An Integrated Model for Locating-Routing in the Goods Delivery and Simultaneous Pickup in the Urban Context

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Abstract. Bibliographic research on facilities location and vehicle routing shows interest in the academic community and contributes to the welfare in cities. In this sense a Mixed Integer linear new Programming model is presented to optimise cost by integrating location and routing. This process is about delivering and collecting goods and wastes at the same time in order to maintain urban sustainability. It also determines the consumption of the used fuel and measures the C02 generation in the routing. This model was implemented by GLPK which obtained results in small simulated scenarios. For sceneries between 21 and 25 customers, optimal solutions were not found in 7200 s despite the timeout.

Keywords: Location · Vehicle routing · Urban sustainability

1 Introduction

Locating a production or distribution centre called facility, is an activity very important in the logistics systems such as the design of a net for a supply network since location is known in a geographic space where it will be possible to choose a centre that is nearer the customers who are the locators. After such localization it is possible to obtain a service for each customer by following a routing plan that starts and ends in the distribution centre, that is to say a vehicle routing. It is crucially important to integrate the facility location problems and vehicle routing but also considers the environment in the process of the logistic network routing. This can be done by integrating the values of cost and C02 emissions

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generated by the vehicles [2]. Facilities location and vehicle routing are two NP-hard problems [10,15], of the combinatorial optimization, for which it is possible to build linear programming models and solution techniques in the context of urban logistics [21].

In [15], examples of applications are presented in the regional planification, telecommunications and transportation as well the energy management. In [6], it is stated that vehicle routing has gained much attention with the distribution and logistic management. According to [13], this kind of problem is a research area that is considered within the locating analysis with emphasis on vehicle routing. This term is not well defined nevertheless it is considered within the location theory which models and solves location problems. It is being applied to food distribution, soda and goods consumption, location of blood banks besides factories and military equipment, delivery of newspapers, collecting wastes, designs of networks and telecommunications and so on. In [13], a review on location-routing is found, a more recent review is presented in [4].

Some models of location-routing have been focused on optimizing economic costs in [3,8], very few proposals have considered urban protection as in the case of transportation that is a great pollution agent [24].

In this work a location–routing model is presented in the urban context that besides optimizing economic costs according to distance travelled by the vehicles measures the amount of fuel that the vehicle is consuming and measures the quantity of C02 emissions generated in the routing process. In the model, the facilities initially locate a group of suppliers who meet your demands. These facilities in turn are located by a group of customers to whom a delivery service of their bought goods is provided and their wastes are collected, that is to say a process of two levels. The process starts and ends in the selected facility by the model according to the geographic location, the vehicle returns with the collected wastes from the customers. (See Fig. 1)

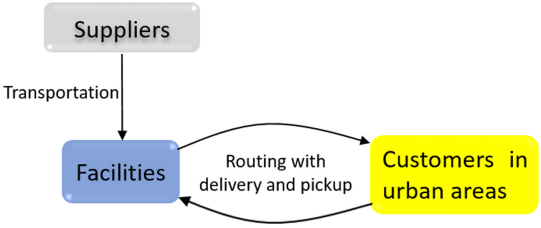

Fig. 1. Location-routing scheme with simultaneous delivery and pickup.

The paper consists of the following points: Sect. 2, this work is underpinned over this section. It is about a revision of the literature related to research. Section 3, the problem is discussed through a description and formulation of a mixed integer linear programming new model with two functions objectives. Section 4, the results and discussions are presented in this section. Section 5, the conclusions.

2 Review of the Literature

With the purpose of getting an integrated location-routing model, a revision of the location-routing literature is made and then experiments with some of these models are carried out but considering the environmental part.

2.1 Location

Four components should be taken into consideration for locating problems: The customers who are located in a geographic zone; the facilities that will be located to give a service; a geographic space where the customers and facilities are. Finally a metric that indicates the distances or time between customers and facilities [5]. From what has been said it follows, network planification integrates the decisions of locating facilities to others relevant in order to set up a logistic net.

The classical problem of facilities location presented in [3], has been very used in the design of supply chains. The problem refers to finding the locations of such facilities and a service they give the customers in such a way as to minimize the costs according to a set of conditions. For this problem, given a set of customers I and other facilities J, at least one solution involves serving the request of each customer $i \in I$ by $j \in J$ facility who will give a service.

A variation of the facility location model which is capacitated and presented in [3], can be seen in (1), it determines the quantity of CO2 generated by the vehicles in the process of serving the customers requests, that is to say quantifying the C02 emitted by the vehicles of transportation, as can be observed in the third sum of function objective. This formula is obtained by the Volvo Trucks Corporation, being X_{ijk} the variable of serving the customer i through the k vehicle whose capacity is q_k.

The two first summations of this variation of the model minimize the fixed costs of locating the facilities $f_j Y_j$ and transportation $c_{ij} X_{ijk}$ being f_j the parameter of fixed cost in the facilities location and Y_j the binary variable that represents location or no location of a better facility, besides c_{ij} that is the transportation cost between the customer and the facility. The third sum has been added to obtain such variation.

$$Minimize \ : \sum_{j \in J} f_j Y_j + \sum_{j \in J, i \in I} c_{ij} X_{ijk} + \sum_{j \in J, i \in I} cc \left(\frac{em_k}{q_k} \right) X_{ijk} \qquad (1)$$

Results of the computational experiments for this variation of the locating model are shown in the Fig. 2, where the capacitated location optimizes the costs since the customers of a total of five applicant facilities, $f_i, \forall i = 1, \ldots, 5$, only located the f_1 and f_3 facilities which are necessaries to give the service.

Discussions related to the facilities location with mathematical rigour are presented in [11], where differences between uncapacitated location and capacitated location are established. In the first case the customers are assigned to the nearer factories; in the second case the customers may not be assigned to the

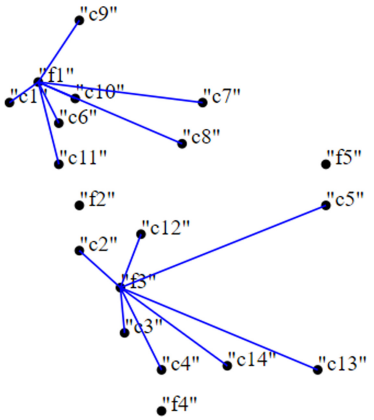

Fig. 2. Network for capacitated localization.

nearer Factory. Recently in [17], present optimization models and heuristics for locating capacited mobile facilities.

2.2 Location and Sustainability

In the current context of cities where the environmental and social objectives rely on the proper use of the natural resources earth provides us. Location becomes more important since it contributes to maintaining the sustainability of cities. The notion of sustainability is an important concept since it reduces the effect of greenhouses, pollution, economic sustainability and social impacts. For this reason it has been taken into account for its evaluation and for the production, distribution, logistics, energy or transportation of people and load. Otherwise they can affect the health in cities [7]. A study undertaken by the European commission results in the urban cargo transportation which generates 21% in C02 emissions whereas other smaller vehicles generate 10% in C02 emissions.

In [19] an interesting proposal was made in order to reduce pollution. This proposal gives a solution for the network design problem of a sustainable supply chain. This model is based on the methodology of binary integer programming that determines the quantities of facilities located in selected areas among a set of candidates besides a genetic algorithm which gives a solution to the complexity of the problem.

These discussions lead to the so-called locating problem of sustainable facilities as [23] mentions. This location has made progress in such a way that the economic criterium is not only important to take into account but the social and environmental ones as well. As can be discussed in [1]. Recently the location of sustainable facilities is discussed in [22], for decision-making in the energy generation.

2.3 Vehicle Routing

The vehicle routing (in Fig. 3 shows three routes), has been presented in various versions in order that they will be used in some applications. The most known are capacitated routing, routing with time windows, routing with delivery and pickup at the same time, open routing, fleet of homogenous and heterogenous vehicles and so on. For each variation, optimization models have been built besides metaheuristic in order to be solved, as discussed in [9,12].

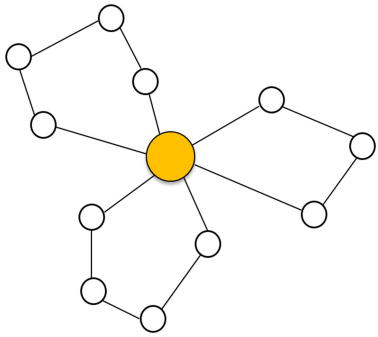

Fig. 3. Vehicle routing.

2.4 Location-Routing

Location–routing from the practical point of view is part of the distribution management of goods. A proposal was presented in [8]. It refers that an application is established on a network and the process of delivery and pickup are made simultaneously to minimise the cost of locating and at the same time assigning vehicles for the routing by meeting the demand of each customer. Research about the state of the art in location-routing and new applications are found in [20], who classify the various contributions published in the specialized literature. An expanded location of sustainable facilities and routing of sustainable vehicles is discussed in [16]. Similarly another sustainable proposal on location–routing that works with a two-compartment vehicle through delivery and pickup at the same time in the service of perishable goods, is presented in [14].

The reference [3] also presents an integrated model of integer programming to locate production facilities and through a routing process meets the requests. For being of interest in the development of the work this last model has been modified by adding to the Z_{ij} transportation variable an additional component related to the use of a vehicle $k \in K$ that means Z_{ijk}. In this way, a new objective function (2) is obtained which quantifies the C02 emissions generated by the vehicles that minimizes the fixed costs of facilities location, freight transportation costs, cost of assigning the facility to the customer, routing cost, and

C02 quantification generated during the trip. The computing experiments show results up to certain quantities of data from which the use of some metaheuristic may be necessary.

$$Minimize: \sum_{j \in J} f_j X_j + \sum_{s \in S, j \in J} c_{sj} W_{sj} + \sum_{i \in I, j \in J} v_j h_i Y_{ij} + \sum_{i,j \in P, k \in K} g_k d_{ij} Z_{ijk} + \sum_{j \in J, i \in I} cc \left(\frac{em_k}{q_k} \right) Z_{ijk} \quad (2)$$

3 Integrated Model Formulation

It is based on [8], the experiments undertaken by (1) in [3] and in [18], present an integrated new location-routing model besides locating suppliers and serving the customers through a routing process in the delivery and pickup of waste, as shown in Fig. 1.

Sets
S: Suppliers.
J: Facilities.
I: Customers.
KK: Big vehicles serving facilities.
K: Urban vehicles serving facilities.
$SF = S \cup J$: Network formed by suppliers and facilities.
$P = J \cup I$: Network formed by facilities and customers.

Parameters
cs_s: Supplier capacity. $s \in S$.
$dist1_{sj}$: Distance between suppliers $s \in S$ and facilities $j \in J$.
$c_{sj} = f1 \times dist1_{sj}/100$: Transportation cost from $s \in S$ to $j \in J$, with freightage $f1$.
qq_{kk}: Big vehicle capacity $kk \in KK$.
t_j: Facilities capacity $j \in J$.
f_j: Fixed cost for the operation of facility $j \in J$.
$dist2_{ij}$: Distance between facility $j \in J$ and customer $i \in I$.
$d_{ij} = f2 \times dist2_{ij}/100$: Transportation cost from $j \in J$ to $i \in I$, with freighge $f2$.
cf_k: Fixed cost for the operation of the urban vehicle $k \in K$.
q_k: Urban vehicle capacity $k \in K$.
g: Number of urban vehicles $k \in K$.
CC: Fuel consumption in litre per kilometre.
EM_k: CO2 emission in grams per litre of the urban vehicle $k \in K$.
T_k: Maximum fuel tank capacity of urban vehicle.
p_i: Pickup of customer waste $i \in I$.
dd_i: Delivery of the product to the customer $i \in I$.

Decision Variables

XX_s: Binary variable that denotes attention or not attention of the $s \in S$.
$W_{sj,kk}$: Transportation from supplier to facility using the $kk \in KK$ vehicle.
X_j: Binary variable that indicates if facility $j \in J$ is open or closed.
Y_{ij}: Binary variable indicating assignment of customer $i \in I$ to facility $j \in J$.
Z_{ijk}: Routing binary variable, indicating attention from $j \in J$ to $i \in I$, with vehicle k.
U_{ij}: Product delivery to customers.
V_{ij}: Collect customer waste if any.
M_k: Binary variable that indicates if urban vehicle $k \in K$ is used.
G_{ik}: Amount of fuel used when vehicle to visit at customer.

The bi-objective mixed integer linear programming model is:

$$Min: \sum_{s\in S, j\in J, kk\in KK} c_{sj} W_{sj,kk} + \sum_{j\in J} f_j X_j + \sum_{i,j\in P, k\in K} d_{ij} Z_{ijk} + \sum_{k\in K} cf_k M_k \quad (3)$$

$$Min: \sum_{i,j\in P, k\in K} CC\left(\frac{EM_k}{q_k}\right) d_{ij} Z_{ijk} \quad (4)$$

s.t.

$$\sum_{j\in J, kk\in KK} W_{sj,kk} \leq cs_s XX_s, \forall s \in S \quad (5)$$

$$\sum_{s\in S, kk\in KK} W_{sj,kk} - \sum_{i\in I} dd_i Y_{ij} = 0, \forall j \in J \quad (6)$$

$$\sum_{s\in S, kk\in KK} W_{sj,kk} \leq t_j X_j, \forall j \in J \quad (7)$$

$$\sum_{s\in S, j\in J} W_{sj,kk} \leq qq_{kk}, \forall kk \in KK \quad (8)$$

$$\sum_{j\in P} Z_{ijk} = 1, \forall i \in I, k \in K \quad (9)$$

$$\sum_{i\in I, j\in J} Z_{ijk} \leq 1, \forall k \in K \quad (10)$$

$$\sum_{j\in P} Z_{ijk} - \sum_{j\in P} Z_{jik} = 0, \forall i \in P, k \in K \quad (11)$$

$$\sum_{m\in P} Z_{imk} + \sum_{n\in P} Z_{jnk} - Y_{ij} \leq 1, \forall i \in I, j \in J, k \in K \quad (12)$$

$$\sum_{i,j\in I} Z_{ijk} \leq q_k M_k, \forall k \in K \quad (13)$$

$$\sum_{i \in I, j \in J} Z_{ijk} \leq g, \forall k \in K \tag{14}$$

$$\sum_{j \in P} U_{ji} - \sum_{j \in P} U_{ij} = dd_i, \forall i \in I \tag{15}$$

$$\sum_{j \in P} V_{ij} - \sum_{j \in P} V_{ji} = p_i, \forall i \in I \tag{16}$$

$$U_{ij} + V_{ij} \leq q_k Z_{ijk}, \forall i, j \in P, k \in K \tag{17}$$

$$G_{jk} \leq G_{ik} - 0.35 \left(\frac{EM_k}{q_k} \right) dist2_{ij} Z_{ijk} + T_k \left(1 - Z_{ijk}\right), \forall i \in P, j \in I, k \in K \tag{18}$$

$$G_{ik} = T_k \sum_{j \in I} Z_{ijk}, \forall i \in P, k \in K \tag{19}$$

The objective function (3) optimizes the transportation cost from the suppliers to the facilities besides the facilities location costs, the routing costs from the facilities to the customers and the use of the vehicles. The generated C02 pollution is measured section by section for the objective function (4) during the routing process in order to meet the customers on the part of the selected facility by the model.

The Eq. (5) indicates that the supplier can supply the facility goods as long as it does not exceed its own capacity and will be available to give a service. Condition (6) models the service of the supplier to the facility and according to the customer's demand it will be met by the selected facility. Condition (7) models the supplier who can provide the facility as long as it does not exceed the capacity of the facility and will be available to receive the supply. Equation (8) indicates that each big vehicle carries a cargo of goods according to its allowance capacity. In (9), refers to the routing that is assigned to each customer.

The fact that a routing can work with only one facility it is modelled in (10), the constraint (11) indicates that every urban vehicle that arrives and meets a customer should go to look for the next customer in order to provide a service, that is, an equilibrium condition.

The Eq. (12), is an assignment and routing condition which assigns a vehicle to service the customer. The constraint (13), it is established that each vehicle carries a load of products according to its capacity. The condition (14) models the fact that the service of the customer is possible as long as there is a vehicle availability. In the conditions (15) and (16) show two simultaneous activities of service to the customer, that is to say the delivery of goods and pickup of wastes will be for free. The Eq. (17) indicates that the customer service is possible as long as it does not exceed the capacity of the urban vehicle when there is a journey. In (18) models the level of the fuel tank and the urban vehicle is in the j customer. Finally, the condition (19) refers to the full tank before starting the process of routing.

4 Results and Discussion

To the evaluation we have used a personal computer equipped with a Core (TM) i7-8550U CPU 1.8 Ghz with 8.00 GB RAM. The optimization software GLPK (GNU Linear Programming Kit) was used to solve the considered scenarios. The experiments were performed with a timeout of 7200 segundos.

Cases with Simulated Data

Case 1: Three suppliers and five facilities with their respective geographic location are considered as a case study, as shown in Table 1. Four big vehicles (kk) with a capacity of 30 tons. to serve the facilities, and three urban vehicles (k) with a capacity of 30 kg. to serve customers.

Table 1. Location of suppliers and facilities.

Suppliers : Location	Facilities : Location
s1 : (35,15)	f1 : (3,13)
s2 : (100,65)	f2 : (50,10)
s3 : (7,59)	f3 : (22,9)
	f4 : (15, 22)
	f5 : (3, 37)

Table 2, shows the location of the customers and their respectives purchase demands as well as the delivery of waste for free.

Table 2. Location of customers and their demands.

Customers	Location	Delivery demand	Demand to collect
c1	(3,25)	4	2
c2	(20,61)	3	2
c3	(31,81)	3	2
c4	(40,90)	2	2
c5	(65,50)	3	2
c6	(15,30)	3	2

Results were obtained for the two levels. The results of the Table 3, shows in level 1, in response to demand for some goods, the model located the supplier s1 who provides to the f3 facility for a value of 18 units of goods by using the kk1 vehicle that runs a distance of 14 km.

Table 3. Transportation from supplier to select facility.

Supplier	Facility	Ordered products	Big vehicle	Distance (km)
s1	f3	18	kk1	14

In level 2, Table 4, shows the results of the process through a vehicle routing that any of the three vehicles can service the customers, starting and ending the tour in the f3 facility. Delivered quantities and picked up wastes from the customers are seen in this level, in addition to the travelled distances by the urban vehicles in km. and the quantity of fuel in litres L, used in the routing process. The vehicle has the tank with 20 L, which is going to be reduced during the tour and in every road section. Finally the C02 emission in kg/ton-km.

Table 4. Delivery of demands products and waste collection.

Origin	Destination	Delivery	Pickup	Distance (km)	Fuel consumption	CO2
f3	c1	18	0	25	20	0.39
c1	c6	14	2	13	18.6	0.2
c6	c2	11	4	31	18	0.49
c2	c3	8	6	23	16.3	0.35
c3	c4	5	8	13	15.1	0.2
c4	c5	3	10	47	14.4	0.74
c5	f3	0	12	59	12	0.93

Case 2: The proposal model was also tested in other sceneries. For this purpose the quantity of suppliers and their locations remained fixed. The quantity of facilities are the same but the location of three of them were modified. See Table 5.

Table 5. Location of suppliers and facilities.

Suppliers : Location	Facilities : Location
s1 : (35,15)	f1 : (1,13)
s2 : (100,65)	f2 : (46,4)
s3 : (7,59)	f3 : (2,3)
	f4 : (15,22)
	f5 : (3,37)

The kind of vehicles for both levels as it was established above are the same but the capacities of the urban vehicles increase and the more customers are the more quantities of demands increase as well. Other information such as the total quantity of customers, their locations and demands are shown in Table 6.

Table 6. Location of customers and their demands.

Customers	Location	Delivery demand	Demand to collect
c1	(31,6)	6	2
c2	(36,20)	6	4
c3	(9,19)	3	3
c4	(47,42)	5	4
c5	(28,20)	4	5
c6	(38,43)	2	4
c7	(41,4)	9	7
c8	(36,30)	3	5
c9	(4,10)	8	10
c10	(43,16)	7	8
c11	(33,45)	9	8
c12	(39,30)	4	5
c13	(6,40)	1	3
c14	(50,20)	2	4
c15	(48,14)	5	7
c16	(34,34)	2	5
c17	(49, 3)	6	7
c18	(26,14)	9	9
c19	(28,44)	5	7
c20	(21,38)	1	3
c21	(15,11)	2	0
c22	(31,22)	3	2
c23	(24,36)	2	1
c24	(24,28)	2	2
c25	(2,23)	3	1

With these pieces of information, Table 7 shows the results of the model when it was implemented in four sceneries. Each one is formed by groups of five, ten, fifteen and twenty customers. The table also shows the time used to obtain computing results which increase as there are more customers, and therefore also the costs and the distances traveled. A fact that drew attention was related to the C02 generation. The work reached the conclusion that this emission was reduced since some customers have a nearer location among them.

Table 7. Results obtained by the model in four scenarios.

Scenarios	Customers	Time (secs)	Cost of tour	Distance (km)	CO2 (kg/ton-km)
1	5	1.2	103	114	1.076
2	10	34.1	132	146	0.691
3	15	157.4	170	189	0.668
4	20	361.3	184	205	0.527
5	21	7 871	–	–	–
6	25	8 812.6	–	–	–

For each one of these scenarios, the model estimates the quantity of fuel used during the formation of the tour such as it was presented in Table 4.

For sceneries greater than 21 customers, a solution was not found in the timeout used in the experiments.

5 Conclusions

The paper show a mixed integer linear programming model new integrated facilities location and vehicle routing in the urban context. In the routing activity goods are delivered and wastes are pickup. It also models situations such as the fuel consumption and measures the C02 emission in every road section during the process of the customer service, that is to say the model can be used in the environment sustainability in cities.

The proposal is based on the premise that there is a set of customers who previously make known their needs. For example: Electrical appliances, computer equipment or some other delivery services whose wastes are also demanded for their pickup. This premise reduces the service and transportation costs such as it was shown in the tests performed. Therefore, the use of vehicle feet that travels by the best selected routes that are part of the urban ways is also reduced.

The results presented show the potential aspect of the new model proposed, for a smaller number of customers quickly finds optimal solutions, however a critical aspect solutions are not found for sceneries with more than 21 customers within the time limit of 7200 s, because the problem is NP-Hard. For medium and big sceneries it is recommended the use of metaheuristics that gives good solutions at reasonable times.

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