Sustainable Optimization Model for Routing the Process of Distribution of Products, Pickup and Transport of Waste in the Context of Urban Logistics

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Abstract. Literature research urban logistics has shown us the growing interest in sustainable supply chain serving the population, which must necessarily be based on location and routing of vehicles in order, using the integer linear programming methodology, to model these cases. This study presents a sustainable four-level bi-objective model to optimize economic costs and measure the amount of carbon dioxide generated by the transportation process. The process consists of a provider that supplies a distribution center or warehouse, which also serves a group of facilities located by a group of customers who expect to receive attention to their two orders, one for the purchase of the acquired product and the other for the delivery of the waste generated. Finally, the waste is transported to specialized centers. The model implemented with GLPK obtained optimal results for small and medium-sized instances. For scenarios with more than 40 customers, it was not possible to find solutions, as the computational processing time limit was exceeded by 7 200 s, for these scenarios it is recommended to solve the model using metaheuristics.

Keywords: Sustainability · Location · Vehicle routing

1 Introduction

In the cities, there are activities such as the purchase and sale of food products, home appliances, cargo and passenger transportation, etc.; as well as waste collection services, transportation of products to areas affected by natural disasters,

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firefighting services etc. In the case of food support for citizens, it is necessary to distribute products coming from the producing companies, which after use must be collected and transported to specialized centers to follow a process of reuse, recycling or rejection in case they no longer have value.

Faced with this situation and in a competitive world, companies have strategies that respond to the dynamic environment of the urban sector. Therefore, an adequate location of suppliers and facilities is necessary, as well as the distribution of products by means of a transportation system and their collection after use. This is achieved by developing and implementing an optimization model through which the logistics system of a city is reorganized in such a way as to achieve a better dimensioning of the transportation network, with the consequent reduction in the number of vehicles circulating in the city, providing an optimized solution for the distribution of products and the pickup-transportation of solid waste in the context of urban logistics.

This study presents a sustainable four-level bi-objective model in the urban context, where the facilities initially locate a warehouse or distribution center that supplies them with products through a vehicle routing process, according to the demand generated by a group of customers. The suppliers in turn supply the warehouse, thus forming three levels. Customers are served through a routing of delivery and pickup vehicles starting and ending at the selected facility. The pickup consists of obtaining waste, which are concentrated in the facility and then transported to the specialized centers in a fourth level as shown in Fig. 1. This article, in addition to optimizing economic costs based on the distance traveled by vehicles, measures the amount of CO2 emissions generated in the routing process, therefore the importance of this article to contribute to the preservation of people's health and the protection of the environment.

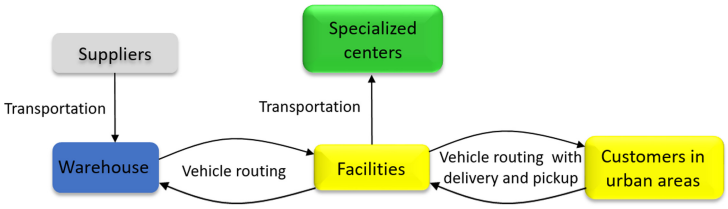

Fig. 1. Diagram of a four-level logistics system.

The article is organized as follows: Sect. 2 comprises a review of the literature related to the research. Section 3 discusses the problem through a description and formulation of a new four-level mixed integer linear programming model. Section 4, shows the results and discussions. Finally, conclusions are presented in Sect. 5

2 Review of the Literature

2.1 Sustainability

Cities are systems that interact continuously and constantly with their environment, being the means of transportation very important for their development. In this dynamic, in the process of supply and demand of various products for the well-being of the citizen, waste of all types is generated, whether industrial, chemical, pharmaceutical, construction, food, hospitals, etc. Waste that for many decades was indiscriminately dumped into the environment without proper supervision and oversight by local governments. Thus, the waste generated in addition to the depletion of natural resources and the lack of environmental preservation, increased the crisis of sustainability of the urban and rural environment in various areas of several countries.

In [8] the notion of sustainability is an important concept, since reducing the greenhouse gas effect, pollution, economic sustainability and social impacts must be taken into account in fields such as production, distribution, logistics, energy or transportation of people and/or cargo. In the opinion of [22] the meaning and importance of sustainable development of cities is great, the objective being to seek the welfare of citizens through the optimal management of the resources that nature and the industrial sector offer. See Fig. 2 due [22].

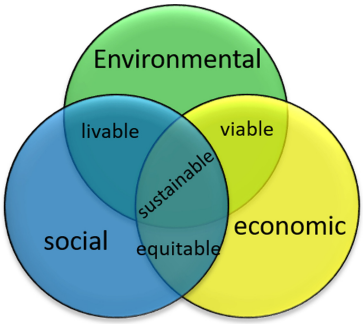

Fig. 2. Key aspects for sustainable development.

Therefore, it becomes necessary as already emphasized in [2], the use of a sustainable supply chain with successful operations and strategies to maintain environmental sustainability.

Recently [24] report that transportation provides a quarter of the total amount of carbon emissions and the proportion continues to grow due to the widespread demand for products from an ever-increasing population. Therefore, it is necessary to implement logistic systems so that the activities of transporting products for their use, pickup, classification and processing, guarantee a sustainable recovery and thus preserve the health of people and the protection of the environment.

In [11] present awareness level for environmental sustainability and economic security as a stochastic optimization. Due to the large amount of related data that exists, [12] presents an advisory framework based on deep neural networks for the achievement of sustainable development goals.

2.2 Localization from the Perspective of Sustainability

The urban population growth brings as a consequence greater needs to be satisfied, therefore, requiring speed and quality in meeting the demands, has determined that there is a change on the part of companies who to maintain urban sustainability have the commitment to use new strategies, in other words, it is necessary the integration of the supply chain and the business sector responsible for the supply of cities under the sustainable approach [2]. Therefore, as indicated by [4], sustainability is an important issue for locating facilities, as environmental, social and economic perspectives are identified.

An interesting application to reduce pollution is presented in [19] who solve the problem of designing a network for a sustainable supply chain. The model presented is based on the binary integer programming methodology, which determines a number of facilities that are located at sites chosen from a set of candidates; in addition to a genetic algorithm for its solution given the complexity of the problem.

Capacitated facility localization in [5] has been extended to the multi-product capacitated facility localization problem, as proposed in [1], who solve the problem with branch-and-bound algorithms. In the context of sustainability [10] formulate a mixed integer quadratic programming model with equilibrium conditions and a branching and refinement algorithm that guarantees convergence to the desired solutions.

Recently [7] indicate that problems in health, safety and environment are issues of concern to those responsible for sustainable supply chain management, since newly established or informal companies can affect the reputation of other formally established companies, as there is a risk that the products offered are not of good quality and are not delivered in a timely manner, in other words, not complying with the logistics principle.

2.3 Sustainable Vehicle Routing

Throughout the historical process of the vehicle routing problem, and in order to be closer to the reality under study, it has been classified into variants such as: capacitated vehicle routing, routing with time windows, routing with simultaneous pickup and delivery and open routing are discussed in [9,13,20,21]. These variants have been applied to distribute products through the supply chain, however, they have focused on optimizing economic logistics costs.

In recent decades, taking into account the pollution generated by transportation, new proposals are framed in the preservation of the environment, in other words sustainability, which is an important issue to preserve the health of the population and all living beings that inhabit the earth. In this context, [6]

establish that environmental objectives should be added to economic objectives, extending the classical definition of logistics in green logistics and propose a variant of heterogeneous fleet vehicle routing whose solution is given by a mixed integer linear programming model and a heuristic.

[18] presents a solution for the sustainable vehicle routing problem using a heterogeneous vehicle fleet by developing a mixed integer linear programming model with three different objective functions which model the economic, environmental and social aspects considered simultaneously. Recently [15] discuss the impact on the environment of carbon dioxide emissions in multi-tank vehicle routing.

2.4 Sustainable Location-Routing

In the research of [16], it is stated that the location of facilities is solved at the level of strategic decisions to be used in the location of factories, warehouses and distribution centers, and the routing of vehicles is used at the tactical or operational level as it is about offering or providing a service to customers, likewise, they analyze, discuss new variants and classify the location-routing problems.

Under the view of sustainability and considering the commitment that the consumer must have with the environment, [23] design an optimization model involving location, routing and inventories; in addition to a particle swarm optimization algorithm for sustainable supply chain. Facility location and decision making for sustainable freight distribution in urban areas through vehicle routing was proposed in [14] which aims to minimize costs and CO2 emissions. A new variation for location-routing is presented in [17], who through a new transport-location-routing model succeed in designing a network for sustainable distribution that minimizes distribution costs, fuel consumption, and CO2 emissions.

3 Formulation of the Integrated Model

Based on the knowledge discussed in Sect. 2, a new integrated four-level model combining transport, location and routing is presented as shown in Fig. 1.

Sets
S: Set of suppliers.
P: Set of warehouses.
F: Set of facilities.
C: Set of customers in urban areas.
CE: Set of specialized centers.
$N2 = P \cup F$: Set of nodes forming the warehouses-facility network.
$N3 = F \cup C$: Set of nodes forming the customer-facility network.
$N4 = F \cup CE$: Set of nodes forming the network facility-specialized centers.

Constant
CC: Fuel consumption in litre per kilometre.

Level 1: Set, Parameters and variables
$K1$: Set of large vehicles.
$d1_{s,p}$: Distance between suppliers and warehouses.
$EM1_{k1}$: CO2 emission of large vehicles in grams per liter.
ggg: Number of large vehicles.
$q1_{k1}$: Capacity of large vehicles.
CP_s: Supplier fixed cost.
$Z1_{s,p,k1}$: Quantity transported from suppliers to warehouses.
$X1_s$: Binary variable, the value 1 denotes a provider located to provide a service.

Level 2: Sets, Parameters and variables
$K2$: Set of medium vehicles.
$d2_{p,f}$: Distance between warehouses and facilities.
$EM2_{k2}$: CO2 emissions by medium-sized vehicles in grams per liter.
g: Number of medium vehicles.
$q2_{k2}$: Capacity of medium vehicles.
ff_p: Fixed cost for the operation of the warehouses.
t_p: Warehouse capacity.
fff_f: Fixed cost for the operation of the facility.
dd_f: Demand for warehouses.
$Z2_{p,f}$: Binary variable, the value 1 denotes supplier's attention to the facility.
$X2_p$: Binary variable, the value 1 denotes depots located to provide a service.
$Y2_{f,p}$: Binary variable, where the value 1 denotes facility served by a warehouse.
$U_{i,j}$: Variable representing delivery of products from the warehouse to the facilities.

Level 3: Sets, Parameters and Variables
$K3$: Set of urban vehicles to serve customers.
$d3_{f,c}$: Distance between facilities and customers.
$EM3_{k3}$: CO2 emissions generated by urban vehicles in grams per liter.
gg: Number of urban vehicles.
$q3_{k3}$: Capacity of urban vehicles.
ddd_c: Customer demand for the delivery of a requested product.
pp_c: Customer demand for the pickup of their waste.
$Z3_{f,c}$: Binary variable, where value 1 denotes attention to customer by facilities.
$X3_f$: Binary variable, the value 1 denotes localized facility to provide a service.
$Y3_{c,f}$: Binary variable, where the value 1 denotes customer served by a facility.
$UU_{i,j}$: Variable denoting delivery of product from the facility to the customer.

Level 4: Sets, Parameters and Variables
KB: Set of waste transport vehicles or compactors.
$d4_{i,j}$: Distance between the facility and specialized centers.
QB: Number of transport vehicles or compactors.
d_i: Demand from specialized centers.
qB_k: Capacity of transport vehicles or compactors.
$XB_{i,j}$: Binary variable, where the value 1 indicates attention from the specialized center.

$DD_{i,j}$: Variable denoting delivery of the waste to the specialized center.

The bi-objective mixed integer linear programming model are:

$$Minimize: \sum_{s\in S} CP_s X1_s + \sum_{s\in S, p\in P, k1\in K1} d1_{s,p} Z1_{s,p,k1} + \sum_{p\in P} ff_p X2_p + \sum_{i,j\in N2} d2_{i,j} Z2_{i,j} + \sum_{f\in F} fff_f X3_f + \sum_{i,j\in N3} d3_{i,j} Z3_{i,j} + \sum_{i,j\in N4} d4_{i,j} XB_{i,j} \quad (1)$$

$$Minimize: \sum_{s\in S, p\in P, k1\in K1: s\neq p} CC\left(\frac{EM1_{k1}}{q1_{k1}}\right)\left(\frac{d1_{sp}}{ggg}\right) Z1_{s,p,k1} + \sum_{i,j\in N2, k2\in K2: i\neq j} CC\left(\frac{EM2_{k2}}{q2_{k2}}\right)\left(\frac{d2_{i,j}}{g}\right) Z2_{i,j} + \sum_{i,j\in N3, k3\in K3: i\neq j} CC\left(\frac{EM3_{k3}}{q3_{k3}}\right)\left(\frac{d3_{i,j}}{gg}\right) Z3_{i,j} \quad (2)$$

s.t.

$$\sum_{s\in S, k1\in K1} Z1_{s,j,k1} - \sum_{f\in F} dd_f Y2_{f,p} = 0, \forall p \in P \quad (3)$$

$$\sum_{s\in S, k1\in K1} Z1_{s,p,k1} \leq t_p X2_p, \forall p \in P \quad (4)$$

$$\sum_{p\in N2: f\neq p} Z2_{f,p} = 1, \forall f \in F \quad (5)$$

$$\sum_{f\in F, p\in P} Z2_{f,p} \leq 1 \quad (6)$$

$$\sum_{j\in N2: i\neq j} Z2_{i,j} - \sum_{j\in N2: i\neq j} Z2_{j,i} = 0, \forall i \in N2 \quad (7)$$

$$\sum_{m\in N2: f\neq m} Z2_{f,m} + \sum_{n\in N2: n\neq p} Z2_{p,n} - Y2_{f,p} \leq 1, \forall f \in F, p \in P \quad (8)$$

$$\sum_{i\in N2, p\in P: i\neq p} Z2_{i,p} \leq g \quad (9)$$

$$\sum_{j\in N2: f\neq j} U_{j,f} - \sum_{j\in N2: f\neq j} U_{f,j} - dd_f = dd_f, \forall f \in F \quad (10)$$

$$U_{i,j} \leq q2_{k2} Z2_{i,j}, \forall i, j \in N2 : i \neq j, k2 \in K2 \quad (11)$$

$$\sum_{f\in N3: c\neq f} Z3_{c,f} = 1, \forall c \in C \quad (12)$$

$$\sum_{c\in C, f\in F} Z3_{c,f} \leq 1 \quad (13)$$

$$\sum_{j \in N3: i \neq j} Z3_{i,j} - \sum_{j \in N3: i \neq j} Z3_{j,i} = 0, \forall i \in N3 \tag{14}$$

$$\sum_{m \in N3: c \neq m} Z3_{c,m} + \sum_{n \in N3: n \neq f} Z3_{f,n} - Y3_{c,f} \leq 1, \forall c \in C, f \in F : c \neq f \tag{15}$$

$$\sum_{i \in N3, f \in F: i \neq f} Z3_{i,j} \leq gg \tag{16}$$

$$\sum_{j \in N3: c \neq j} UU_{j,c} - \sum_{j \in N3: c \neq j} UU_{c,j} = ddd_c, \forall c \in C \tag{17}$$

$$\sum_{j \in N3: c \neq j} VV_{c,j} - \sum_{j \in N3: c \neq j} VV_{j,c} = pp_c, \forall c \in C \tag{18}$$

$$UU_{i,j} + VV_{i,j} \leq q3_{k3} Z3_{i,j}, \forall i, j \in N3 : i \neq j, k3 \in K3 \tag{19}$$

$$\sum_{j \in N4} XB_{i,j} = 1, \forall i \in N4 : i \neq j \tag{20}$$

$$\sum_{j \in N4} XB_{j,i} = 1, \forall i \in N4 : i \neq j \tag{21}$$

$$\sum_{i,j \in N4: i = \text{facilidad}: i \neq j} XB_{i,j} \leq QB \tag{22}$$

$$\sum_{j \in N4} DD_{j,i} - \sum_{j \in N4} DD_{i,j} = d_i, \forall i \in N4 : i \neq \text{facilidad seleccionada} \tag{23}$$

$$DD_{i,j} \leq qB_k XB_{i,j}, \forall i, j \in N4, k \in KB \tag{24}$$

The objective function (1) minimizes the costs of supplier location, supplier to warehouse transportation, warehouse location, warehouse to facility transportation, facility location, vehicle routing from facility to customer, finally the transportation of waste from the facility to the specialized centers. Objective function (2) minimize amount CO2 emissions at each of the first three levels. Constraint (3) models the flow coming into a facility from a supplier in terms of the total demand that is served by the facility

Constraint (4) states that the supplier supplies the warehouse as long as the capacity of the warehouse is not exceeded and it is operating. Constraint (5) formalizes the process that each facility is assigned a route. In constraint (6), a route operated with only one warehouse. Constraint (7) models the arrival and departure of the medium vehicle of a certain facility, in other words equilibrium condition. Constraint (8) indicates that a facility is assigned to the warehouse. Constraint (9) establishes that service to the facilities is possible if there are medium vehicles. The equilibrium condition to meet the demand of the facilities is given in constraint (10). The final level two constraint is given by (11) whose equation models the attention to the facilities, provided that the capacity of the medium vehicles is not exceed.

At level three, constraint (12) states that each customer is assigned a route. In constraint (13) a route can operate with only one facility. Constraint (14) indicates that a vehicle, after serving a customer, continues its journey in search of another customer to serve. It is also called equilibrium condition. Constraint (15) a customer is assigned to a facility that will provide a service. Constraint (16) states that the customer is served as long as there are vehicles available. The constraint that guarantees attention to all customers, also called equilibrium, is given in (17). With constraint (18) it is guaranteed that all waste will be collected. Finally, constraint (19) models that facilities are served as long as they do not exceed the capacity of urban vehicles.

At level four, vehicle routing is also applied, starting from the facility whose collection vehicle will deliver the waste to the specialized centers according to the demand requested by them. A specialized center is a factory, recycling center or sanitary landfill. The constraint (20) establishes that each specialized center is visited once by the transporting vehicle. Constraint (21) a specialized center is visited exactly once. Constraint (22) establishes that the vehicle begins transporting the collect waste, starting at the facility selected by the customers for their attention, taking into account the number of available transport vehicles. The equilibrium condition for meeting the demand of specialized centers is given in constraint (23). Finally, in constraint (24), service to specialized centers is possible depending on the capacity of the transport vehicles.

4 Results and Discussion

A Core (TM) i7-8550U CPU @ 1.80 GHz with 8.00 GB of RAM was used to evaluate the model. The optimization software used to solve the scenarios was GLPK (GNU Linear Programming Kit). In addition, considering that it is an integrated four-level vehicle location and routing model, a time limit of 7 200 s was set for processing to obtain solutions in the scenarios considered.

Cases with Simulated Data

Case 1: Three suppliers, two warehouses, five facilities and three specialized centers with their respective geographic locations were considered as shown in Table 1 and Table 2. Two large vehicles, one medium vehicle and one urban vehicle with their respective capacities were considered as means of transportation to serve the warehouse, facilities and customers.

Table 1. Location of suppliers, warehouses and specialized centres.

Suppliers: Location	Warehouse : Location	Specialized centres
s1: (35,15)	p1: (3,25)	C. Transformation: (120,120)
s2: (100,65)	p2: (20,61)	R. Sanitary landfill: (80, 170)
s3: (7,59)		Factory: (55,135)

Table 2. Facility location and demands.

Facility	Location	Demands
f1	(10,15)	4
f2	(20,50)	3
f3	(30,70)	3
f4	(55,105)	1
f5	(80,40)	3

Table 3 shows the customers, their geographic locations, quantities of products requested and quantities of waste to be collected for further processing, which can be reused or recycled or discarded because they have no value.

Table 3. Customers, location, quantities of products purchased and waste quantities.

Customers	Location coordinates	Number of products purchased	Quantity of waste
c1	(80,120)	2	1
c2	(100,40)	1	1
c3	(78,100)	4	1
c4	(70,90)	2	0
c5	(120,50)	2	2

With these data, the model implemented reported results for each of the four levels. In level 1, Table 4, supplier s3 was located to supply products to warehouse p2 with 14 units of products, which will be transported to the facilities in level 2, being the distance traveled 13.15 km and 1.46 of CO2 generated in this route.

Table 4. Transportation of products from selected supplier to warehouse.

Supplier	Warehouse	Ordered products	Distance (km)	CO2 (kg/ton-km)
s3	p2	14	13.15	1.46

In level 2, Table 5, following a vehicle routing process, the facilities are served, starting and ending at the p2 warehouse selected in level 1. The table shows that the number of products decreases as the demand of the respective facility is met. In addition, during the transportation process, this table shows the distances traveled and the amounts of CO2 generated.

Table 5. Transportation of products from selected warehouse to facilities.

Origin	Destination	Delivery	Distance (km)	CO2 (kg/ton-km)
p2	f3	14	14.45	0.34
f3	f4	11	43.01	1.09
f4	f5	10	69.64	1.77
f5	f1	7	74.33	1.89
f1	f2	3	36.4	0.92
f2	p2	0	11	0.28

Following the same methodology shown in Table 5; the Table 6 shows the results when using routing of delivery vehicles for requested products and pickup of waste delivered by customers. In addition, the distances traveled and carbon dioxide emitted.

Table 6. Delivery of products and pickup waste from customers.

Origin	Destination	Delivery	Pickup	Distance (km)	CO2 (kg/ton-km)
f5	c2	11	0	20	0.05
c2	c5	10	1	22.36	0.06
c5	c1	8	3	80.62	0.24
c1	c3	6	4	20.09	0.05
c3	c4	2	5	12.8	0.03
c4	f5	0	5	50.99	0.15

Finally, level 4 is based on the demand generated by the specialized centers according to their requirements. In this case, it was considered that the transformation center (TC) requires 5 tons of waste that can be recycled, and the factory (FA) requires 4 tons of products that will be reused. See Fig. 3 where it can be seen that the warehouse p2 was chosen to supply the facilities located on the way of the route with blue lines. Customers can locate facility f5 which serves through the route with the green lines. Last but not least, regarding level 4 with red lines, it is clear that all the waste will be used and will not need to be transported to the sanitary landfill (RS).

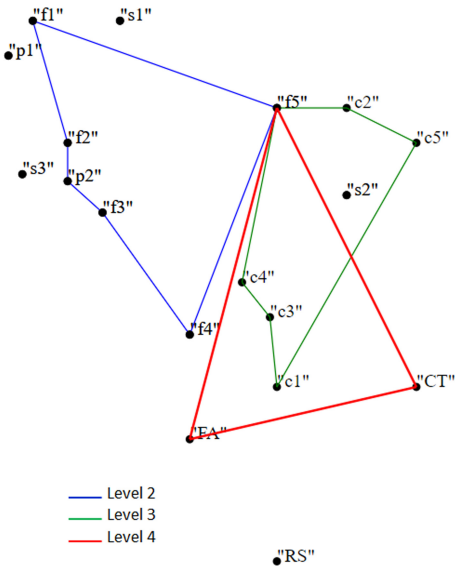

Fig. 3. Attention to specialized centers. (Color figure online)

Case 2: The proposed model was tested in other scenarios formed in customer groups. In this case, the quantities and geographic locations of suppliers, warehouses and facilities remained fixed (see Tables 1 and 2). The number of vehicles was also the same, only their capacities changed according to the demand determined by the customers. Data related to customers is shown in Table 7.

Table 8 shows the results of the model implemented for ten scenarios. The table also shows the time taken to obtain the results, which increases when working with more customers. In addition, the total travel in the four levels of the model, as well as the total amount of CO2 generated in the first three levels. CO2 generation was not evaluated at level 4. A special situation occurred in scenario 8 (35 customers), as the execution time increased greatly, then in scenario 9 (37 customers), this process time decreased. It was concluded that it was due to how close some customers are to others. For scenarios larger than 40 customers, no response was obtained within the time limit. This limitation is due to the computational complexity of vehicle routing from facility to customer.

Table 7. Location of customers and their demands.

Customers	Geographical location	Products purchased	Waste to be pickup
c1	(31,6)	2	1
c2	(36,20)	1	1
c3	(9,19)	4	1
c4	(47,42)	2	0
c5	(28,20)	2	2
c6	(38,43)	1	1
c7	(41,4)	4	0
c8	(36,30)	2	1
c9	(4,10)	3	2
c10	(43,16)	3	1
c11	(26,40)	1	0
c12	(39,57)	2	1
c13	(4,40)	1	2
c14	(55,20)	3	0
c15	(65,10)	1	0
c16	(70,20)	2	1
c17	(53, 5)	1	1
c18	(22,14)	4	2
c19	(30,55)	2	0
c20	(21,35)	1	0
c21	(34,11)	2	1
c22	(41,34)	5	1
c23	(46,48)	3	0
c24	(28,48)	1	2
c25	(4,35)	2	0
c26	(64,32)	2	1
c27	(50,27)	1	0
c28	(36,26)	3	2
c29	(80,16)	2	1
c30	(14,7)	5	0
c31	(18,30)	3	0
c32	(50,30)	1	1
c33	(28,60)	1	1
c34	(26,65)	1	0
c35	(47,50)	2	1
c36	(45,48)	1	0
c37	(73,20)	1	1
c38	(5,43)	2	0
c39	(65,15)	1	1
c40	(80,20)	1	1

Table 8. Results obtained for each of the scenarios considered.

Scenarios	Customers	Time (secs)	Distance traveled (km.)	CO2 (kg/ton-km)
1	5	0.1	762.77	7.69
2	10	10.8	795.38	7.76
3	15	35.3	881.34	8.01
4	20	221.1	903.66	8.04
5	25	184.0	909.39	8.02
6	30	261.9	949.87	8.12
7	33	4094.3	965.03	8.15
8	35	–	–	–
9	37	5693.6	975.23	8.16
10	40	–	–	–

5 Conclusions

The results show that the sustainable four-level bi-objective mixed integer linear programming model, in the context of urban logistics, integrates transportation to service warehouses from the selected supplier; location of warehouses by facilities and routing of vehicles for their supply; location of facilities by customers and their routing of vehicles for delivery of requested products and pickup of waste which will be transported to specialized centers. CO2 emissions are also measured at levels 1, 2 and 3.

The proposal is based on the premise of two demands generated by customers to the facilities, one for products to be used and the other to pickup waste to be collected and subsequently transported to specialized centers. This premise determines the timely attention since the facilities will be supplied from a warehouse, thus reducing transportation costs as observed in the tests carried out in the scenarios presented. Therefore, the vehicles used in the four levels travel along the best routes determined by the model through vehicle routing.

The results of the cases presented show the potential of the proposed model obtaining optimal solutions quickly in scenarios with up to 30 customers. From 33 customers the processing time starts to increase, obtaining optimal solutions up to 37 customers. A critical aspect is from 40 customers onwards no response was obtained within the time limit. Given the difficulty of the problem, a new perspective recommended is the use of metaheuristics for higher dimensional scenarios to obtain good solutions in reasonable times.

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