The impact of horizontal collaboration on CO_2 emissions due to road transportation

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Abstract

In this article we try to quantify the potential environmental benefits of horizontal collaboration in transportation and to study the sensibility of CO_2 emissions to transportation cost reduction. We adopted an approach based on bi-objective mathematical modeling to minimize both total transportation cost and total environmental effect by simultaneously combining facility location and routing decisions in urban freight distribution. Extended known instances reflecting real distribution urban area are used to evaluate several goods delivery strategies. The results obtained by comparing a collaboration scenario and non-collaboration one, show that collaboration leads to a reduction in CO_2 emissions, transportation cost, travelled distances and in addition to the improvement of the vehicle load rate. This work opens up new lines of research in this area.

Keywords
horizontal collaboration; sustainable urban road transport; estimation of CO_2 emissions; two-echelon Location Routing problem; multi-objective optimization

1. Introduction

"Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C" was the ambition goal for climate action set out in the Paris Agreement at COP21[1]. In accordance with paragraphs 19 of the article 4 of this agreement, all Parties should strive to formulate and communicate long-term low greenhouse gas emission development strategies by 2020. Therefore, governments and companies are now being put under increasing pressure to pay attention to environmental concerns and to decarbonize their operations. According to the Accenture and World Economic Forum Report 2009, logistics and transportation activities contribute approximately 5.5% of total greenhouse gas (GHG) emissions and 57% of the transport emissions came from road freight. Several strategies with the aim of improving efficiency and sustainability from urban road transport have been suggested both in practice and in the academic literature. Logistics collaboration is gaining traction as a one of the key policies to assure this mission. As affirmed by (Danloup et al. 2013), the implementation of collaborative supply chain should yield positive effects linked to sustainable development to balance between environmental and economic impacts.

[1] Paris agreement at COP 21 available at January 30,2017 in http://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf

We talk about collaborative supply chain when two players (or more) of the "Supply Chain" seek to optimize together the logistics of the distribution circuit in which they are linked (Juvien 2011). Logistics collaboration was studied in two main areas: Vertical and horizontal collaboration. The vertical collaboration occurs between members of the same chain value (industrial and distributor) while the horizontal collaboration occurs between companies (may be competitors or not) that can provide goods or complementary services (Taieb & Affes 2013). Vertical cooperation has already led to an abundant literature. Nevertheless, less attention has given to research on horizontal logistics collaboration ((Leitner et al. 2011), (Amer & Eltawil 2015),(Moutaoukil, Derrouiche, et al. 2013),(Soysal et al. 2016)).

In the academic literature, the operations management of horizontal collaborative supply chain was mainly based in single objective mathematical modelling approach dealing with economic concern and the integration of sustainability is accordingly in his infancy. Moreover, the majority of papers on the subject were based on vehicle routing problem by proposing models for the operational level of the supply chain under horizontal collaboration and the strategic level, like facility location problem, has received less attention. (Montoya-torres et al. 2016) have put the emphasize on the need to establish models allowing preliminary analysis (before implementation) of the impacts and the benefits that can be achieved under collaborative systems for goods transportation in urban area. This finding sheds lights on the need, for logistics horizontal collaboration, of more preliminary quantitative models that deal with environmental dimensions and take into account more logistical aspects like facility location.

There is no predefined schema for the horizontal collaboration in logistics transportation. It takes many forms and several configurations that can be probable scenarios to test the collaborative approach. In this paper, we are interested to the case of horizontal cooperation between several suppliers (shippers) who decide to joint deliveries to their customers located in urban area subcontracting the truck service to a private transportation company. We assume that authorities prohibit large vehicle to entry to congested areas in the aim of reducing the GHG emissions of freight distribution, congestion and accidents. Goods are delivered to customers via intermediate depots (e.g Urban Consolidation Center (UCC)) than direct shipments. Large trucks are used to transport, directly, goods over long-distances to intermediate depots where consolidation takes place. After that, products are transferred to customers using small vehicles (Gonzalez-feliu et al. 2010). Our objective is to minimize the amount of CO_2 emissions and total cost of upstream and downstream transportation in a two-echelon distribution system. The main decisions involved in this problem are: (1) which depots/satellites out of a finite set of potential ones should be used (2) How to assign each customer to one open depot (3) How to determine routes to perform distribution. Thus, this problem can be modeled as an extension of the two echelons Location Routing Problem (2E-LRP) for a more comprehensive resolution than separate decision levels.

As defined by (Cuda et al. 2015), the Two-Echelon Location Routing Problem (2E-LRP) involves both strategic (typically the location of facilities) and tactical (typically the routing of freight and the allocation of customers to the intermediate facilities) planning decisions. Goods are available at different sources and have to be delivered to the respective destinations move mandatorily through intermediate facilities called depots or satellites. An opening cost is associated with each source and each satellite. Sources and depots, to be opened have to be selected from a set of possible sources (depots) location.

Recently, (Drexl & Schneider 2015) and (Prodhon & Prins 2014) published two exhaustive literature reviews of LRP and these variants. In particular, (Cuda et al. 2015) provides an overview of 2E-LRP. From these reviews we can conclude that the majority of existing researches on the LRP have focused on economic approach, single echelon and single source at a fixed location. Multi echelons LRP like 2E-LRP begins to attract the interest of researchers in recent years. Within the literature of the 2E-LRP, few works considered a multiple objective approach were found.

Our previous work (Ouhader & El kyal 2017a),addressed a preliminary decision support tool evaluating the economic and environmental effects of collaborative freight delivery in urban areas. We applied a multi-objective optimization to a two echelon location routing problem (2E-LRP). The objectives of the model were (i) minimizing total transportation cost and (ii) minimizing total amount of CO_2 emissions from transportation operations. We generated a set of efficient solutions and the Pareto frontier using the ε-constraint method considered the best known technique to solve multi-criteria optimization problems (Collete & Patrick Siarry 2003). This approach is based on optimizing one of the most preferred objective functions, and considering the other objectives as constraints (Beigi 2016). We chose minimizing the total transportation cost, while the total amount of CO_2 emissions was transformed to constraint. The difficulty with ε-constraint method is to express decision maker's (DM) preferences at early stages of the optimization cycle (MathWorks 2007) as they don't completely known the importance of each objective. To enhance the decision making process, this paper presents an extension to the work (Ouhader & El kyal 2017a) by studying additional scenario where the preferred objective is minimizing the total amount of CO2 emissions and the total transportation cost is transformed to a constraint. Such scenario can happen, for example, if suppliers are forced to reduce CO2 emissions to be in compliance with a new environmental regulation. The goal of the work is to perform an environmental analysis and study the sensitivity of the total CO2 emissions versus total transportation cost reduction to maintain the control of the transportation cost when optimizing CO2 emissions generated by transportation.

The current work does not aim to improve the state-of-the-art of the 2E-LRP, the estimation of CO2 emission or the multi-objective resolution methods, instead the goal of this research is to focus on the environmental effect of including simultaneous routing and facilities location decisions in the designing of the collaborative supply chain. We propose a preliminary decision support tool for evaluating the environmental benefits of collaborative freight delivery in urban areas before companies agree to participate in a horizontal cooperation scheme.

The rest of this paper is organized as follows: The second section presents the environmental impact studies in horizontal collaboration. The third section describes the adopted mathematical model. The fourth section discusses the results, whereas the last section deals with our conclusions for the sake of providing a new perspective.

2. Related works

(Bahinipati et al. 2009) defined the horizontal collaboration as "a business agreement between two or more companies at the same level in the supply chain or network in order to allow ease of work and co-operation towards achieving a common objective".

Few surveys on horizontal collaboration have been presented in the literature. A good recent review on it can be found in (Amer & Eltawil 2014) and (Amer & Eltawil 2015). In the first paper, authors present an extensive review and analysis on the literature of horizontal collaboration in supply chain networks design. In the second one, they reviewed the existing quantitative models developed in literature for successfully establishing horizontal relationships between partners.

From operations management view, few works dealing with the environmental impact in collaboration between shippers was found in literature. (Ballot & Fontane 2010) used logistical data from real firms to demonstrate the potential saving of CO2 emissions in horizontal collaboration supply chain. (Shenle 2010) optimized separately the total transportation cost and the CO2 emission by developing transportation problem models based in a mixed linear integer programming (MILP).(Elena et al. 2014) adapted a set of well-known benchmarks for the Multi-depot Vehicle Routing Problem (MDVRP) to illustrate an example of horizontal cooperation between shippers owning the vehicle fleet and to quantify routing costs savings both in terms of distance-based costs as well as in terms of environmental costs due to greenhouse gas emissions. (Juan et al. 2014) studied the same example as (Elena et al. 2014) but discussed backhaul based horizontal collaboration to evaluate the relevance of this way in saving routing and environmental costs. (Danloup et al. 2015) have analyzed the potential for improving sustainability performance in collaborative distribution by measuring the potential improvements regarding the reduced total number of running by delivery trucks and also regarding the reduced amount of CO2 emissions.

Recently, (Montoya-torres et al. 2016) used the multi-depot vehicle routing problem (MDVRP) for horizontal collaborative delivery between firms and a variant of the location–allocation problem to design the transport infrastructure and to quantify the benefits that can be achieved when collaborative logistics operations are implemented, represented in transportation costs and CO2 reduction. (Soysal et al. 2016) were interested in analyzing the benefits of horizontal collaboration related to perishability, energy use (CO2 emissions) from transportation operations and logistics costs in the Inventory Routing Problem (IRP) with multiple suppliers. (Muñoz-villamizar et al. 2017) studied the implementation of an electric fleet of vehicles in collaborative urban distribution of goods, in order to reduce environmental impacts while maintaining a level of service. They proposed an approach using mathematical modeling with multiple objectives, for tactical and operational decision-making to explore the relationship between the delivery cost and the sustainability impact.

In our previous works, (Ouhader & El kyal 2016) quantified the aggregated economic benefit of horizontal collaboration basing on two echelons Location Routing problem (2E-LRP) model and we performed a posterior evaluation of the impact of collaboration in CO2 emissions based in travelled distances. (Ouhader & El kyal 2017b) quantified the economic and environmental effects of collaborative freight delivery in urban areas based on two single mathematical models as 2E-LRP with the objectives of to minimize cost transportation and CO2 emissions. Well known allocation methods were compared to evaluate the effect of chosen method in allocated gains. As extension of the latter study, (Ouhader & El kyal 2017a) adopt a multi-objectives approach to evaluate simultaneously the economic and the environmental benefits of Combining facility location and routing decisions in horizontal collaboration.

3. Model description

Our problem is defined on an undirected, weighted and complete graph. The nodes are partitioned into three subsets: K = {1, 2,. . . F} F factories, J = {1, 2,…. W} W satellite / possible platform and I = {W + 1, W + 2…. , W + S} S clients. Each j∈ J satellite has a capacity Wcap (j) and an opening cost Hj. Each satellite works as a cross-dock, meaning that when products arrive at the cross-dock, they are unloaded at the receiving dock before being split and consolidated with other products according to customer's orders (Yu et al. 2015) and satellites do not perform any other activity. So we considered a transshipment cost Lj proportional to the quantity loaded or unloaded in the cross-dock. Each customer i ∈ I has a demand q (ip) for each product p∈ P such as P= {1, 2,…F}F product (each plant has its own product). A homogeneous fleet of trucks, with the same capacity Tcap and fixed cost FCT (primary or first-level vehicles) serve the satellites. A homogeneous fleet of smaller vehicles (secondary or second-level vehicles) with the same capacity Vcap and fixed cost FCV is shared by the open satellites to supply customers.

The first objective function is based on the cost-minimizing model proposed by (Ouhader & El kyal 2016), and improved by adding the handling cost in the satellites and the fixed costs of using trucks and vehicles. The second devotes to minimize CO2 emissions in term of transportation. In their review of recent research on green road freight transportation, (Demir et al. 2014) presented the factors affecting fuel consumption. They concluded that the fields of green road freight transportation have focused on a limited number of factors, mainly vehicle load and speed. in dependence of a bunch of parameters, a variety of methods for estimating fuel consumption and emission of road transportation exist (Kopfer 2013). The decision on which model to adopt depends mainly on data availability (Demir et al. 2014).

Due to the complexity of the estimation of CO2 emissions, our calculation is simplified and based on European studies as (Hickman 1999), (Moutaoukil et al. 2015), (Moutaoukil, Derrouich, et al. 2013), (Pan et al. 2013). In this study, CO2 emissions depend on the weight carried by the vehicle , on the capacity of the vehicle that is used , on the distance traveled and the average speed of the vehicle. The calculation formula of CO2 emissions with the variable of load is:

$$\varepsilon\left(d_{ij}, c_k, x_{ij}^k\right) = \sum_k \sum_i \sum_j d_{ij} * \left[\left(E_{(full)} - E_{(empty)} \right) * \frac{x_{ij}^k}{c_k} + E_{(empty)} * \left\lceil \frac{x_{ij}^k}{c_k} \right\rceil \right] \qquad (1)$$

ε (d, c, x) is the CO 2 emissions from a vehicle in g/km .The variable x_{ij}^k is the flows on arcs (i, j) loaded on vehicle of type k in unit . $E_{(full)}$ is the CO2 emissions of a fully loaded (by weight) vehicle. $E_{(empty)}$ is the CO2 emissions of an empty vehicle, c_k is the capacity of a type k vehicle and d_{ij} is distance on the arc ij. The term $\left\lceil \frac{x_{ij}^k}{c_k} \right\rceil$ represents the nearest larger integer to $\frac{x_{ij}^k}{c_k}$. The detailed formulation was described in (Ouhader & El kyal 2017b).

For the calculation of the values of $E_{(full)}$ and $E_{(empty)}$, we used data adapted by (Moutaoukil et al. 2015) and (Moutaoukil, Derrouich, et al. 2013) and provided by (Hickman 1999). These values are linked to the average speed of the vehicle used which depends on the type of path in urban, regional or national routes (Moutaoukil et al. 2014). In our study, we set the value of the average speed to 45 km/h for regional routes (from suppliers to satellites) and to 20 km/h for urban routes (from satellites to customers).

4. Numerical experiments

4.1 Instances description

In this section, the proposed model was validated and tested for small and medium-sized data instances. The model was implemented by using MATLAB 2014 and tested on a 2.67 GHz Core i5 with 4 GB RAM under Windows 7 environment.

To the best of our knowledge, there are no available benchmark instances in literature to test our model. For this reason, we have tried to inspire from standard instances from the literature to our problem. Specially, we have chosen Sterle's instances (Sterle 2009) regenerated by (Contardo et al. 2012) according to the specifications explained in (Boccia et al. 2010) with the scope of reproducing a schematic representation of a multi-level urban area[2] (see figure1)

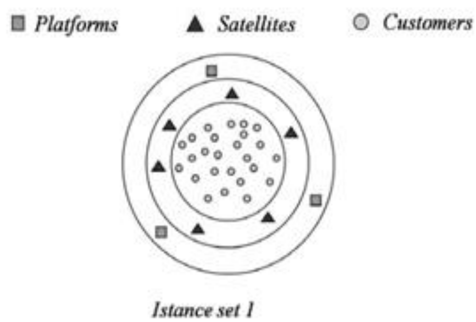

Figure 1. Satellite distribution in the I1 instances (from (Boccia et al. 2010))

In our study, for the aim of simplifying the implementation of the model, we treated a case of 3 suppliers, 5 satellites (S1,S2,S3,S4 and S5) and 40 costumers. Locations of these points and customers' demands are selected from Sterle's instance I1-50x8x5. We assume that suppliers have different sizes in terms of total amount of products sent to their customers (F1 big size, F2 medium size and F3 small size)

In this study, emission is limited to carbon dioxide (CO2) caused by transportation activities. These emissions are calculated based on the MEET model, which is developed by (Hickman 1999) and widely used in the literature. We refer to (Moutaoukil et al. 2015) and (Moutaoukil, Neubert, et al. 2013) papers' to determine $E_{(\mathrm{empty})}$ and $E_{(\mathrm{full})}$ for trucks and vehicles. We used fleets of homogeneous vehicles and trucks. Their characteristics were summarized in table 1.

Table 1.Truck and vehicle characteristics

	Trucks (regional routes)	Vehicle (urban routes)
Capacity (unit)	800	200
Fixed cost	100	50
Average speed (km/h)	45	20
Total authorized weight(ton)	7.5-16	<1.5
$E_{(\mathrm{empty})}$ (g/CO2)	532.6	59
$E_{(\mathrm{full})}$ (g/CO2)	479.82	58,6

[2] Instances are available in http://claudio.contardo.org/instances/

In order to replicate the experiments, full origin-destination matrixes, demand sets and the other parameters are available upon request to the corresponding author of this paper.

4.2 Optimization approach

Transportation cost and CO2 emissions are considered as the two objective functions to minimize. A posterior evaluation of other metrics can be assessed such as the opened satellites, the customers' allocation, the number of used vehicle and truck, vehicle loading rate and distances travelled.

In order to provide a useful tool for decision-makers addressing such issues, we presented two decision-making scenarios: (i) Non collaborative scenario NCS in which horizontal collaboration does not exist between the suppliers, (ii) collaborative scenario CS in which horizontal collaboration exists between the suppliers. The 2E-LRP model adopted can be used to analyze both cases. In the scenario NCS, each manufacturer must define its own distribution scheme and solve the model separately. In the scenario CS, the industrials share resources and information to develop common distribution patterns.

In the base case, the model is divided into two mono-objective models and solved separately for optimal level of CO2 emissions (Em_min case) and optimal level of transportation cost. Based on those results, the epsilon constraint method is implemented to evaluate the sensitivity of the total CO2 emissions versus transportation cost (Em_st_ct case). For most details about this method reader is addressed to (Paterakis et al. 2015) .

4.3 Results analysis

Applying ε-constraint method, we minimized the total CO2 emissions due to transportation and a constraint was added in which the total transportation cost of the supply chain should not exceed a predefined admissible value ε Em_st_ct case. We generated 10 instances by lowering ε value from the highest transportation cost level at each instance. A set of efficient solutions and the Pareto frontier can be generated. Therefore, a DM should intervene and decide one single solution to be implemented, according to his preferences.

Let's take the example of collaborative scenario (CS), the amount of ε for Pareto chart is calculated by the equation:

$$\varepsilon = 2422 - \left(\frac{2422 - 1726}{11} * \text{counter}\right) \tag{2}$$

Then the model is solved for different values of upper bounds of total transportation cost. The payoff table and Pareto frontier derived from implementation of generated instances are given in table 2 and figure 2.

Table 2 : Payoff table of collaboration scenario

objective function	cost	Emissions (g/CO2)
C_min	1726	138836
Em_min	2422	31422

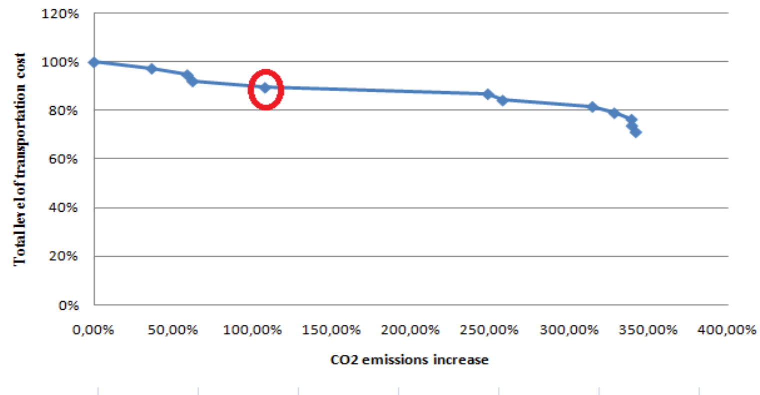

Figure 2. Trade-offs between transportation cost and CO 2 emissions in collaborative scenario

From figure 2, it can be said that the slope of the Pareto frontier is decreasing. The CO2 emissions increase as the upper bound of transportation cost decreases. When transportation cost level is around 90% , slop starts decreasing greatly. So the CO2 emissions of achieving the same percentage of cost reduction are increasing.

We conclude that the total transportation cost and CO2 emissions are two conflicting objectives. Thus, the multi-objective optimization helps decision makers to decide about the best trade-off by determining the cost of being sustainable from the point of reducing transportation emissions. As explained above, one of the solutions in Figure 2 can be selected for analyzing the collaborative supply chain. Transportation cost level of 90% on the Pareto chart, equivalent to a reduction of 10% of this cost, seems to be a significant solution.

In order to compare between the collaborative and non collaborative scenarios, we assume that each supplier wants to reduce the transportation cost by 10% in the scenario NCS.

The results obtained from simulating the two cases (Em_min and Em_st_ct) in non-collaborative and collaborative scenarios are presented in Tables 3. In addition to CO2 emissions amount, other parameters can be assessed. The third to the last columns in Table1 show: transportation cost, total distances travelled in both levels by trucks and vehicle, number of trucks used, number of vehicle (City freighter), number and name of satellites opened and number of customers assigned to this satellites, average load rate of tracks and average load rate of vehicle. The row (Total_NCS) presents the global situation of our supply chain in a stand-alone scenario (Aggregated contributions of all partners)

Table 3. Summary results after simulating the two cases Em_min and Em_st_ct

Factory	Case	CO2 emissions (g/CO2)	cost	Distances travelled (Km)	Trucks number	vehicle number	satellites number : opining satellites/number of assigned customers	TLR	VLR
F1	Em_min	40543	1538	356	2	7	2 : S1/12; S4/8	55,80%	78,65%
	Em_st_ct	43066	1457	375	3	7	3 : S1/14; S3/6	47,20%	76,25%
F2	Em_min	14826	713	167	1	3	1 : S3/12	54,00%	90,00%
	Em_st_ct	16425	690	223	1	3	1 : S1/12	54,00%	90,00%
F3	Em_min	11345	501	160	1	2	1 : S4/8	30,20%	50,50%
	Em_st_ct	13088	451	168	1	2	1 : S1/8	30,20%	50,50%
Total NCS	Em_min	66714	2752	683	4	12	3 : S1/12;S4/16;S3/12	46,67%	73,05%
=F1+F2+F3	Em_st_ct	72579	2598	766	5	12	2 : S1/36; S3/6	43,80%	72,25%
CS	Em_min	31422	2421	351	4	11	3: S1/4;S3/20;S4/16	46,60%	83,00%
	Em_st_ct	65324	2169	613	5	11	3: S1/21;S3/9;S4/10	43,00%	82,06%

TLR: Load rate of tracks VLR: Load rate of vehicle

In both scenario NCS, the solution constrained by transportation cost limit (Em_st_ct) had higher CO2 emissions than the base case (Em_min). This result can be explained by the increase of distances travelled in Em_st_ct case (see figure 3) due to change in the opened satellites and the allocation of customers to them. These satellites have less expensive opening or transhipment costs which justify the increase of transportation cost.

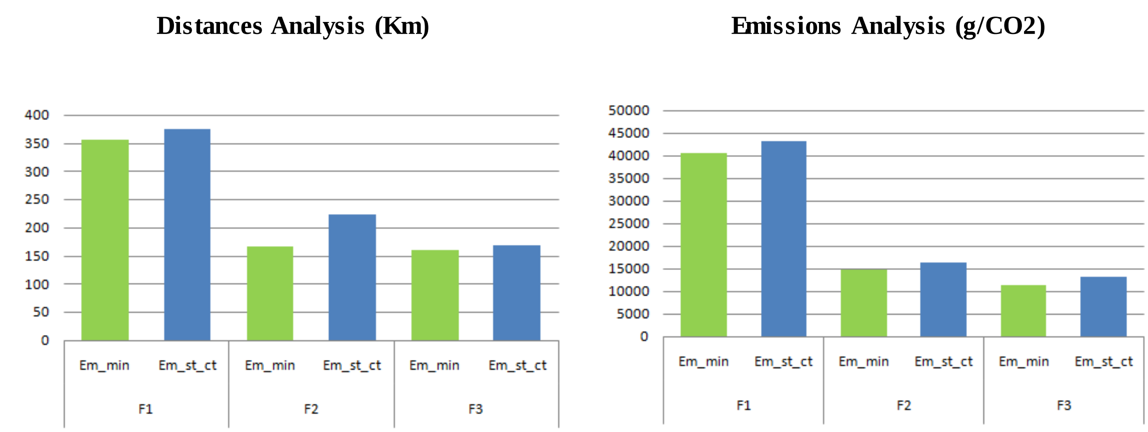

Figure 3. CO2 emissions and distances analysis of solutions of two cases (Em_min versus Em_st_ct) in non collaborative scenario

To evaluate the potential effects of horizontal collaboration in the transportation scheme studied in this paper, the cooperative scenario CS is compared to its non-cooperative counterpart NCS (see table 2). Results illustrate the positive environmental and economical effect of the supplier's collaboration. It can be seen that the cooperative scenario outperforms the non-cooperative one in all considered cases. From Figure 4, in the base case (Em_min), 52,90% total CO2 emissions and 12,03% total cost reductions have been obtained. In the case Em_st_ct , compared to Em_min case, CO2 emissions gains decreased to 10% and transportation cost gains increased to 16,5%.This can be explained by the decrease of distances gains in the Em_st_ct case related to the new customers' allocation to opened satellites.

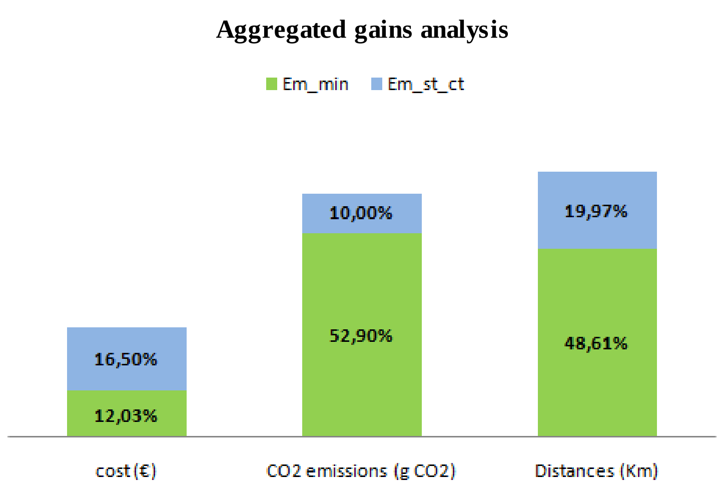

Figure 4. Aggregated gains analysis in collaborative scenario

The partners are not, generally, interested in the profits generated by the entire alliance, but in the impact of the cooperation on their own P&L (profit and lost) instead (Vanovermeire et al. 2014). A wide range of possible cost (or profit) allocation methods have been developed (Frisk et al. 2010). The most prevalent concepts for cost allocation

in cooperative game theory are the Shapley value. This method is easy to calculate, and remains the most commonly used in practice (Krajewska et al. 2007). As explained in (Vanovermeire et al. 2014) ,for each player, this value is calculated as the weighted average of the marginal contributions of a player to any possible coalition that can be formed given the game at hand. This implies that the cost effect that each player generates when he is added to the coalition as well as the different sub-coalitions is used to determine the allocated profit. The Shapley value can not only divide cost, but also other (metrics) gains such as service level or CO2 emissions.
Given a player i, a coalition N, which consists of sub-coalitions S ⊆ N, that each generates a cost c(S), the Shapley value is:

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

In this work, we allocate the collaborative CO2 emissions and transportation cost with the Shapley value method for both cases Em_min and Em_st_ct. To be able to divide the cost allocation according to the Shapley value, the costs of the sub-coalitions are also determined by creating lists that contain orders of the sub-coalitions and repeating this calculation. The total cost is then divided over the different companies by using the Shapley value.

Results are presented in Figure 5. They show that collaboration can result in more considerable cost and CO2 emissions reductions than those that individual companies can achieve.

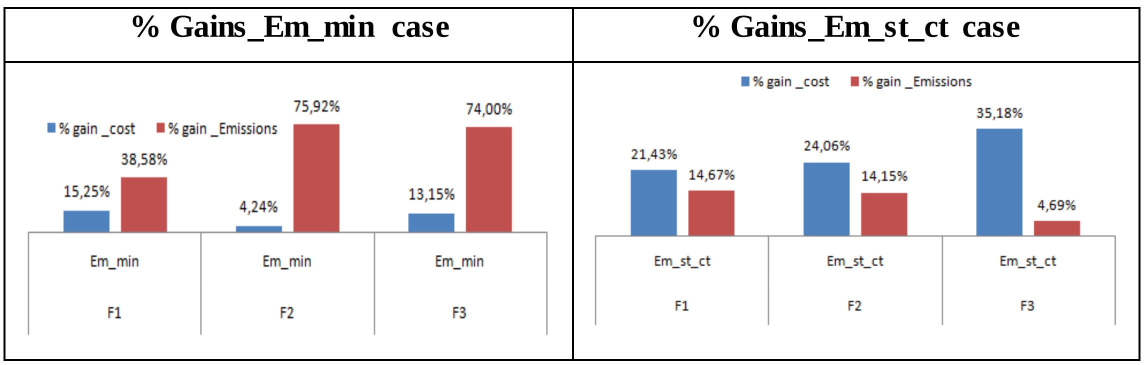

Figure 5. Analysis of Cost and emissions gains allocated to each partner in collaborative scenarios

By comparing gains allocated to each supplier in the two cases (Em_min and Em_st_ct) in collaborative scenario we can see that in Em_st_ct case, gains related to cost and CO2 emissions change based on the supplier size. When the supplier size increases, the CO2 emissions increase and the cost gains decrease. In Em_min case, we can't remark the same trend. The medium size supplier (F2) generated the higher CO2 emissions gain and the smaller cost gain.

5. Conclusion

In this paper, we propose a preliminary decision support tool for evaluating the environmental benefits of collaborative the freight delivery in urban areas before that companies agree to participate in a horizontal cooperation scheme and studying the sensitivity of the CO2 emissions versus total transportation cost reduction.The main goal was to help decision makers to be in compliance with environmental regulation and maintain the control of the transportation cost when optimizing CO2 emissions generated by transportation. A modeling approach based on bi-objective mathematical programming optimization was adopted. To obtain the tradeoffs between different types of objectives, the model was solved with the ε-constraint method with Matlab solver using extended known 2E-LRP instances reflecting real distribution urban area. Results show that a collaborative approach can reduce CO2 emissions, transportation costs, the number of vehicles used, and indirectly minimize nuisance and traffic congestion in cities. Social concern was omitted from this work but can be easily extended to the model.

Concerning the conclusions drawn in this work, we want to emphasize that they only apply to the developed experimental design. However, reviewing current literature reveals that the results presented here display clear similarities with conclusions drawn in other logistics collaboration contexts.

As an extension of this work, the complexity of the model adopted requires choosing a heuristic resolution, especially for instances with a large number of served points. It will also be advisable to study the sensitivity of the results when using heterogeneous vehicles.

Finally, the inclusion of other product life cycle stages such as production and reverse logistics activities can be added to the model to study the whole supply chains.

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