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Consolidation centers in city logistics: A cooperative approach based on the location routing problem

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A B S T R A C T

In the context of city logistics, freight transportation is one of the prominent causes of traffic congestion, high levels of pollution, and safety concerns. To decrease the negative impact of these issues, different methods have been traditionally implemented. On the one hand, the location of urban consolidation Centers (UCCs) near a city can be used to consolidate freight delivery services. Therefore, the number of trucks moving in urban areas can be reduced. On the other hand, Horizontal Cooperation can also help to reduce environmental impact while increasing service level. This paper combines both strategies, that is, we deal with the location of UCCs and, simultaneously, we analyze different scenarios where the players of different supply chain processes exhibit various levels of cooperation. Thus, different levels of cooperations regarding routing and UCCs-location decisions are considered in the following scenarios: (a) non-cooperative case, in which all decisions are decentralized (i.e., each enterprise solves its own vehicle routing problem); (b) low-cooperative case, where depot capacities are shared but the customers are still being served by each company's fleet of vehicles; (c) semi-cooperative case, based on centralized route planning decisions (i.e. facilities and fleets are shared among participating enterprises); and (d) fully cooperative scenario, where the routing plans and facility-location decisions are taken by consensus amongst all the participants. In order to estimate the benefits of both strategies, we propose a flexible metaheuristic algorithm to deal with the combined location and routing problem under the different cooperative scenarios. Our results show impressive benefits of the proposed approach.

1. Introduction

Urban goods distribution is a crucial component for the well-being of an inner city. However, the transportation of goods generates noise, air pollution, congestion and lower levels of traffic safety, which are troublesome issues in urban logistics. In addition, some urban structural designs and policies that have been implemented to reduce these issues might have a negative impact on the efficiency of transportation activities. This results in higher travel times, reduced service quality (reliability), and logistic systems using more vehicles than required (Van Binsbergen & Visser, 1999).

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Thus, Horizontal Cooperation (HC) appears as an alternative to execute transportation tasks (Serrano-Hernandez et al., 2017). HC has the potential to reduce logistics costs as well as the related environmental impact of delivery tasks, especially those associated with greenhouse gas emissions and noise. The sharing of information (e.g. customer demands or geo-positional data of available vehicles) and facility capacities among members of the same supply chain level promises to be an innovative transportation concept in last-mile deliveries. HC in logistics involves two or more companies cooperating to achieve a common goal, which is usually related to the optimization of the global distribution cost. Through close cooperation the partnering agents aim at reaching higher productivity levels by optimizing the usage of vehicle capacity, reducing the number of empty trips, improving the allocation of vehicles and depots, and lowering costs of complementary tasks in order to increase the efficiency of their logistics network (Cruijssen et al., 2007a). Different degrees of cooperation can be considered, as pointed out by Quintero-Araujo et al. (2019).

Urban consolidation centers (UCCs) are locations in or near cities where freight vehicles (long haul) deliver goods. These goods are then consolidated and delivered to numerous points across the city, ideally using eco-friendly vehicles (electric or hybrid vehicles). Using UCCs considerably cuts down the number of kilometers traveled by larger and more polluting freight vehicles, which saves fuel and reduces emissions. Hence, making cities cleaner and healthier for their citizens.

According to the advantages pointed out by Thompson and Taniguchi (2008), the creation of UCCs allows for a much more efficient urban logistics system, with the same capacity of service than conventional systems but with lower environmental impacts. Optimally determining the location and operation of UCCs would not only have an economic impact, but also an environmental and a social one as well. The Location Routing Problem (LRP) is incorporated in the UCC problem. The LRP is one of the most complete problems in logistics and transportation, since it involves all the decision levels involved in the design and management of supply chains, these are: *(i)* strategic decision making for the location of UCCs; *(ii)* tactical decision making regarding the customer allocation to available UCCs; and *(iii)* operational decision making to assign delivery routes to each UCC and its associated customers.

Traditionally, these different decision-making levels have been considered independently in the literature. Thus, in order to fulfill this gap, we propose the combined use of these strategies. In addition, for the first time in the literature, we assume that some of the companies involved in the final distribution of goods to customers are not willing to participate in the HC alliance. As mentioned before, this paper concentrates on the implementation of HC strategies when considering the location of consolidation centers and the associated vehicle routing to reduce operational costs and environmental impacts. In order to achieve this goal, an integrated approach based on the LRP is adopted to find the location of urban consolidation centers. The LRP is a combination of the Facility Location Problem (FLP) and the Vehicle Routing Problem (VRP), so it is an NP-hard problem. In addition, these scenarios are observed and analyzed according to different percentages of cooperation among several distribution companies. This work differs from previous ones by considering that there are companies which could not be interested in being part of the cooperation agreement. In that sense, we have considered for each cooperative scenario (i.e. scenarios 2, 3, and 4, explained later) three sub-scenarios with 50%, 75%, and 100% of companies participating in the partnership, respectively.

According to the level of cooperation, the aforementioned scenarios are addressed, and the resulting optimization problems are solved by employing a metaheuristic algorithm. This algorithm enables us to deal with the combined location and routing problems. The structure of the paper is as follows. Section 2 presents a literature review on HC concepts, UCCs, and the LRP. Section 3 introduces the problem under study. Section 4 describes the methodology used in this work, together with the proposed solution approach. In Sections 5 and 6 we specify the experiments that were carried out and present the results of the executed tests, respectively. Finally, Section 7 presents some conclusions and outlines further research lines.

2. Literature Review

The literature review is structured in three parts. The first part reviews the benefits and the types of HC of land-side transportation and logistics in urban areas. The second part concentrates on the implementation of HC, especially on the advantages of employing UCCs, and the impact of UCCs in city logistics. Finally, the third part focuses on the LRP for allocation of UCCs to optimize transportation in city logistics.

2.1. Horizontal Cooperation

When it comes to city logistics development, HC is widely discussed as one of the innovative solutions, which comprises the cooperation of participants in different supply chain levels in urban areas (Cruijssen et al., 2007a). Despite the practice of HC is well documented for maritime and aviation transportation, it is still an emerging topic in the context of land-side transportation and logistics (Pomponi et al., 2013). Synergies obtained from cooperation are consequently the main reasons for implementing HC practices. Cruijssen et al. (2007b) explained in detail the role of HC in transportation and logistics and its implications. Vanovermeire et al. (2014) proposed a strategy to allocate costs among the partners.

Perez-Bernabeu et al. (2015) analyzed HC in road transportation under different scenarios, where distance and environmental costs were considered. To understand the importance of HC in city logistics, it is also important to consider non-cooperative scenarios. In this regard, Quintero-Araujo et al. (2017b) compared non-cooperative and HC by formulating a multi-depot vehicle routing problem and embedding Monte Carlo simulation into a metaheuristic process. Quintero-Araujo et al. (2016) analyzed the effects of implementing HC among three Colombian companies, while considering uncertain demands. Later, Quintero-Araujo et al. (2017c) extended the previous scenarios by integrating facility location decisions to the routing process. Recently, Muñoz-Villamizar et al. (2018) analyzed the use of electric vehicles in collaborative urban freight distribution. Regarding collaborative strategies in vehicle routing, readers are referred to Gansterer and Hartl (2018) who present an updated review on the topic.

HC is often discussed in the context of city logistics development, which is based on the cooperation of different supply chain actors in urban areas. Serrano-Hernandez et al. (2017) analyzed the main benefits and optimization challenges associated with the use of HC at the strategic, tactical, and operational levels.

2.2. Urban Consolidation Centers

UCCs play an important role in supply chain management, as they constitute the main facilities where the consolidated cargo is transshipped from large and polluting vehicles to smaller environmentally friendly ones. These smaller vehicles are utilized to perform the last-mile distribution in urban zones. This configuration aims to protect urban and restricted areas from high traffic density and environmental externalities, thus improving safety and quality of life. Although costly and time demanding, it has been proved that these city logistics strategies are effective, relieve traffic, and safeguard the environment (Grimm et al., 2008). Allen et al. (2012) compared 114 UCC schemes in 17 countries. These schemes have been either feasibly studied, made a trial run or fully operated in the past 40 years. Some of the best known implementations of consolidation centers are in the Europeans cities of Nijmegen (Van Rooijen and Quak, 2010) and London (Browne et al., 2012; Patier & Browne, 2010). Browne et al. (2011) evaluated the trial run made by a major office supplies company in central London to reduce freight traffic and its impacts by considering UCCs. This led to reductions in total distance and CO_2 emissions of 20% and 54%, respectively, per parcel delivered. De Assis Correia et al. (2012) presented a methodology to analyze the economic and environmental impacts of UCCs in Belo Horizonte (Brazil). To allocate the freight carriers, the main criteria is the selection of most appropriate locations for establishment of each facility and the solution of the corresponding vehicle routing for efficient delivery of goods to customers. Gogas and Nathanail (2017) provided a methodology for solving an FLP and an integrated assessment model used to evaluate the operation of UCCs. To achieve optimal transport in city logistics and to reduce environmental impacts, the location of the UCCs and the associated vehicle route planning for deliveries in urban areas are crucial. These two problems are solved as an integrated LRP.

2.3. The Location Routing Problem

The LRP comprises all decision levels (strategic, tactical, and operational) in supply chain management. Strategic decisions are related to the number and size of facilities to be opened, while tactical and operational ones are associated with customers' allocation to opened facilities and the corresponding distribution routes, respectively. In terms of classical optimization problems, the LRP combines the FLP -which is associated with strategic decisions-, and the multi-depot vehicle routing problem (MDVRP), which is related to customers' allocation to facilities and the subsequent route planning (Nagy & Salhi, 2007). The benefits derived from considering routing decisions while locating facilities were firstly estimated in Salhi and Rand (1989). The authors proved that solving the associated subproblems (i.e., FLP and VRP) independently, does not necessarily generate optimal solutions. Despite the importance of the LRP in supply chain management, the number of published works is lower than the number of articles related to other VRP variants. However, the amount of publications related to the topic has increased considerably in recent years.

Muñoz-Villamizar et al. (2013) solved the combined LRP in urban scenario by using a hybrid algorithm which employs biased-randomization into several stages of the optimization process. This research was carried out considering real-life data. Prins et al. (2006) proposed a Greedy Randomized Adaptive Search Procedure (GRASP) based on an extended and randomized version of the Clarke and Wright (1964) savings (CWS) algorithm called RECWA. This is combined with a learning process to identify promising subsets of depots and Path Re-linking as a post optimization step. Quintero-Araujo et al. (2017a) presented an efficient and simple approach for solving the CLRP. The proposed method combines biased randomization techniques with perturbations of the allocation maps to generate good solutions for the CLRP.

Solving the VRP using green logistics comprises a number of problems. Reyes-Rubiano et al. (2018) proposed a metaheuristic approach for the MDVRP, while considering economic, environmental, and social dimensions. This paper also discusses how the cost values change according to the prioritized dimension. Further, Juan et al. (2014) discussed the VRP with multiple driving ranges by considering heterogeneous fleet and attempted to solve the problem by applying a multi-round heuristic algorithm.

3. Description of Horizontal Cooperation Scenarios

Four different scenarios of urban distribution are considered in this paper to study the effect of horizontal cooperation, in the context of a problem that combines the location of UCCs and the associated VRPs to serve customers demands in the most efficient way. In the following sub-sections, an overview of each scenario is provided.

3.1. Non-Cooperative Scenario without UCCs

In a non-cooperative scenario, we assume that each company serves its allocated customers from its central depot employing its own vehicles. Both the depot and the available vehicles have limited capacities. In other words, both the location of UCCs and the implementation of HC strategies are not considered.

3.2. Depot Cooperation without UCCs

In this scenario, the location of UCCs is not considered, that is, each company uses its own central depot. While the objective function is to minimize the total cost, the main criterion is to implement HC in terms of sharing depots among companies. The problem constraints include that customers are served only by the company they were allocated to and are served only by this company's vehicles. That is, vehicles of different companies deliver the demand of their own customers, but the vehicles can depart from different depots, even if these are not the company's depot. Here, we study the following different percentages of HC among the companies and its impact on total cost and travel costs (including distances, times, and CO_2 emissions):

a) 50% cooperation level: from the case study, only 50% of the companies share their depots (still, fleets are not shared, so each company delivers its own customers).
b) 75% cooperation level: 75% of the companies share their depot capacities (this includes the ones in the previous case plus a new 25%).
c) 100% cooperation level: all companies share their depot capacity with others (still, each company services its own customers).

3.3. Depot and Fleet Cooperation without using UCCs

Once again, the location of UCCs is not taken into account in this scenario. In addition, companies cooperate to execute the goal of serving different customers. Here we assume the cooperation includes sharing of depot capacities as well as the fleet of vehicles. Each customer must be assigned to an existing depot and, subsequently, a set of routes is planned to satisfy all customer demands. This scenario corresponds to a MDVRP. As before, different percentage levels of cooperation, in terms of participating companies, are considered: 50%, 75%, and 100%.

3.4. Depot and Fleet Cooperation using UCCs

In this fully-cooperative scenario with UCCs the degree of joint supply chain decisions increases. By sharing customer information, storage facilities, and vehicle capacities, route planning can be optimized on a supply chain level through a more efficient customer-depot allocation. Apart from jointly planning the delivery routes, this scenario also includes the joint determination of the most efficient number and location of logistics facilities. As before, this scenario is analyzed with 50%, 75%, and 100% of cooperating enterprises. This scenario corresponds to a LRP, which integrates: *(i)* facility location decisions; *(ii)* customer assignment; and *(iii)* delivery route planning (Prodhon & Prins, 2014).

4. Solving Methodology

Once all scenarios have been defined, our methodology consists of: *(i)* identifying the related optimization problems; *(ii)* developing a general algorithm to efficiently solve all scenarios; and *(iii)* analyzing the obtained results. Scenario 1 can be represented by a set of capacitated VRPs, one per each considered company. The MDVRP can be used to represent Scenarios 2 and 3. Finally, scenario 4 can be modeled as an integrated LRP.

The first approach to solve the problem is based on two main concepts. The initial idea is to develop a relatively easy-to-implement algorithm without too many parameters. In addition, we make use of Biased Randomization (BR) techniques (Juan et al., 2013) to obtain good-quality solutions, which are then integrated inside a traditional Iterated Local Search (ILS) framework (Lourenco et al., 2010). BR has been successfully used in several fields. Dominguez et al. (2014) apply a biased randomized constructive routing heuristic to solve the two-dimensional capacitated VRP. Alvarez Fernandez et al. (2018) used a BR-ILS to tackle a particular facility location problem: the uncapacitated single allocation p-hub median problem. Likewise, BR has been profitably applied to scheduling problem in Gonzalez-Neira et al. (2017). In order to better guide the random search process, BR techniques introduce biased (non-uniform) randomness in such a way that the logic behind the deterministic heuristic is conserved (Grasas et al., 2016). Thus, to generate random but good solutions a biased-randomized version of the classical CWS heuristic is used.

Two main phases define our solving strategy: *(i)* generation and selection of feasible and most promising solutions; and *(ii)* enhancement of the selected solutions. To generate feasible solutions the problem is divided into a set of successive steps and the complexity of the problem is lowered by using simple and fast procedures. Indeed, the first step in the construction of a new solution consists of deciding which depots to open. Because scenarios 1, 2, and 3 do not contemplate UCCs, all depots are opened. In the fourth scenario, all depots belonging to non-cooperative companies are opened (but they can also be used by the owner). Moreover, a random subset of the shared depots is also opened. The second step of the constructive phase consists of assigning the customers to the opened depots. Each client is served by a specific company. The clients of companies that are not cooperating are assigned to the depot of the company to which they are affiliated. The remaining customers are randomly assigned to some of the shared depots. In the last step, the routes are created with the biased-randomized version of the aforementioned CWS heuristic (BR-CWS). An example of the constructive phase is depicted in Fig. 1.

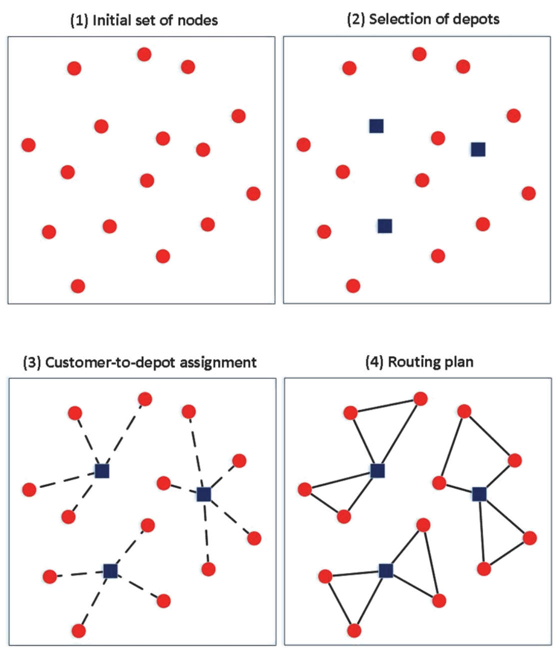

Fig. 1. Construction of a new solution.

The pseudo-code of the algorithm is depicted in Algorithm 1. Line 2 identifies the first phase of the algorithm. The second phase (lines 3-27) represent the ILS framework. Each of the best *nSol* solutions generated in the first phase are processed by the ILS in order to improve their quality. At each iteration, the base solution is perturbed in order to increase the diversification of the algorithm (line 6), and a local search is applied to the solution obtained (line 9). If the new solution is better than the base solution, the latter is updated (lines 11-13); otherwise a Demon-based acceptance criterion -based on the concept of accumulated credit- is used to accept even worst solutions (lines 16-18). At the end, the output of the algorithm is the best solution that it could find (line 27). The perturbation operation aims at modifying the customer-to-depot allocation. A percentage of shared customers are reassigned to the shared depots and the BR-CWS heuristic is used to generate the routes. The local search operator that was applied is a 2-opt intra-route exchange.

5. Computational Experiments

The proposed solving framework was implemented as a Java application and tested on a Dell Workstation Precision Tower Serie 7000 (7910), with CPU Intel Xeon E5-2650 at 2.2GHz and 32GB of RAM. Each instance was solved using ten different random seeds. Thus, the reported results correspond to the best-found solution in these runs. After a quick parameter fine-tuning experimentation, the following parameter settings are applied for our BR-ILS algorithm:

- Stopping criterion for the first phase: 1000 iterations.
- Probability distribution for the biased-randomized process in the constructive phase: geometric distribution with a parameter β , which is randomly selected in the interval (0.07, 0.23).
- Perturbation (customers re-allocation) percentage: a random value is selected in the interval (0.1, 0.5).

Algorithm 1

Solving Approach

```
Function BR-ILS(inputs,parameters)
  baseSols ← createInitialSolutions(inputs,parameters) ;
  cost(bestSol) ← +∞ ;
  foreach baseSol ∈ baseSols do
    while stopping criteria not reached do
      newSol ← perturbate(baseSol);
      improving ← true;
      while improving do
        newSol ← localSearch(newSol);
        delta ← cost(baseSol) – cost(newSol);
        if delta ≥ 0 then
          credit ← delta;
          baseSol ← newSol;
        else
          improving ← false;
          if -delta ≤ credit then
            credit ← 0;
            baseSol ← newSol;
          end if;
        end if;
      end while;
      if cost(bestSol) > cost(baseSol) then
        bestSol ← baseSol;
      end if;
    end while;
  end foreach;
return bestSol;
```

The proposed algorithm was used to solve the problem instances proposed by Akca et al. (2009), in order to validate its performance. Then, we compared our results to the corresponding best-known solutions (BKS) reported in literature. As shown in Table 1 our algorithm has an average gap of 0.36% with respect to the BKS. Moreover, we reach 3 BKS over 12 instances and our worst gap is below 1%. Next, we adapted the instances from Akca et al. (2009) for each of the considered scenarios. The possible facility locations are capacitated, and the vehicles are homogeneous and capacitated. The objective is to minimize the overall distribution cost, which is computed as the sum of facility opening, vehicle, and routing costs. In order to represent the scenarios without UCCs, it is assumed that all possible facility locations are opened. Also, the CO_2 emissions model employed in the study by Ubeda et al. (2011) is used here to estimate the environmental impact of the different scenarios. Since this model calculates CO2 emissions depending on traveled distance and vehicle load, travel distances and vehicle loads are estimated as outlined in Table 2. The emissions depend also on the direction of the delivery route. Since customers have different demands, the load of the vehicle in a given edge will be different depending on the direction of the route. Therefore, emissions for each route are calculated in both directions. The reported emissions represent the lowest value obtained for both computations.

Table 1
Comparison of our results against BKS for the CLRP - Akca's set

Instance Name	BKS	OBS	GAP
cr30×5a-1	819.51	819.51	0.00%
cr30×5a-2	821.45	826.57	0.62%
cr30×5a-3	702.29	707.97	0.81%
cr30×5b-1	880.02	881.5	0.17%
cr30×5b-2	825.32	825.32	0.00%
cr30×5b-3	884.58	884.58	0.00%
cr40×5a-1	928.1	931.5	0.37%
cr40×5a-2	888.42	889.57	0.13%
cr40×5a-3	947.26	948.64	0.15%
cr40×5b-1	1052.04	1058	0.57%
cr40×5b-2	981.54	990.58	0.92%
cr40×5b-3	964.33	969.76	0.56%
Average			0.36%

Table 2
Estimation of Emission Factors (Adapted from Ubeda et al. (2011))

Vehicle load	Load Percentage	Consumption (l/100km)	Conversion factor (kg CO_2/l)	Emission factor (kg CO_2/km)
Empty	[0-25)	29.6		0.773
Low	[25-50)	32		0.831
Half	[50-75)	34.4	× 2.61	0.900
High	[0.75-100)	36.7		0.958
Full	100	39		1.018

Table 3
Results for Scenarios 1 and 2

	Scenario 1				Scenario 2											
					50%				75%				100%			
Instance	Opening Cost	Routing Cost	Total Cost	CO_2	Opening Cost	Routing Cost	Total Cost	CO_2	Opening Cost	Routing Cost	Total Cost	CO_2	Opening Cost	Routing Cost	Total Cost	CO_2
cr30×5a-1	500	1401.39	1901.39	1179.93	500	1401.39	1901.39	1179.93	500	1390.80	1890.80	1170.59	500	1351.75	1851.75	1133.15
cr30×5a-2	500	1475.41	1975.41	1246.66	500	1415.65	1915.65	1183.38	500	1387.12	1887.12	1169.25	500	1366.39	1866.39	1144.88
cr30×5a-3	500	1109.65	1609.65	941.14	500	1109.65	1609.65	941.14	500	1094.64	1594.64	923.14	500	1094.64	1594.64	923.14
cr30×5b-1	500	1601.15	2101.15	1336.37	500	1539.40	2039.40	1271.04	500	1601.04	2101.04	1339.48	500	1443.94	1943.94	1206.94
cr30×5b-2	500	1537.81	2037.81	1316.19	500	1504.27	2004.27	1261.56	500	1491.72	1991.72	1276.24	500	1485.46	1985.46	1271.74
cr30×5b-3	500	1399.87	1899.87	1180.55	500	1364.58	1864.58	1149.44	500	1374.63	1874.63	1160.30	500	1359.74	1859.74	1147.66
cr40×5a-1	500	1388.28	1888.28	1170.23	500	1388.28	1888.28	1170.23	500	1339.59	1839.59	1125.00	500	1345.28	1845.28	1137.70
cr40×5a-2	500	1722.27	2222.27	1474.20	500	1689.83	2189.83	1374.71	500	1596.52	2096.52	1341.31	500	1629.35	2129.35	1355.49
cr40×5a-3	500	1458.21	1958.21	1229.49	500	1458.21	1958.21	1229.49	500	1424.10	1924.10	1204.26	500	1354.04	1854.04	1126.42
cr40×5b-1	500	1903.30	2403.30	1614.70	500	1784.49	2284.49	1485.61	500	1847.21	2347.21	1560.99	500	1683.55	2183.55	1408.41
cr40×5b-2	500	1815.70	2315.70	1529.76	500	1815.70	2315.70	1529.76	500	1690.02	2190.02	1422.33	500	1707.24	2207.24	1432.66
cr40×5b-3	500	1576.11	2076.11	1327.36	500	1576.11	2076.11	1327.36	500	1575.36	2075.36	1323.12	500	1549.84	2049.84	1310.07
Average	500	1532.43	2032.43	1295.55	500	1503.96	2003.96	1258.64	500	1484.40	1984.40	1251.33	500	1447.60	1947.60	1216.52

Table 4
Results for Scenario 3

	Scenario 3											
	50%				75%				100%			
Instance	Opening Cost	Routing Cost	Total Cost	CO_2	Opening Cost	Routing Cost	Total Cost	CO_2	Opening Cost	Routing Cost	Total Cost	CO_2
cr30×5a-1	500	1229.55	1729.55	1032.86	500	1069.97	1569.97	915.98	500	964.38	1464.38	817.34
cr30×5a-2	500	1258.38	1758.38	1062.01	500	1112.68	1612.68	942.97	500	928.86	1428.86	783.74
cr30×5a-3	500	993.73	1493.73	850.36	500	863.89	1363.89	737.81	500	725.08	1225.08	597.51
cr30×5b-1	500	1442.80	1942.80	1203.95	500	1141.09	1641.09	978.79	500	1055.46	1555.46	888.78
cr30×5b-2	500	1396.47	1896.47	1190.31	500	1274.17	1774.17	1085.34	500	1000.11	1500.11	844.41
cr30×5b-3	500	1302.21	1802.21	1098.84	500	1164.49	1664.49	990.12	500	1006.23	1506.23	860.86
cr40×5a-1	500	1248.31	1748.31	1040.92	500	1160.09	1660.09	977.40	500	990.48	1490.48	831.55
cr40×5a-2	500	1473.50	1973.50	1241.14	500	1396.45	1896.45	1182.44	500	1067.98	1567.98	906.37
cr40×5a-3	500	1330.54	1830.54	1126.42	500	1147.16	1647.16	973.18	500	1030.62	1530.62	874.14
cr40×5b-1	500	1675.46	2175.46	1425.90	500	1405.33	1905.33	1182.64	500	1237.57	1737.57	1062.63
cr40×5b-2	500	1551.41	2051.41	1308.57	500	1420.08	1920.08	1214.20	500	1156.36	1656.36	995.52
cr40×5b-3	500	1425.17	1925.17	1214.94	500	1307.25	1807.25	1106.41	500	1090.18	1590.18	933.07
Average	500	1360.63	1860.63	1149.68	500	1205.22	1705.22	1023.94	500	1021.11	1521.11	866.33

Table 5
Results for Scenario 4

Instance	Scenario 4											
	50%				75%				100%			
	Opening Cost	Routing Cost	Total Cost	CO_2	Opening Cost	Routing Cost	Total Cost	CO_2	Opening Cost	Routing Cost	Total Cost	CO_2
cr30×5a-1	400	1229.55	1629.55	1032.86	400	1051.66	1451.66	901.33	200	753.01	953.01	647.57
cr30×5a-2	400	1258.38	1658.38	1062.01	400	1094.35	1494.35	936.70	200	794.92	994.92	686.04
cr30×5a-3	400	993.73	1393.73	850.36	300	881.51	1181.51	762.12	200	645.16	845.16	553.23
cr30×5b-1	400	1447.67	1847.67	1209.26	300	1167.30	1467.30	994.74	200	876.25	1076.25	747.85
cr30×5b-2	400	1396.47	1796.47	1190.31	300	1248.47	1548.47	1067.27	200	864.18	1064.18	755.20
cr30×5b-3	400	1294.12	1694.12	1102.12	300	1160.54	1460.54	997.24	200	873.31	1073.31	757.19
cr40×5a-1	400	1301.30	1701.30	1091.43	300	1162.48	1462.48	984.24	200	850.95	1050.95	729.74
cr40×5a-2	400	1521.75	1921.75	1289.07	300	1366.66	1666.66	1162.70	200	864.93	1064.93	741.92
cr40×5a-3	400	1330.43	1730.43	1126.75	300	1114.06	1414.06	947.85	200	920.79	1120.79	787.08
cr40×5b-1	400	1675.46	2075.46	1425.90	300	1354.90	1654.90	1157.06	200	1047.02	1247.02	907.75
cr40×5b-2	400	1577.87	1977.87	1339.96	300	1330.84	1630.84	1142.67	200	957.04	1157.04	836.27
cr40×5b-3	400	1426.13	1826.13	1216.98	300	1256.29	1556.29	1071.23	200	964.63	1164.63	847.66
Average	400	1371.07	1771.07	1161.42	316.66	1182.42	1499.09	1010.43	200	867.68	1067.68	749.79

6. Analysis of Results & Insights

Savings in costs and in CO_2 emissions were expected as HC strategies were considered. The results reported in Tables 3 to 5 on the different scenarios confirm this hypothesis. Regarding the non-cooperative scenario, HC entails cost savings of 4.17%, 25.16%, and 47.47% in the first three, respectively, scenarios with 100% of cooperation in the fourth scenario. Emissions have a similar behavior, the environmental impact can be reduced by 6.10%, 33.13%, and 42.13%, respectively.

In general, our results suggest that both total costs and environmental impact can be reduced via the use of HC practices. Moreover, as showed by the results depicted in Fig. 2 and Fig. 3, the savings are strongly dependent on the cooperation percentage. Clearly, a higher level of cooperation among the agents induces larger benefits for both total costs and CO_2 emissions. Adopting this approach in a real-life scenario can substantially optimize the total cost of transportation and, at the same time, reduce the environmental cost for all supply chain partners. Some of the main advantages are: *(i)* a substantial reduction in warehousing and maintenance cost; *(ii)* an opportunity to increase the capacity and service levels offered to customers; *(iii)* a reduction in transit times, with faster delivery of goods; *(iv)* a complete utilization of the vehicle capacity, as the routing is planned for customers of different companies; *(v)* CO_2 emissions are reduced and shared among the partners for the last mile delivery, thus the carbon footprint of individual players is reduced; *(vi)* strategically planning in locating the consolidation centers and associated capacities and routing helps to better understand the market and the customers' needs; this also provides a great benefit as companies can provide better services to existing customers and business is improved; *(vii)* there can be a considerable advantage in economies of scale as the cost reduces and the delivery time increases; *(viii)* adopting a fully cooperative scenario provides benefits such as a reduction in individual investment costs, thorough research of the market, and higher levels of marketing and servicing.

7. Conclusions

This paper analyzes the use of HC concepts in routing and locations decisions. Four different scenarios are considered: *(i)* a non-cooperative scenario, in which all companies take decisions without any form of cooperation; *(ii)* a partial-cooperation scenario, in which the capacities of the depots are shared by different companies but each company uses its own fleet of vehicles to serve its clients; *(iii)* an advanced-cooperation scenario, in which both depot capacities and vehicle fleets are shared; and *(iv)* a total cooperation scenario, in which also the decision about which depots have to be opened is shared. Moreover, each scenario (except the non-cooperative one) is investigated under different cooperation settings. Particularly, three percentage levels of cooperation among companies are taken in account for each scenario: 50%, 75%, and 100%.

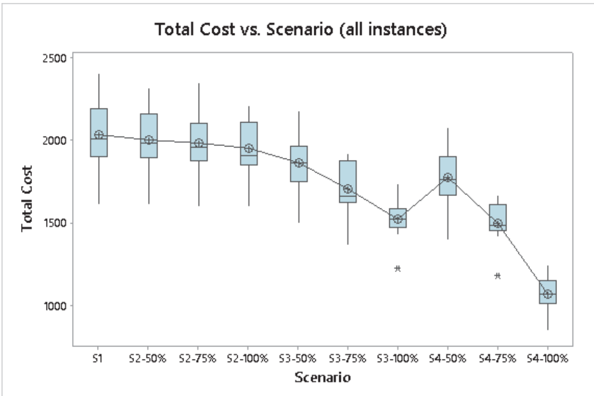

Fig. 2. Comparison of Total Costs for the Different Scenarios

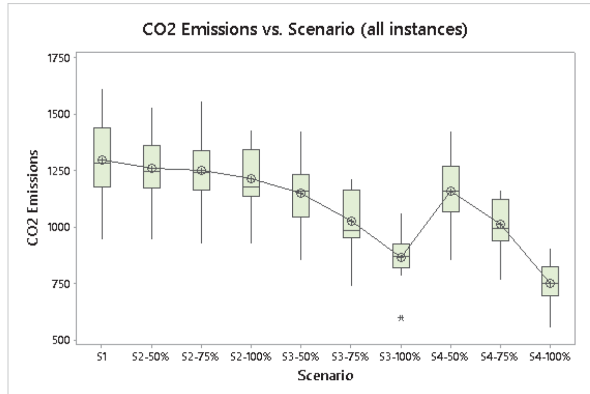

Fig. 3. Comparison of Total Cost for the Considered Scenarios

The different problem settings are solved with a metaheuristic algorithm, which combines BR and ILS. All scenarios are compared through extensive experiments employing a well-known benchmark set. Reported results suggest that significant overall costs savings and a reduction in CO_2 emissions can be achieved with a higher degree of cooperation. Several research lines arise from this work. Some problem extensions introduce heterogeneous vehicles or the inclusion of stochastic values (demands, travel times, etc.) in order to tackle even more realistic scenarios.

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