle inventory and order cost at DCs** are computed supposing an EOQ structure, where the order size is $q_d^i = \sqrt{2\, K_d^i\, \lambda_d^i / H_d^i}$. The single sourcing assumption allows to replace the variable λ_d^i by $\sum_r \lambda_r^i\, y_{dr}$. The cycle inventory and order cost at DCs can thus be formulated as follows:

$$\sum_{d,r,i} \sqrt{2\, K_d^i\, H_d^i\, \lambda_r^i\, y_{dr}} \tag{3}$$

Finally, we include safety stocks to account for the demand uncertainty and the risk pooling at DCs. They are sized to satisfy the uncertain demand during the lead time with a probability equal to the service level, α^i. Demands are supposed to be normally distributed with mean λ_r^i and variance $(\sigma_r^i)^2$. The **safety stock costs at retailers and at DCs** are computed as the unit holding cost times the average safety stock. The latter is computed as the standard normal deviation, z_α^i, multiplied by the standard deviation of the demand during the lead time. The safety stock costs at retailers and at DCs are thus as follows.

$$\sum_{d,r,i} H_r^i\, z_\alpha^i\, \sigma_r^i\, \sqrt{LT_{dr}}\, y_{dr} + \sum_{d,i} H_d^i\, z_\alpha^i \sqrt{\sum_r (\sigma_r^i)^2 y_{dr}}\, \sqrt{LT_d^i} \tag{4}$$

3.3. Mathematical Formulation

Now that the cost components have been described, in this subsection, we give our location-inventory model in the form of a conic quadratic mixed integer program. The main idea is to move the nonlinearities in equations (3) and (4) from the objective to the constraints introducing auxiliary variables v_{1d}^i and v_{2d}^i, and using the fact that $y_{dr} = y_{dr}^2$ and $y_d = y_d^2$ (Atamtürk et al., 2012).

$$Min \qquad \sum_d F_d\, y_d + \sum_{d,r} O_{dr} \frac{\Lambda_r}{Q_{dr}}\, y_{dr} + \sum_{d,r,i} H_r^i \frac{Q_{dr}}{2} \frac{\lambda_r^i}{\Lambda_r}\, y_{dr} \tag{5}$$

$$+ \sum_{d,i} \sqrt{2\, K_d^i\, H_d^i}\, v_{1d}^i + \sum_{d,r,i} H_r^i\, z_\alpha^i\, \sigma_r^i\, \sqrt{LT_{dr}}\, y_{dr} + \sum_{d,i} H_d^i\, z_\alpha^i\, \sqrt{LT_d^i}\, v_{2d}^i \tag{6}$$

s.t.

$$\sum_r \lambda_r^i\, (y_{dr})^2 \leq (v_{1d}^i)^2 \qquad \forall d, i \tag{7}$$

$$\sum_r (\sigma_r^i)^2 (y_{dr})^2 \leq (v_{2d}^i)^2 \qquad \forall d, i \tag{8}$$

$$\sum_d y_{dr} = 1 \qquad \forall r \tag{9}$$

$$y_{dr} \leq y_d \qquad \forall d, r \tag{10}$$

$$v_{1d}^i, v_{2d}^i \geq 0 \qquad \forall d, i \tag{11}$$

$$y_{dr}, y_d \in \{0, 1\} \qquad \forall d, r \tag{12}$$

The terms of the objective function represent the costs of fixed facility opening, transportation, cycle inventory at retailers, cycle inventory and ordering at DCs, safety stocks at DCs and at retailers. Constraints (7) and (8) define the auxiliary variables v_{1d} and v_{2d}. Constraints (9) ensure that each retailer is assigned to exactly one DC. Constraints (10) insure that a retailer can be served by a DC only if the latter is opened. Constraints (11) impose non-negativity for the auxiliary variables, while constraints (12) enforce the binary nature of decision variables y_{dr} and y_d.

4. Numerical Experiments

In this section, we use our location-inventory model to assess the benefits of horizontal cooperation, through a large set of experiments. We first present our parameter setting and then present our experimental results in details. We analyze the impact of each parameter on the synergy value, discuss the proportion of the cost components and highlight the service improvement.

4.1. Experimental Setting

In our experiments, we first look at two companies that are similar in terms of size and market characteristics (see Section 5 for cases with more companies notably). The requirement to have companies of an equivalent size for successful cooperation is highlighted by many authors such as Verstrepen et al. (2009); Audy et al. (2011) or Verdonck et al. (2016). This characteristic increases the trust between partners, avoids a difference in negotiation power and facilitates the fair cost allocation.

Our parameter setting is presented in Table 1. We consider a single period planning horizon. Sixty retailers are randomly located in a square with a width of 500 or 1000 kilometers. The retailers locations are also the possible locations for the distribution centers. This assumption is common and well accepted in the facility location literature (e.g. Nozick and Turnquist (2001); Shen et al. (2003); Atamtürk et al. (2012)). The expected demand for each product and for each retailer is randomly generated within the interval [50,250], which allows to have retailers of different sizes. The variability of the demand is introduced using the coefficient of variation CV (0.4, 0.7 or 1). The service level is fixed at 97.5% which leads to a standard normal deviation of 1.96. A transportation cost of 1€/km is considered

Parameter Setting	
$Width$	(500, 1000*) km
$Cap\%$	(10*, 20, 30, 40*, 50, 60, 70*, 80, 90, 100*)
CV	(0.4*, 0.7, 1*)
F_d	(1000*, 2000*, 4000*) €/week
K_d^i	(250*, 500, 1000*) €/order
$H_d^i = H_r^i$	(0.25*, 0.50, 1*) €/item·week

Table 1: Summary of the parameters values for the numerical experiments. Parameter values marked with an asterisk constitute the subset tested in the additional experiments presented in section 5.

per vehicle. We test three values for each of the cost parameters F_d, K_d^i, H_d^i and H_r^i (see Table 1). Lead times between DCs and retailers are directly proportional to the distance, assuming an average speed of 50 km/h. The order lead time from all DCs to all plants is fixed equal to the average lead time from all potential DCs to all retailers.

The vehicles' capacity is an important parameter in our experiments, as improving the loading rate of vehicles is an important objective of horizontal cooperation. For that reason, we choose ten values for the vehicles' capacity, and rely on the optimal uncapacitated shipment sizes in order to get realistic values. We begin by running the model without vehicles' capacity for both independent companies, and we obtain the corresponding optimal uncapacitated shipment sizes. Among these shipment sizes, we only keep those where d and r are indeed connected ($y_{dr} = 1$), and reject values for which retailers are at the same location as opened DCs. Then, we rank the remaining values in ascending order. Finally, among these ordered values, the vehicles' capacity is selected according to what we call the capacity percentage (see Table 1, noted $Cap\%$). These percentages can be translated as the theoretical percentages of retailers which are not constrained by the vehicle capacity in the stand-alone case. For example, when $Cap\% = 10$, the capacity is highly restrictive: 10% of the shipments are made with their optimal quantities in the stand-alone case and the other 90% are limited by the capacity. A capacity percentage of 100 implies that the vehicles' capacity is equal to the largest shipment size for all retailers when companies are independent. The capacity percentage 100 is thus not constraining in the stand-alone case, but it will likely be when companies cooperate, as the shipment is composed of products of both companies in this case. Finally, note that we restart the calculation of the capacities for each parameter combination as the latter has an impact on the optimal shipment sizes.

All the parameter values lead to create 1,620 parameter combinations $(2 \cdot 10 \cdot 3 \cdot 3 \cdot 3 \cdot 3)$. Five different maps with different retailer locations and demands are generated, resulting in 8,100 settings in our basic set of experiments (complementary experiments are discussed in section 5). Finally, to have the possibility to assess the coalition gain, we run the model when companies are independent (2 cases) and when they cooperate. A total of 24,300 experiments is thus run for our analysis. This large number of experiments allows us to deeply study the impact of various company and market characteristics, and eventually derive reliable managerial insights on the value of horizontal cooperation. The model is implemented in

CPLEX and run on a 3.2 GHz computer with 8 GB of RAM. The computational time per instance is limited to 30 minutes. The average optimality gaps we got for instances in the stand-alone cases and in the cooperation case equal 0.14% and 0.35%, respectively.

4.2. Synergy Value Analysis

In order to assess the benefits of horizontal cooperation, the synergy value, also called coalition gain, is often used (Cruijssen et al., 2007b; Cuervo et al., 2016). The coalition profit corresponds to the difference between the sum of the stand-alone costs and the cooperation cost. The synergy value is a relative measure, as it is computed as the coalition profit divided by the sum of the stand-alone costs. Thus, this percentage represents the proportional reduction of costs that two companies can obtain if they decide to merge their supply networks. The use of the synergy value to compare cases is efficient because it is independent of the size the company and reveals the relative savings on the total cost. However, we will see that additionally analyzing the coalition profit can be useful, as a decreasing synergy value may sometimes disguise a increasing coalition profit (when the total stand-alone costs increase faster than the coalition profit).

In Table 2, we present the average synergy values obtained for our 8,100 configurations, depending on four parameters (facility opening cost, vehicles' capacity, demand variability and unit holding cost). Overall, we observe an average synergy value of 22.4%, showing the significant benefits that horizontal cooperation can bring. However, we also see that the synergy value varies significantly depending on the parameter combination, ranging between 15% and 30%. Moreover, when companies cooperate, they benefit from sharing facilities and the total number of DCs is reduced, from around 3 to 2 DCs. Horizontal cooperation also allows to improve the average vehicle loading rate by 10%, from 80% to 90%. Overall, the large range of synergy values highlight the need to better understand the impact of each parameter to determine when it is more beneficial to collaborate and why. We already observe some sources of benefits through the better loading rate and the smaller number of DCs used when companies collaborate. In the following, we discuss the evolution of the total supply chain cost and then the impact of the most important parameters.

Total Cost Composition

Figure 1 shows the different cost components and how they change when companies cooperate. We see that the benefit of cooperating mainly comes from the reduction of the cycle inventory cost at retailers (reduction by 42.5%), of the facility opening cost (37%) and of the transportation cost (19%). These reductions are explained, respectively, by an increased shipment frequency as the vehicles carry both products, by a reduction of the total number of DCs as they are jointly used, and by a better vehicle loading rate and improved DC positioning. On the contrary, the ordering cost and the cycle inventory cost at DCs increase by around 12% when companies cooperate. This is due to the higher number of DCs carrying a given product in the cooperation case, as each facility stores inventory for each product in this case, reducing the pooling effect. Finally, we note that the safety stock

F_d	Cap%	CV = 0,4			CV = 1			Average
		H = 0.25	H = 0.5	H = 1	H = 0.25	H = 0.5	H = 1	(all cases)
1000	10%	19.78% 5.10|3.23 0.94|0.97	14.44% 6.23|4.27 0.95|0.98	15.74% 7.37|4.87 0.96|0.99	19.02% 5.17|3.37 0.94|0.97	16.75% 6.50|4.10 0.95|0.98	14.59% 7.77|5.03 0.96|0.99	16.91% 6.36|4.12 0.95|0.98
	40%	21.94% 2.83|2.47 0.86|0.92	20.85% 4.50|3.00 0.85|0.93	19.01% 5.83|3.60 0.86|0.94	21.22% 3.00|2.50 0.86|0.92	19.78% 4.90|3.13 0.85|0.93	17.43% 6.03|3.77 0.86|0.95	20.05% 4.53|3.06 0.85|0.93
	70%	23.62% 2.50|1.83 0.76|0.87	22.59% 3.80|2.50 0.74|0.88	21.08% 5.17|3.00 0.75|0.89	22.70% 2.73|1.93 0.75|0.87	21.46% 4.23|2.63 0.74|0.88	19.32% 5.57|3.10 0.74|0.89	21.79% 3.99|2.49 0.75|0.88
	100%	25.55% 2.43|1.33 0.54|0.72	24.43% 3.50|1.93 0.51|0.71	23.02% 4.80|2.27 0.50|0.70	24.34% 2.53|1.57 0.53|0.70	23.00% 3.90|2.17 0.50|0.68	20.95% 5.23|2.70 0.50|0.68	23.53% 3.72|1.99 0.51|0.70
2000	10%	19.46% 2.20|2.30 0.96|0.97	20.25% 3.33|2.80 0.95|0.98	19.32% 5.17|3.33 0.95|0.98	19.09% 2.30|2.30 0.96|0.97	19.60% 3.50|2.83 0.95|0.98	17.98% 5.53|3.37 0.95|0.98	19.28% 3.67|2.83 0.95|0.98
	40%	22.49% 2.00|1.30 0.88|0.94	21.76% 2.27|1.80 0.87|0.94	21.42% 2.97|2.50 0.87|0.93	21.69% 2.00|1.33 0.88|0.94	20.76% 2.40|1.97 0.87|0.93	20.23% 3.40|2.67 0.85|0.92	21.39% 2.50|1.93 0.87|0.93
	70%	25.28% 2.00|1.07 0.78|0.92	23.98% 2.10|1.27 0.78|0.90	23.02% 2.70|1.90 0.76|0.88	24.25% 2.00|1.10 0.78|0.91	22.64% 2.20|1.40 0.77|0.89	21.40% 2.87|2.13 0.76|0.87	23.42% 2.31|1.49 0.77|0.89
	100%	27.27% 2.00|1.03 0.58|0.78	26.03% 2.07|1.13 0.55|0.74	24.73% 2.50|1.47 0.54|0.71	26.22% 2.00|1.03 0.57|0.77	24.50% 2.13|1.20 0.54|0.73	22.82% 2.70|1.73 0.53|0.69	25.25% 2.23|1.27 0.55|0.74
4000	10%	20.45% 2.00|1.03 0.97|0.99	18.82% 2.00|1.57 0.97|0.98	19.22% 2.23|2.30 0.97|0.98	19.79% 2.00|1.07 0.97|0.98	18.14% 2.00|1.63 0.97|0.98	18.44% 2.37|2.37 0.96|0.98	19.14% 2.10|1.66 0.97|0.98
	40%	25.99% 2.00|1.00 0.88|0.96	23.59% 2.00|1.03 0.89|0.97	21.94% 2.00|1.33 0.90|0.95	25.06% 2.00|1.00 0.88|0.96	22.36% 2.00|1.07 0.89|0.97	20.49% 2.03|1.40 0.89|0.95	23.23% 2.01|1.14 0.89|0.96
	70%	28.77% 2.00|1.00 0.78|0.93	26.55% 2.00|1.00 0.78|0.93	24.58% 2.00|1.10 0.79|0.92	27.72% 2.00|1.00 0.78|0.93	25.10% 2.00|1.00 0.78|0.93	22.75% 2.00|1.13 0.79|0.91	25.90% 2.00|1.04 0.78|0.92
	100%	30.53% 2.00|1.00 0.58|0.79	28.57% 2.00|1.00 0.55|0.77	26.65% 2.00|1.03 0.56|0.76	29.48% 2.00|1.00 0.56|0.78	27.00% 2.00|1.00 0.55|0.77	24.55% 2.00|1.07 0.56|0.75	27.79% 2.00|1.01 0.56|0.77
Average (all cases)		24.41% 2.35|1.51 0.81|0.91	22.88% 2.91|1.87 0.80|0.91	21.70% 3.62|2.33 0.80|0.90	23.51% 2.41|1.55 0.80|0.91	21.82% 3.04|1.96 0.80|0.90	20.12% 3.84|2.49 0.80|0.90	**22.41%** 3.03|1.95 0.80|0.90

Table 2: Average synergy values when the fixed opening cost (F_d), the capacity percentage (Cap%), the coefficient of variation (CV) and the unit holding cost ($H_d^i = H_r^i = H$) are varied. Below each synergy value, we present the number of DCs in the stand-alone and cooperation cases and then the loading rate of vehicle in both cases. Each value gives corresponds to an average over 30 experiments (2 widths, 3 order costs and 5 maps). Note that some parameter values are not detailed, e.g. $CV = 0.7$ or various $Cap\%$, but their values are used in the averages computation (last column and line).

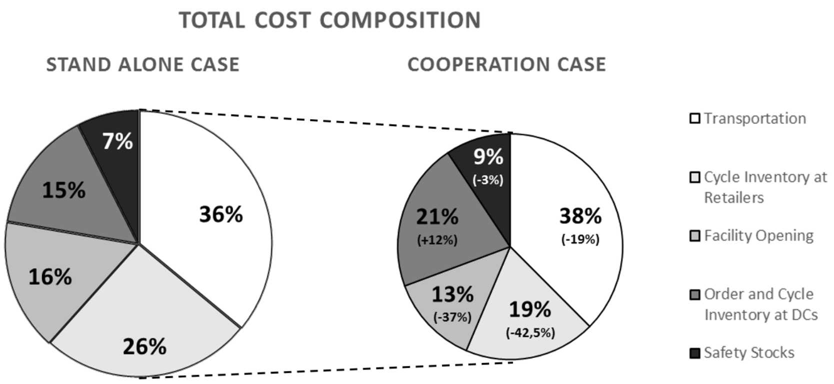

Figure 1: Proportion of each cost component in the average total cost when companies are stand alone and when they cooperate. The sizes of circles are proportional to the total costs (the total cost is 22.4% smaller in the cooperation case). The change in each cost (in absolute value) due to collaboration is presented in brackets.

cost share in the total cost increases, while its value is quite stable (+3%, see Figure 4). In sum, in the average synergy value of 22.4%, 11% come from the reduced cycle inventory at retailers, 6.9% from the transportation, 6% from the opening of joint facilities and 0.4% from the safety stocks at retailers. On the opposite, the cycle inventory and order costs at DCs contribute to decrease the synergy value by 1.7% and the safety stock at DCs by 0.2%.

Facility Opening Cost

When looking at the impact of the facility opening cost (F_d) on the synergy value, we first see in Table 2 that, when the cost of opening DCs increases, the coalition gain increases, as the benefit of sharing those DCs increases. Companies with expensive facilities benefit even more from horizontal cooperation. When the opening cost is high, its impact tends to become more and more important. Non-cooperating companies have a minimum of 2 DCs and cannot reduce it when the facility cost further increases, while cooperating companies can reduce the number of DC to one and share high facility costs. When the opening cost is high, cooperating companies have strong incentives to share one expensive DC.

Besides, several more specific observations are worth nothing. With very limiting capacities (10%), the evolution of the synergy value with the opening cost becomes less regular. In this case, the transportation cost makes a large share of the total costs, and more DCs are opened to shorten distances. Moreover, in rare cases (about 4%), the number of DCs in the cooperation case exceeds the number of DCs with two independent companies, and the opening cost thus increases when cooperating. This can be explained as follows. When the facility opening cost increases, at some point, the potential benefits in terms of transportation cost do not warrant the opening of more DCs. This balance point is lower for independent companies than for collaborating companies, as the latter share the opening cost. There is thus a range of opening costs in-between where collaborating companies still benefit from opening more DCs while independent companies do not, and where collabora-

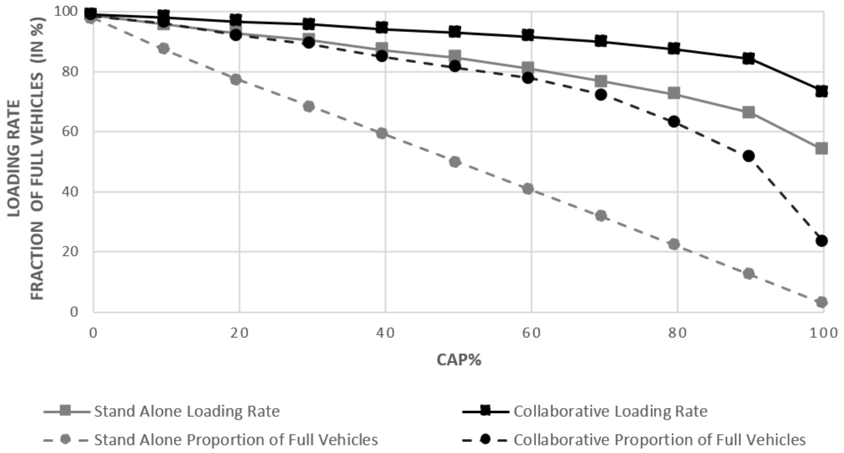

Figure 2: Evolution of the fraction of full vehicles and average loading rate, when companies are alone and when they collaborate, as a function of the capacity percentage of vehicles.

tion is thus particularly beneficial. In such cases in particular, a finer quantitative analysis is needed and our model can be applied to assess the coalition gain.

Vehicle Capacity

The vehicle capacity is important to analyze as the ability to load vehicles more efficiently is an important advantage of cooperation (McKinnon, 2000; Cruijssen et al., 2007b). We can see in Table 2 that, unsurprisingly, the synergy value increases with the capacity, and it seems to be the most impactful parameter. To better understand the effect of the vehicle capacity, Figure 2 depicts how the fraction of full trucks and the vehicles loading rate evolves with it. The fraction of full trucks for stand-alone companies follows directly from the computation of the capacities (see Section 4.1). When companies collaborate, they are able to get more full trucks, and the difference is higher for mid-size to large vehicles ($Cap\%$ between 50% and 90%). The loading rate of the vehicles has a more direct impact on the coalition gain. As seen in Figure 2, it decreases with the vehicle capacity. However, it does so less steeply when companies collaborate as both of their products fill the vehicles. At the maximum capacity, the difference between the loading rates in the stand-alone and collaboration cases is around 20%. It represents a significant reduction of the number of vehicles necessary to ship the products, around 25%. The improvement of the loading rate when collaborating is thus an important source of cost reduction. Companies with large, not fully loaded, vehicles (or, equivalently, small products) will thus benefit even more from collaborating.

In Figure 3, we see that when the capacity increases, so does the coalition profit. A large share of the coalition profit comes from the transportation and the inventory costs at retailers (as already seen in Figure 1). This again shows the importance of the vehicle loading in the benefits of cooperation. Interestingly, the benefits coming from transportation first decrease and then increase, while the cycle inventory cost at retailers evolves in the opposite way. This can be related to Figure 2 and the fraction of full vehicles. When the vehicle capacity

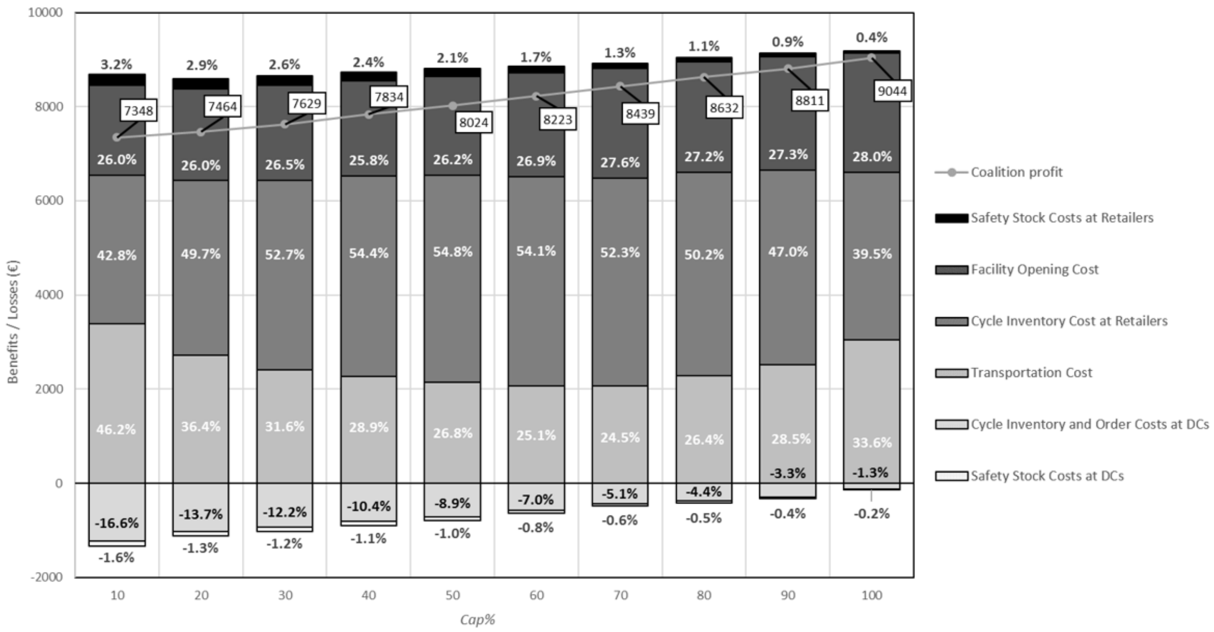

Figure 3: Evolution of the average benefits or losses of the cooperation regarding transportation cost, cycle inventory cost at retailers, facility opening cost, cycle inventory and ordering costs at DCs, and safety stock costs at retailers and at DCs, as well as the coalition profit, as a function of the capacity percentage of vehicles ($Cap\%$).

is increasing, stand-alone companies get to their optimal shipment size before cooperative companies do. With larger capacities (around $Cap\% = 60\%$), cooperative companies still benefit from relaxing capacity constraint while stand-alone companies have mostly reached their optimal shipment size. Furthermore, Figure 3 shows that the cycle inventory and order costs at DCs as well as the safety stock cost at DCs impact negatively the coalition profit. When the vehicle capacity increases, the number of DCs decreases and this negative impact thus dwindles. Overall, the coalition profit increases with the capacity of vehicles while the total cost decreases which leads to a positive synergy value.

Demand Variability

Regarding the demand uncertainty, Table 2 shows that, in general, a larger variability leads to a smaller synergy value. In Figure 4, we examine in more details the effect of the demand variability on the safety stock cost, which is the costs that are mainly impacted by it. We first see that the safety stock cost at retailers is lower when companies cooperate as they deliver from more DCs, reducing the lead time to retailers. On the contrary, the safety stocks at DCs increases as the risk pooling effect is reduced. However, the safety stock cost at retailers clearly outweighs those at DCs. The total safety stock cost is thus reduced when companies collaborate, but to a limited extent as the effect goes in opposite directions at retailers and at DCs. The synergy value decreases with the demand variability because the safety stock costs increase faster than the coalition profit. In short, a company

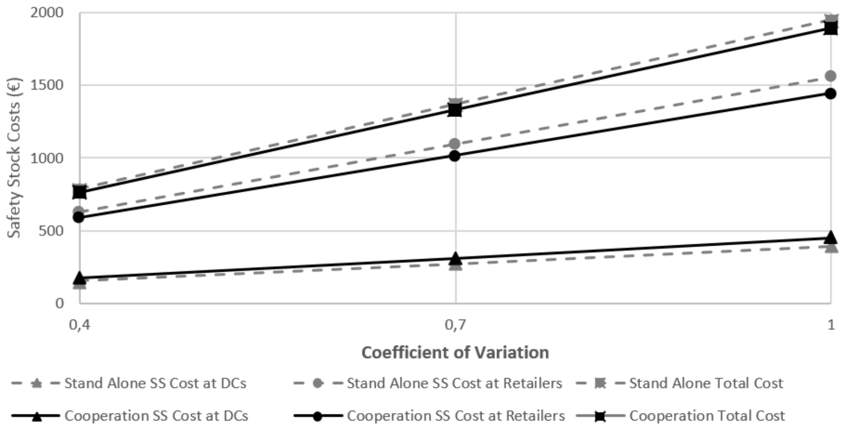

Figure 4: Evolution of the average safety stock cost at DCs, at retailers and in total, in the stand-alone and the cooperation cases, as a function of the coefficient of variation.

will benefit proportionally more from collaboration when the demand variability is low, even if the absolute profit increases slightly with this variability.

Inventory Holding Cost

When looking at the impact of the unit holding cost on the synergy value, we first see in Table 2 that cooperation is more beneficial when the holding cost is low. From the computation of the shipment size (see Equation (2)) and the way we compute the capacity percentages (see Section 4.1), it can be seen that increasing the holding cost leads to decrease the computed vehicle capacity. This implies that a costly product, thus with a high holding cost, has also a larger size in our experimental setting. As a consequence, when the holding cost increases, the number of trucks needed to deliverer the demands increases as well. We see in Table 2 that the number of DCs increases to limit the rise of the transportation cost. This leads to a total cost raising faster than the total profit. For example, when the unit holding cost increases from H = 0.25 to H = 1, the total cost increases by 89% while the coalition profit raises by 64%. Note that the shipment size and the capacity evolve proportionally, leading to stable loading rates (see Table 2). In brief, companies with a low inventory holding cost (and smaller products) will have a larger proportional coalition gain. In other terms, cooperation is proportionally less beneficial for companies with large costly products than for small cheaper products.

Order Cost

Besides the values detailed in Table 2, our experiments also reveal the impact of the order cost. An increase of the order cost has a negative impact on the synergy value. Companies with a high unit order cost tend to open less DCs, to aggregate the orders and reduce their number. For the same reason, a high order cost is more detrimental to companies with many DCs since they have to order from each of them. As cooperating companies have more DCs from which they order than independent companies, the total supply chain cost is more impacted by an increase of the unit order cost in cooperation than in stand-alone cases. In summary, companies for which ordering is inexpensive have more incentives to collaborate.

Service Improvement

The potential savings in costs should not be seen as the sole benefit of horizontal cooperation (Sanchez Rodrigues et al., 2015). The horizontal cooperation is valuable for the partners but also for their customers as it allows to propose a better service in several ways. First, retailers need to carry less inventory. The analysis of all cases studied shows that the cycle inventory at retailers is reduced, on average, by about 42.5%. Moreover, retailers can keep the same service level with less safety stock (reduced on average by 6%), as the lead time between DCs and retailers is reduced by 11.2% when cooperating. Alternatively, retailers could decide to keep the same safety stock level and rather improve their service level from 97.5% to 98.2%, on average. The last benefit for retailers is related to the delivery frequency. This benefit is two-fold as, when companies cooperate, retailers are delivered more often for a specific product (vehicles carry products from both companies), while the total number of delivery is reduced (vehicles are better filled). In our experiments, independent companies both deliver every 13 days and a retailer thus gets a delivery every 6.5 days. When companies collaborate, they visit the retailers every 7.5 days (with both products in vehicles). In conclusion, the horizontal cooperation allows companies to be more competitive with reduced total costs but also with improved service to their customers.

4.3. Collaboration Setting

In this subsection, we present three sets of experiments to question some assumptions made for the main set presented in the previous section. First, we explore collaborations with more than two companies, and analyze the impact of the number of partners on the synergy value. In the second set of experiments, we do not allow the opening of new DCs when collaborating but only allow the use of existing DCs, with or without the possibility to close DCs. Finally, in the third set, we test the effect of a different geographical distribution of the retailers locations. For these additional experiments, we use the same setting (see subsection 4.1) but with a subset of the parameter values tested in the main set of experiments. These values are highlighted with an asterisk in Table 1, resulting in 96 parameter combinations ($4 \cdot 2 \cdot 3 \cdot 2 \cdot 2$). As we still use five different maps, and as we test various configurations for our three additional sets of experiments (3 and 4 partners, no DC opening, DCs closure, and different retailers locations), it leads to a total of 4,800 new experiments. For these experiments, the average synergy value is equal to 22.6% (compared to 22.4% on the main set of experiments).

Number of Partners

In this subsection, we assess the benefits of horizontal cooperation with more than two partners. The computational time is limited to 30 minutes for cooperation cases with 3 partners (leading to a 0.65% average optimality gap) and 60 minutes with 4 partners (0.94% gap). We observe in Table 3 that the average synergy value increases with the number of

	Avg	F_d 1000	2000	4000	$Cap\%$ 10	40	70	100	$H_d^i = H_r^i$ 0.25	1	$Coop.$ DCs	LR
2 Partners	22.6%	21.0%	22.7%	24.0%	19.1%	21.7%	23.9%	25.6%	23.9%	21.2%	2.40	88.0%
	+8.6%	+7.9%	+8.9%	+9.2%	+7.7%	+8.1%	+8.8%	+10.1%	+9.2%	+8.2%	+0.46	+4.9%
3 Partners	31.2%	28.9%	31.6%	33.2%	26.8%	29.8%	32.7%	35.7%	33.1%	29.4%	2.86	92.9%
	+4.8%	+4.3%	+4.9%	+5.2%	+4.4%	+4.5%	+4.7%	+5.5%	+5.1%	+4.5%	+0.31	+1.9%
4 Partners	36.0%	33.2%	36.5%	38.4%	31.2%	34.3%	37.4%	41.2%	38.2%	33.9%	3.17	94.8%

Table 3: Average synergy values of partnerships with 2, 3 and 4 partners, when the fixed opening cost (F_d), the capacity percentage (Cap%) and the holding cost ($H_d^i = H_r^i$) are varied. The last columns give the average number of DCs and loading rate (LR) in the cooperation cases. The difference between values is presented between them.

companies, from 22.6% with 2 partners to 31.2% and 36% with 3 and 4 partners respectively. The cooperation is clearly attractive to the new entrant which profits from the totality of the synergy value. In contrast, the cost reduction for existing partners adding a new partner equals the marginal gain, and it decreases with each newcomer (8.6% and 4.8% for 3 and 4 partners respectively). Companies have thus to find the trade-off between the marginal gain and the coordination costs related to the additional complexity caused by a new partner in the cooperation (Verdonck et al., 2016).

The improvement of the synergy value with more than 2 partners comes from various sources. First, the delivery frequency increases from 0.5 deliveries a week in the stand-alone case, to 0.91, 1.32 and 1.72 deliveries with 2, 3 and 4 partners respectively. That means that with 4 partners, products from a given company are delivered 3.4 times more often to a retailer, compared to the stand-alone case. Therefore, the total cycle inventory cost at retailers rises by only 5% and 2% when adding a third and a fourth partner to the cooperation. Furthermore, including more partners allows to improve the vehicles loading rate, and have a more efficient transportation. The loading rate increases from 78.1% in the stand-alone case to 94.8% with 4 partners (see Table 3). Therefore, there is more benefit from including more partners when the vehicle capacity is large and when the holding cost is low (and thus the product is small in our setting), as shown by the impact of $Cap\%$ and H in Table 3. Finally, when more partners are collaborating, they share the facility opening costs and are able to open more DCs. This leads to a reduction of the transportation (retailers are closer) and cycle inventory costs (shipment size are reduced). However, while more DCs are opened, the number of facilities per company decreases when the number of partners increases (see Table 3). The total facility opening cost is thus reduced. This leads to larger synergy values when the facility opening cost is higher, as seen in Table 3. In sum, the addition of new partners allows to reduce inventory by delivering products more frequently, to load the vehicles more efficiently, and to open more joint DCs. Increasing the size of the partnership is thus beneficial, but the marginal benefit decreases with each new partner.

		F_d			$Cap\%$				$H_d^i = H_r^i$		$Coop.$	
	Avg	1000	2000	4000	10	40	70	100	0.25	1	DCs	LR
New DCs	22.6%	21.0%	22.7%	24.0%	19.1%	21.7%	23.9%	25.6%	23.9%	21.2%	2.40	88.0%
	−0.6%	−0.4%	−0.6%	−0.6%	−1.2%	−0.6%	−0.3%	−0.1%	−0.5%	−0.5%	−0.45	+1.9%
Closing DCs	22.0%	20.6%	22.1%	23.4%	17.9%	21.1%	23.6%	25.5%	23.4%	20.6%	1.95	89.9%
	−7.6%	−6.7%	−7.0%	−9.2%	−8.1%	−7.6%	−7.5%	−7.4%	−8.5%	−6.7%	+1.75	−1.4%
Same DCs	14.4%	13.9%	15.1%	14.2%	9.8%	13.5%	16.1%	18.1%	14.9%	13.9%	3.70	88.5%

Table 4: Average synergy values depending of the option to open new DCs, when the fixed opening cost (F_d), the capacity percentage (Cap%) and the holding cost ($H_d^i = H_r^i$) are varied. In the "New DCs" case, new DCs may be opened when cooperating. In the "Closing DCs" case, DCs may be closed but not opened. In the "Same DCs" case, companies keep exactly the same facilities. The average number of DCs as well as the average loading rate (LR) in the cooperation cases are presented in the last columns. The difference between values is presented between them.

No New DC Opening

In our main set of experiments, we assumed that the supply chain design was completely revamped when companies started to collaborate, potentially including the closing of old DCs and the opening of new shared DCs. However, it could be that companies prefer to keep the same facilities locations than before the collaboration, in order to have an easier way out. Two options are then available for partners: keep exactly the same DCs, leading to a synergy value of 14.4%, or accept to close some of them, improving the synergy value to 22%. These results are detailed in Table 4.

Being forced to keep exactly the same DC is clearly not optimal. The opening and the transportation costs rise by 54% and 10% respectively in comparison with the base case where DCs are relocated. The number of DCs is higher (see Table 4) but they are not optimally located for the consortium, and thus the distances with the retailers are larger than when new joint DCs are well positioned. These larger distances are even more detrimental when the vehicle capacity is small. As shown in Table 4, when the same DCs are kept, the synergy value doubles between the cases with the most and the least restrictive capacities. However, even if less so, the cooperation without facility changes stays profitable in comparison with the stand-alone companies. This is related to the shared DCs, the reduced distances, the joint loading of vehicles, and the reductions in inventory costs.

When the partners keep exactly the same facilities, we observe that a good share of the DCs are not used because another DC is close by. The slightly shorter delivery distances do not cover the increase in the order and safety stock costs at DCs. Accordingly, we see in Table 4 that the possibility to close some DCs strongly improves the synergy value of a cooperation (from 14.4% to 22%). It reduces in particular the facility opening cost of the partnership since the number of DCs decreases by 47%. In fact, the synergy value when DCs closures are allowed (but no opening) is close to the value when DCs opening are also allowed (22.0% vs. 22.6%). It appears from our results that the option to close DCs is quite important, but the option to open DCs is much less important for the success of the collaboration. Moreover, Table 4 shows that this observation stays true independently of the

	Avg	F_d 1000	F_d 2000	F_d 4000	$Cap\%$ 10	$Cap\%$ 40	$Cap\%$ 70	$Cap\%$ 100	$H_d^i = H_r^i$ 0.25	$H_d^i = H_r^i$ 1	Coop. DCs	Coop. LR
Even Demand	22.6%	21.0%	22.7%	24.0%	19.1%	21.7%	23.9%	25.6%	23.9%	21.2%	2.40	88.0%
	−0.8%	−0.5%	−0.8%	−0.9%	−0.9%	−0.8%	−0.7%	−0.7%	−0.8%	−0.6%	+0.08	+1.0%
Uneven Demand	21.8%	20.5%	21.9%	23.1%	18.2%	20.9%	23.2%	24.9%	23.1%	20.6%	2.48	89.0%

Table 5: Average synergy values as a function of the demand geographical distribution, when the fixed opening cost (F_d), the capacity percentage (Cap%) and the holding cost ($H_d^i = H_r^i$) are varied. The average number of DCs as well as the average loading rate (LR) in the cooperation cases are also presented, in the last columns. The first line corresponds to evenly distributed demands (in [50 250]). The second line corresponds to companies with uneven and opposite demand distributions ([50;150] or [150,250] on the right or left half of the map). The difference between value is presented between them.

facility opening cost. On the opposite, Table 4 shows that the capacity of vehicles ($\%Cap$) has a stronger impact. When many small vehicles are delivering the products, it is more important to relocate the DCs optimally.

In conclusion, if companies want to reduce their long-term commitment to the cooperation by keeping their existing facilities, our results show clearly that the synergy value is significantly decreased, even if still around 15%. However, to avoid hurting the collaboration benefits much at all, companies may just accept to close (resale) some of their DCs. Then, additionally accepting to open new DCs is far less impactful.

Geographical Distribution of the Demands

In this section, we investigate the importance of the markets locations. For this, we run a new set of experiments where the retailers are not evenly distributed across the map, unlike in the main set. The total demand for all retailers is however kept the same as in the main set. For both companies, half the retailers have demands randomly chosen in [50, 150] and half in [150, 250]. However, one company has its larger retailers in the right-hand half of the map and the smaller retailers in the left-hand half, while the other company has the opposite configuration. The average optimality gaps we got for instances in the stand-alone cases and in the cooperation cases are equal to 0.19% and 0.43%, respectively.

Results in Table 5 show that the average synergy value is negatively but mildly affected (-0.8%) when the demand is not evenly distributed. Furthermore, we observe that the number of DCs increases by 3.3% when companies cooperate and decreases by 1.4% when they do not. Independent companies open DCs focusing on the area where they have more demand and accept to increase the distance with smaller retailers. On the opposite, when companies cooperate, DCs will serve disparate demands for the products from both companies. These disparate demands will lead to a slight increase in the cycle inventory and order costs (see Equation (3)), encouraging to decrease the number of DCs. Consistently, we observe in Table 5 that the synergy value is more impacted by uneven demands when the facility opening cost is higher. Low vehicle capacities and low unit holding costs lead to slightly larger decrease in synergy value with unevenly distributed demands. In sum, even if the impact is limited, the potential benefits from cooperation are higher for partners with a similar market distribution.

5. Conclusion

This paper analyzes the benefits for companies to use a joint supply chain network (facilities and vehicles), and investigates the characteristics that influence these benefits to understand when horizontal cooperation is particularly profitable. For this, we propose a location-inventory model, formulated as a conic quadratic mixed integer program. The model integrates the main logistical costs such as facility opening, transportation, cycle inventory, ordering and safety stock costs. The transportation cost is accounted per vehicle and shipment size decisions are included so that an important benefit of collaboration, the improvement of the vehicle loading rate, is accurately assessed.

We perform a total of 29,100 experiments varying the parameters values (i.e. vehicle capacity, facility opening cost, inventory holding cost, ordering cost and demand variability) and the network setting. From these experiments, we infer valuable managerial insights to help companies assessing the potential benefits they can get when cooperating, depending on their characteristics. The synergy value ranges from around 15% to 30% with an average of around 22.5%. The benefits come from, in order of importance, the cycle inventory at retailers (increased delivery frequency), the transportation (improved loading rate and reduced distances), the opening of joint facilities (reduced opening cost) and the safety stock cost at retailers (reduced lead times). On the opposite, the order and the safety stock costs at DCs increase, slightly reducing the benefits of the cooperation. Our results also pinpoint the characteristics that should motivate companies to collaborate, and for which they should look for in their partners. In particular, the horizontal cooperation is more profitable for companies with a high facility opening cost, a large vehicle capacity (or small size products) and a low order cost, carrying cheap products (low unit holding cost) on a market with a low demand variability. Moreover, we observe that horizontal cooperation also improves the service to customers, increasing the service level from 97.5% to 98.2% (or further reducing the costs for a fixed service level) and increasing the delivery frequency for a specific product.

With additional experiments, we show that the synergy value continues to increase with the number of partners but that the marginal benefit is smaller with each new entrant. Companies have to balance the additional gains from adding a partner and the higher complexity to manage the partnership to decide on the right number of partners. Then, we look at cases where companies do not want to open new DCs or to close existing DCs. It appears that allowing DCs closures has a important impact on the potential benefits from cooperation, while the possibility to open new DCs has a relatively limited impact. When entering a cooperation, a company can decide not to open new DCs, but should accept to close some existing ones. Finally, the demand regional distribution has a minor impact on the synergy value, and mainly related to the number of opened DCs.

This research could be extended in several directions. Other benefits of horizontal cooperation could be investigated, in particular analyzing the reduction in CO_2 emissions. Now that the potential savings are assessed, the natural next step could be to look at the best way to obtain a fair allocation of the costs or benefits among partners. Lastly, few papers study the complexity to manage a partnership and the associated cost while it can be a serious impediment for potential partners.

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