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► To cite this version:

Aymen Aloui, Nassim Mrabti, Nadia Hamani, Laurent Delahoche. Towards a collaborative and integrated optimization approach in sustainable freight transportation. IFAC INCOM 2021, Jun 2021, Budapest (virtual), Hungary. 10.1016/j.ifacol.2021.08.178 . hal-03207262

HAL Id: hal-03207262

<https://hal.science/hal-03207262>

Submitted on 24 Apr 2021

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Towards a collaborative and integrated optimization approach in sustainable freight transportation

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Abstract: In a growing transportation market, the optimization and organization of distribution networks have become an important issue for companies that are looking for improving the efficiency of their freight transport systems. In this context, the adoption of a collaboration strategy between various logistics actors can enhance the operational efficiency of the networks and reduce sustainability impacts. In this paper, we evaluate the economic, environmental and social benefits of the logistics collaboration using an integrated planning approach that simultaneously optimizes the inventory, location and routing decisions. Firstly, we propose and adapt a Mixed-Integer Linear Programming (MILP) model to design a collaborative and non-collaborative sustainable distribution network. Secondly, we examine one of the problems that can cause conflict between partners, namely the cost-sharing problem. Finally, we discuss a case study of a French distribution network. The obtained results show that collaboration in integrated planning can significantly reduce CO_2 emissions, logistics costs and accident rate.

Keywords: Collaborative logistics, freight transport, integrated planning, sustainability, cost allocation, inventory-location-routing problem

1. INTRODUCTION

In today's competitive environment, companies have to find new strategies to meet the customer's demand while improving responsiveness, logistical efficiency and taking into account sustainability aspects as decision-making objectives (Ouhader and El Kyal, 2017). In fact, during the last two decades, external preoccupations related to sustainability levels have been imposed as the main constraints of the supply chain organization (Ayadi et al., 2021). They include greenhouse gas emissions, noise, traffic congestion, etc. To acquire a sustainable competitive advantage, freight transport optimization has attracted particular attention and is considered as a major factor of supply chain optimization (Mrabti et al., 2020). Moreover, logistics collaboration is viewed as one of the most effective practices to improve the efficiency of freight transportation in terms of sustainability (Aloui et al., 2021b; Hacardiaux and Tancrez, 2020). It is defined as the cooperation between companies that do not belong to the same supply chain but having the same level.

In fact, collaborative logistics is involved in various decision-making problems. At the strategic level, it is particularly studied by the collaborative distribution network design problem with sustainability objectives (Mrabti et al., 2020; Pan et al., 2014). At the tactical level, it is examined by the distribution organization problem and the problem of cost sharing between partners (Guajardo and Rönnqvist, 2016; Xu et al., 2012; Habibi et al., 2018). At the operational level, it is addressed mainly by the col-

laborative vehicle routing problem under several variants (Aloui et al., 2021b).

A major challenge for improving the competitiveness in logistics networks consists of addressing simultaneously the planning decisions with sustainability considerations (Aloui et al., 2021b). To this end, some recent studies that integrate simultaneously two decision-making levels have been conducted in the collaborative transport research context, such as the location-routing problem and the inventory-routing problem. Nevertheless, no attempts have been made to quantify the benefits of collaboration using an integrated model that combines location, inventory and routing decisions.

The objective of this paper is to quantify the economic, environmental and social benefits of implementing a collaborative strategy in integrated inventory, location and routing decisions. For this reason, a mathematical model using MILP that minimizes the total cost is proposed and a posteriori evaluation of CO_2 emissions and accident risks is also performed. Two scenarios are discussed to assess the performance of the collaboration among suppliers. The first one is a non-collaborative scenario where each supplier is independent of the other in transport and storage. The second is a collaborative scenario where suppliers share their means and resources to satisfy their customers' needs. Besides, we use two cost allocation methods to equitably share the cost between partners. The results of this study were provided by carrying out a case study in the French agri-food sector.

This paper is structured as follows. Section 2 presents the state-of-the-art and the existing approaches. Section 3 describes and presents both inventory-location-routing models, without and with collaboration. Case study results are discussed in Section 4. Finally, Section 5 summarizes this study and suggests future research directions.

2. LITERATURE REVIEW

2.1 Integrated planning

In recent years, some researchers have attempted to integrate two planning decisions into collaborative networks optimization, such as location-routing problem, inventory-routing problem and inventory-location problem. Regarding the location-routing problem, the location of distribution centers and the vehicle routing decisions are combined in a comprehensive approach. This problem has been investigated by Ouhader and El Kyal (2017) in a collaborative context by optimizing logistics costs, CO_2 emissions and created job opportunities. The results of their study have shown that horizontal collaboration can contribute significantly to CO_2 emissions and transportation costs reduction, but it has a negative impact on the social aspect evaluated since it minimizes the number of created jobs. For this reason, Ouhader and El Kyal (2020) have been interested in showing how the economic and environmental preoccupations can be balanced in a collaborative coalition using a multi-objective approach. Furthermore, Quintero-Araujo et al. (2019) and Nataraj et al. (2019) have examined the urban distribution network design based on the location-routing problem. The researchers have studied the use of horizontal collaboration concepts in integrated routing and location decisions for a single-echelon distribution network where a single distribution part is considered (distribution centers-customers). Several scenarios with different levels of collaboration have been also proposed and solved using meta-heuristics by minimizing the distribution costs. For the inventory-routing problem, two decisions have been integrated: the inventory management and the routing problem. Among the studies that addressed this problem, we can cite that of Stellingwerf et al. (2018) where the environmental and economic benefits of horizontal cooperation in a food supply chain were assessed. Furthermore, Soysal et al. (2018) have dealt with this problem in a collaborative context between suppliers of perishable products. Their work aimed at evaluating the environmental impacts of collaboration with uncertain demand. In the inventory-location problem, location-allocation and inventory decisions have been combined. Hacardiaux and Tancrez (2020) have studied this problem to assess the CO_2 emissions when companies jointly manage their logistics activities.

2.2 Cost-sharing

The cost allocation problem is one of the main factors that can prevent the success of the horizontal collaboration. Indeed, unfair sharing can cause conflict between partners and lead to the breakdown of collaboration. To address this problem, the literature suggests several approaches which can be classified into two categories. The first category includes traditional approaches that allocate costs using

a proportional sharing based on volume, weight of goods or travelled distance (Guajardo and Rönnqvist, 2016). The second category contains cooperative game theory-based approaches. They are considered the most advanced and effective in resolving conflicts between partners. Some recent studies that have addressed this problem in collaborative distribution are listed below.

Habibi et al. (2018) have used three approaches to allocate the costs generated by freight transportation and warehouse facilities. The first approach is the Shapley value which relies on the cooperative game theory. The two other approaches are classical; they are the Egalitarian Allocation and Volume method which consist respectively in distributing the costs by averaging and proportionally to the number of transported pallets. In the same context, Ouhader and El Kyal (2020) have utilized the value of Shapley to allocate costs and CO_2 emissions generated by transport when designing a collaborative distribution network. Similarly, Xu et al. (2012) have employed the Shapley value to share costs and taxes on CO_2 emissions generated by freight transport. Leenders et al. (2017) have applied two approaches to allocate CO_2 emissions generated by collaborative transport. The first approach combines the volume and the travelled distance to satisfy the customers' needs, while the second approach τ -Value is based on the cooperative game theory.

To the best of our knowledge, there is no literature dealing with logistics collaboration, integrated planning of location, inventory and routing problems with sustainable considerations. Thus, in this research, two MILP models are developed to solve the inventory-location-routing problem in two scenarios: collaborative and non-collaborative. The economic, environmental and social benefits of the collaborative approach are also evaluated. Moreover, two methods are applied to equitably share costs between several members.

3. PROBLEM DESCRIPTION AND FORMULATION

3.1 Problem description

This paper addresses the distribution network design problem by analyzing two logistics configurations. Fig. 1 shows the difference between the two considered scenarios. In the non-cooperative scenario (Fig. 1a), the suppliers are autonomous and each of them treats the routing, inventory and distribution centers location decisions independently of the others. In the collaborative scenario, location, inventory and routing decisions are made jointly by all companies (Fig. 1b).

The inventory-location-routing problem is defined as a complete graph $G=(V,A)$, where V denotes the set of nodes comprising the set of customers $I=\{1,\dots,N_{Customers}\}$, the set of potential distribution centers $D=\{1,\dots,N_{DCs}\}$ and the set of suppliers $J=\{1,\dots,N_{Suppliers}\}$, and $A=\{(i,j): i,j \in V; i \neq j\}$ is the set of arcs that includes the delivery and pickup arcs. Each customer has a non-constant and deterministic demand q_{ij}^t from supplier j at each period $t \in T=\{1, \dots, N_{periods}\}$ and it is served by a homogeneous fleet of vehicles $V=\{1,\dots, N_{vehicles}\}$ with a fixed capacity Q_v and a fixed cost F_v . Each potential distribution $d \in D$ has a storage capacity C_d and is subjected to a fixed

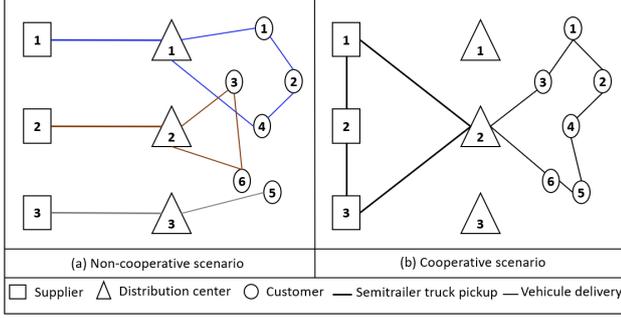


Fig. 1. Logistics network without and with collaboration

cost FO_d when it is open. To transport the goods between suppliers and distribution centers, a homogeneous fleet of semitrailer trucks $K = \{1, \dots, N_{trucks}\}$ with a fixed capacity Q_s and a fixed cost F_s is used in the first echelon. The objective of this problem is to determine the distribution centers to be opened, the customer and supplier allocation as well as the routes and quantity to be stocked in each period while minimizing the total cost. The remaining of this work follows the fundamental assumptions below:

- (1) Each customer i can be visited no more than once by one of the vehicles and served from a single distribution center d ;
- (2) Customers' demands are deterministic;
- (3) The pickup and delivery processes are independent and the pickup is made before delivery to the second level by trucks;
- (4) Demands must be consolidated, i.e. direct transport from supplier to customer is not possible.

The notations used in this study and their definitions are given in Table 1.

3.2 Performance Indicators

The performance evaluation of transport networks is mainly based on economic indicators. However, socio-environmental concerns push companies to rethink their logistics networks by integrating environmental and social objectives (Aloui et al., 2021b). In this study, we assess three quantitative sustainability indicators having a considerable impact on network design efficiency.

3.2.1. Economic indicator: This study integrates simultaneously the location, inventory and routing decisions into freight transportation. Therefore, the total cost (C) can be calculated by summing the fixed costs (C_F), the variables costs of transportation (C_T) and inventory (C_I) activities by applying Eq.(1).

$$C = C_F + C_T + C_I \quad (1)$$

The fixed costs can be computed by summing the distribution center opening costs and transport means operating costs, as shown in Eq.(2).

$$C_F = N_{periods} \left(\sum_{d \in D} y_d FO_d + \sum_{t \in T} \sum_{d \in D} \sum_{j \in J} x_{d,j}^t F_s + \sum_{t \in T} \sum_{d \in D} \sum_{i \in I} x_{d,i}^t F_v \right) \quad (2)$$

Table 1. Notations used in this paper

Notation	Description
I, J, D	The set of customers, suppliers and distribution centers nodes
$A1, A2$	The set of arcs of the pickup and delivery routing
T	Set of planning periods
C_d, FO_d	Storage capacity and opening cost of distribution center d
Q_v, F_v	Storage capacity and fixed cost of a vehicle
Q_s, F_s	Storage capacity and fixed cost of a semitrailer truck
Tv_E, Tv_L	Fuel consumption rate of an empty and loaded vehicle (L/Km)
Ts_E, Ts_L	Fuel consumption rate of an empty and loaded semitrailer truck (L/Km)
c_I, c_f	Unit cost of storage ($\text{€}/Kg$) and fuel per litre ($\text{€}/L$)
e_F	Fuel to CO_2 emissions factor ($Kg CO_2/L$)
A_c	Number of accidents per year
$d_{i,j}$	Distance between two nodes i and j : $i, j \in J \cup D \cup I$
q_{ij}^t	Demand of customer i from supplier j in period t
y_d	Variable to determine if the distribution center i is open or close
z_{id}^t	Variable to determine if the node i is assigned to center d , $i \in I \cup J, d \in D$
Q_{jd}^t	Quantity delivered by supplier j to center d in period t
I_{jd}^t	Inventory level of product j in center d at period t
$x_{i,j}^t$	Binary variable to determine if the arc (i, j) is traversed in period t by a vehicle/semitrailer truck
$f_{i,j}^t$	Semitrailer truck/vehicle load on the arc (i, j) if a semitrailer truck/vehicle travels directly from node i to node j in period t , otherwise 0, $(i, j) \in A1 \cup A2$

Pan et al. (2014) have shown that the transportation cost is linearly related to the transported load and the distance. In this study, inspired by the previous studies, we modelled the transportation cost using the following formula (Eq.(3)):

$$C_T = \sum_{t \in T} \sum_{(i,j) \in A1} d_{ij} c_f [x_{ij}^t Ts_E + (Ts_L - Ts_E) \frac{f_{ij}^t}{Q_s}] + \sum_{t \in T} \sum_{(i,j) \in A2} d_{ij} c_f [x_{ij}^t Tv_E + (Tv_L - Tv_E) \frac{f_{ij}^t}{Q_v}] \quad (3)$$

The inventory cost is calculated by Eq.(4).

$$C_I = \sum_{t \in T} \sum_{d \in D} \sum_{j \in J} c_I I_{jd}^t \quad (4)$$

3.2.2. Environmental indicator: As the CO_2 emission factor is the main pollution factor in freight distribution (Pan et al., 2014), the environmental impact is quantified, in this work, by measuring the quantity of emissions emitted during transport activities. We adapt the emissions calculation proposed by Pan et al. (2014), which is commonly used in the literature (Ouhader and El Kyal, 2020; Haccardiaux and Tancrez, 2020; Aloui et al., 2021a). The total CO_2 emissions E_m are calculated by adding all delivery and collection emissions using Eq.(5).

$$E_m = \sum_{t \in T} \sum_{(i,j) \in A1} d_{ij} e_F [x_{ij}^t Ts_E + (Ts_L - Ts_E) \frac{f_{ij}^t}{Q_s}] + \sum_{t \in T} \sum_{(i,j) \in A2} d_{ij} e_F [x_{ij}^t Tv_E + (Tv_L - Tv_E) \frac{f_{ij}^t}{Q_v}] \quad (5)$$

3.2.3. *Social indicator*: Modelling social considerations is a complex task that was not given great attention in the literature (Aloui et al., 2021b). In this study, we assess the social/societal impact by evaluating the accident rate caused by transportation activities. Therefore, we adopt the formula proposed by (Pašaitis and Petraška, 2012) to estimate the accident rate per thousand kilometers (Eq.(6)).

$$A_r = \frac{Ac \ 1000}{Distance \ 365} \quad (6)$$

Since distance and accident rate are inversely proportional, we evaluate the accident rate for both scenarios with respect to a reference value.

3.3 Gains Allocation methods

We adopt two allocation approaches to share the cost between partners. The first is the Shapley value, presented by Eq.(7), is one of the most widely used allocation methods in the literature (Guajardo and Rönnqvist, 2016).

$$C_j = \sum_{\substack{j \in S \\ S \subseteq J}} \frac{(|J| - |S|)! (|S| - 1)!}{|J|!} (C(S) - C(S \setminus \{j\})) \quad (7)$$

Given that partner j belongs to the coalition J , the parameter S presents, then, the possible sub-coalitions in J , i.e. S is a subset of N . The term $j \in S$ expresses that for any partner j belonging to all sub-coalitions S is included in the computation if they are a proper subset of J and if j is part of it. $(C(S) - C(S \setminus \{j\}))$ represents the marginal cost of partner j to an existing coalition S . Moreover, there are $|J|!$ different combinations of how all partners $|J|$ can join the coalition J . Therefore, there are exactly $(|J| - |S|)! (|S| - 1)!$ combinations in which j joins the coalition lastly. Finally, the sum means that all marginal costs of partner j weighted by the term $((|J| - |S|)! (|S| - 1)! / |J|!)$ have to be summed up, if j joins the sub-coalition S .

The second approach is the Volume method given by formula (Eq.(8)). This technique allows calculating the total cost of collaboration based on the shipping volume.

$$C_j = \frac{\sum_{t \in T} \sum_{i \in I} q_{ij}^t}{\sum_{t \in T} \sum_{j \in J} \sum_{i \in I} q_{ij}^t} \quad (8)$$

3.4 Collaborative integrated model formulation

Using the previously-defined the parameters and decision variables, we modelled the collaborative inventory-location-routing problem as a MILP that minimizes the total cost (9). The proposed model is presented below:

$$\text{Minimize } C \quad (9)$$

Subject to

$$z_{id}^t \leq y_d \quad \forall t \in T, \forall i \in I \cup J, \forall d \in D \quad (10)$$

$$\sum_{d \in D} z_{id}^t \leq 1 \quad \forall t \in T, \forall i \in I \cup J \quad (11)$$

$$\sum_{j \in J} \sum_{i \in I} z_{id}^t q_{ij}^t \leq C_d z_d \quad \forall t \in T, \forall d \in D \quad (12)$$

$$\sum_{j \in J} Q_{jd}^t \leq C_d z_d \quad \forall t \in T, \forall d \in D \quad (13)$$

$$x_{dj}^t \leq z_{jd}^t \quad \forall t \in T, \forall j \in J, \forall d \in D \quad (14)$$

$$x_{jd}^t \leq z_{jd}^t \quad \forall t \in T, \forall j \in J, \forall d \in D \quad (15)$$

$$x_{jj'}^t + z_{jd}^t + z_{j'd'}^t \leq 2 \quad \forall t \in T, \forall j, j' \in J, \forall d, d' \in D \quad (16)$$

$$x_{di}^t \leq z_{id}^t \quad \forall t \in T, \forall i \in I, \forall d \in D \quad (17)$$

$$x_{id}^t \leq z_{id}^t \quad \forall t \in T, \forall i \in I, \forall d \in D \quad (18)$$

$$x_{ii'}^t + z_{id}^t + z_{i'd'}^t \leq 2 \quad \forall t \in T, \forall i, i' \in I, \forall d, d' \in D \quad (19)$$

$$I_{jd}^0 = 0 \quad \forall j \in J, \forall d \in D \quad (20)$$

$$I_{jd}^t = Q_{jd}^t + I_{jd}^{t-1} - \sum_{i \in I} q_{ij}^t z_{id}^t \quad \forall j \in J, d \in D, t \in T \quad (21)$$

$$I_{jd}^t \leq C_d y_d \quad \forall j \in J, \forall d \in D, \forall t \in T \quad (22)$$

$$\sum_{j \in J} Q_{jd}^t \leq C_d y_d - \sum_{j \in J} I_{jd}^{t-1} \quad \forall d \in D, \forall t \in T \quad (23)$$

$$\sum_{i \in JUD} x_{ij}^t \leq 1 \quad \forall t \in T, \forall j \in J \quad (24)$$

$$\sum_{j \in J} x_{dj}^t = \sum_{j \in J} x_{jd}^t \quad \forall t \in T, \forall d \in D \quad (25)$$

$$\sum_{i \in JUD} x_{ij}^t = \sum_{i \in JUD} x_{ji}^t \quad \forall t \in T, \forall j \in J \quad (26)$$

$$\sum_{i \in JUD} f_{ji}^t - \sum_{i \in JUD} f_{ij}^t = \sum_{d \in D} Q_{jd}^t \quad \forall t \in T, \forall j \in J \quad (27)$$

$$f_{ij}^t \leq Q_s x_{ij}^t \quad \forall t \in T, \forall i, j \in J \cup D \quad (28)$$

$$\sum_{j \in J} f_{dj}^t \leq 0 \quad \forall t \in T, \forall d \in D \quad (29)$$

$$\sum_{i \in IUD} x_{ji}^t \leq 1 \quad \forall t \in T, \forall i \in I \quad (30)$$

$$\sum_{i \in I} x_{di}^t = \sum_{i \in I} x_{id}^t \quad \forall t \in T, \forall d \in D \quad (31)$$

$$\sum_{j \in IUD} x_{ji}^t = \sum_{j \in IUD} x_{ij}^t \quad \forall t \in T, \forall i \in I \quad (32)$$

$$\sum_{j \in IUD} f_{ji}^t - \sum_{j \in JUD} f_{ij}^t = \sum_{j \in J} q_{ij}^t \quad \forall t \in T, \forall i \in I \quad (33)$$

$$f_{ij}^t \leq Q_v x_{ij}^t \quad \forall t \in T, \forall i, j \in I \cup D \quad (34)$$

$$\sum_{i \in I} f_{id}^t \leq 0 \quad \forall t \in T, \forall d \in D \quad (35)$$

$$y_d \in \{0, 1\} \quad \forall d \in D \quad (36)$$

$$z_{id}^t \in \{0, 1\} \quad \forall t \in T, \forall d \in D, \forall i \in I \cup J \quad (37)$$

$$x_{ij}^t \in \{0, 1\} \quad \forall t \in T, \forall (i, j) \in A1 \cup A2 \quad (38)$$

$$f_{ij}^t \geq 0 \quad \forall t \in T, \forall (i, j) \in A1 \cup A2 \quad (39)$$

$$Q_{jd}^t, I_{jd}^t \geq 0 \quad \forall t \in T, \forall d \in D, \forall j \in J \quad (40)$$

Constraints (10) ensure that customers and suppliers can be assigned to a distribution center only if it is open. Constraints (11) force each customer (respectively supplier) to be assigned to only one distribution center. Constraints (12) and (13) guarantee that the capacities of the distribution centers are not exceeded. Constraints (14)-(19) eliminate the routes that do not start and finish at the same distribution center and also allow allocating customers and suppliers. Constraints (20) define the initial inventory level in distribution centers. Constraints (21) calculate the stock level in the distribution centers at each planning period. Constraints (22) ensure that the inventory amount at each distribution center does not exceed the available storage capacity. Constraints (23)

limit the quantity to be delivered in order to respect the centers distribution capacities. Constraints (24)-(29) guarantee a reasonable pickup process. Constraints (24) ensure that each supplier must be visited only once at most in each period. Constraints (25) and (26) ensure an equal number of incoming and outgoing arcs. Constraints (27) guarantee the flow conservation for the collection process. Constraints (28) ensure that semitrailer truck capacities are not violated. Constraints (29) guarantee that the load on the semitrailer truck is zero when starting from an open distribution center. Constraints (30)-(35) concern the delivery process. They present conditions similar to those for the pickup process (24)-(29). Finally, constraints (36)-(40) specify the nature of each decision variable used in this modelling.

3.5 Non-collaborative integrated model formulation

In the non-collaborative inventory-location-routing problem, each company resolves individually the different planning decisions. To treat this scenario, we adapted the MILP (9)-(40) presented in the previous section and we added the constraints (41).

$$\sum_{j \in J} x_{jd}^t \leq 1 \quad \forall t \in T, \forall d \in D \quad (41)$$

4. CASE STUDY AND DISCUSSION

4.1 Description and data

A case study of a French agri-food distribution network is carried out in this work to evaluate the proposed approach. The considered network distribution is composed of four suppliers located in the Hauts-de-France region. In the current situation, each supplier uses its specific means and resources to serve their customers. The customers are geographically dispersed in urban areas. The demand matrix for each client at each period is given in Table 2. Note that each period represents ten days horizon.

4.2 Results and discussion

To compare both scenarios, we solved the two models presented above, using IBM ILOG CPLEX Optimization Studio 12.9 on a PC with Intel Core i5 processor (2.6 GHz) and 6 GB RAM, and we assessed the three sustainability indicators. The obtained optimization results are summarized in Table 3. Figure 2 shows the networks configurations for the first period. These findings reveal that collaboration in integrated planning can generate significant savings in costs and emissions as well as in accident rate. In terms of costs, the collaboration allows reducing the total cost by 47.53%, compared to the non-collaborative scenario. In fact, sharing distribution centers minimizes significantly the opening and operating costs by approximately 50%. In addition, the collaborative transport reduces accident rate and emissions by 28.78% and 29.68%, respectively. However, by jointly planning decisions, the inventory cost becomes slightly higher than of the non-collaborative scenario. This increase leads to a lower delivery frequency by consolidating flows in order to reduce transport costs.

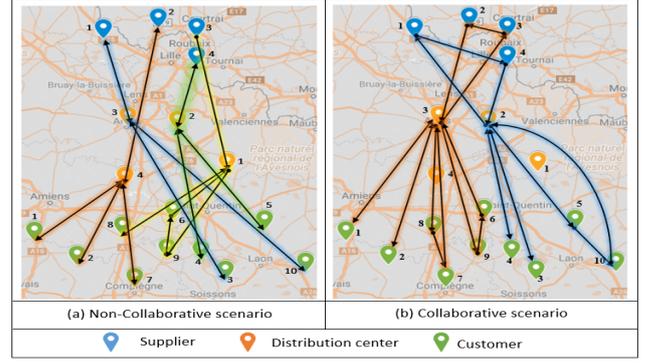


Fig. 2. Comparison between both configurations in the first period

Table 2. Customers' demand matrix

Customer ID	Supplier ID	Demand (Kg)		
		Period 1	Period 2	Period 3
1	2	7000	4000	4000
2	2	8000	3000	2000
3	1	7000	2000	7000
4	4	4000	6000	3000
5	4	5000	7000	4000
6	3	2000	5000	2000
7	2	5000	8000	8000
8	3	2000	6000	3000
9	3	6000	3000	2000
10	1	3000	4000	8000

Table 3. Key performance indicators for different scenarios

Key performance	ILRP Cost		Gap%
	NCS	CS	
Opening cost (€)	12000	6000	50.00
Truck cost (€)	1200	600	50.00
Vehicle cost (€)	600	300	50.00
Inventory cost (€)	0	20	-
Transportation cost (€)	2359.40	1587.89	32.70
Total cost (€)	16159.40	8507.89	47.53
CO ₂ emissions (Kg CO ₂)	3914.25	2752.34	29.68
Accident rate (%)	2.05	1.46	28.78

In summary, collaboration between suppliers can generate significant savings. However, costs should be equitably allocated to check if collaboration is beneficial for each partner. As mentioned above, we used two methods of cost allocation, namely the Shapley value and volume method. The sharing results are shown in Fig. 3.

From the findings presented in Fig. 3 and independently of the type of method used to allocate cost, we may conclude that all partners take advantage of the collaboration, especially the three first suppliers ($j1$, $j2$ and $j3$). Supplier $j2$ has the highest cost because it has the largest quantity of goods and the longest travelled distance. It is also obvious that, when the Volume method is applied, the costs allocated to suppliers $j1$ and $j3$ are equal because they deliver the same quantity of goods. In practice, this can cause a problem because the travelled distance to satisfy customers of $j1$ is greater than the travelled distance to satisfy customers of $j3$. The Volume method is not fair and it allows some partners to profit from others, which leads to conflict between them. On the other hand,

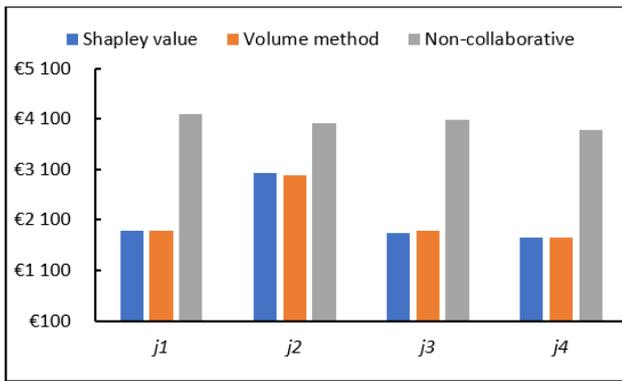


Fig. 3. Cost-sharing using both allocation methods

the Shapley value adjusts the cost-sharing more equitably because it takes into account the impact of each partner's participation on sub-collaborations. As a result, supplier j_4 has the most reduced cost, supplier j_1 has a higher cost than supplier j_3 , and supplier j_2 has the highest cost.

5. CONCLUSION

This paper presents a new comprehensive and collaborative approach to design two-echelon logistics networks. Firstly, two MILP models were introduced to simultaneously optimize planning decisions in two distribution scenarios. The first is a non-collaborative scenario, while the second is a collaborative scenario. We evaluated the economic, environmental and social benefits of collaboration in integrated decision planning. Afterwards, we examined the cost-sharing problem between partners. The obtained results show that horizontal collaboration is a powerful solution to improve sustainability indicators. However, there are several factors that can block its success and continuity, namely the compatibility of the products, the confidence, and the efficiency of information sharing between the stakeholders.

This research could be extended in several directions. For instance, we can consider the evaluation of social/societal and environmental levels in conjunction with the economic level and introduce other sustainability indicators like congestion, road and green space damage. Moreover, a heuristic approach may also be developed to address large-scale real problems.

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