Last Mile Delivery with Lockers: Formulation and Heuristic

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Keywords: Combinatorial Optimization, Vehicle Routing, Facility Location, Location Routing Problem, Last Mile Delivery.

Abstract: The creation of efficient routes is essential for different areas having several practical applications mainly in the transport of goods. With the growth of e-commerce and consequently the increase in demand for delivery to end users, minimizing costs in the delivery process has gained more importance, especially the last mile stage. It is in this context that the use of lockers emerges to optimize last mile deliveries. Lockers have compartments of different sizes, with self-service interface and they can be positioned in supermarkets, parks and other areas that are of interest to customers. The problem addressed in this work is to determine the positioning of the lockers and the necessary routes to supply them and to serve the remaining customers. We present a mathematical model to define the problem, but due to the complexity of the problem obtaining a solution can be very expensive and require a lot of computational effort, therefore we present a heuristic, based on Variable Neighborhood Descent (VND), using a greedy construct inspired by the Clark & Wright savings method. By comparing the results of the heuristic with the Gurobi optimizer, we conclude that the heuristic is capable of obtaining competitive solutions in less time than the exact methods.

1 INTRODUCTION

The creation of routes and facilities allocation have been the focus of studies for a long time due to its applicability in different areas. Several characteristics can be explored in these problems, such as the homogeneity of the vehicle fleet to be used, delivery time constraints, among others. The growth of e-commerce in recent years and, consequently, the demand for delivery to customers, turned the efficient routes planning an increasingly important problem. Due to the worldwide urbanization trend, traffic problems have increased. There are several challenges to deal with the delivery of goods, among them the last mile problems have gained more attention, mainly due to the traffic of large centers.

The last mile step consists of distributing products from the distribution center to final consumers. This step may have different characteristics from the rest of the delivery process and that is why it is necessary to study it separately.

The problem addressed in this work assumes the inclusion of lockers as an alternative to reduce costs in last mile deliveries. Lockers are kiosks with compartments accessed by self-service interface that can be used to store the goods of customers until they can collect them, reducing completely the fail to delivering caused by the absence of the customer. The model proposed defines the problem mathematically and a heuristic is suggested to obtain satisfactory solutions to the problem. In the next section we detail the use of lockers with real-world examples and related works in the literature.

2 THE PROBLEM AND ITS IMPORTANCE

There are several challenges in last mile deliveries. Among them, we can highlight the increasing in congestion in large centers, the increasing in pollution, the demand of the consumer in relation to services, in addition to restrictions, such as the time window available for delivery. The use of lockers has been shown as an alternative to deal with such challenges due to the flexibility of the collection and supply schedule. The use of several shifts of the same vehicle can help to reduce the size of the fleet. Song et al. (2009) shows that the use of lockers generates savings in the last mile stage, mainly due to the repeated deliveries that need to be made when the consumer is

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Oliveira, W. and Santos, A.
Last Mile Delivery with Lockers: Formulation and Heuristic.
DOI: 10.5220/0009580004600467
In *Proceedings of the 22nd International Conference on Enterprise Information Systems (ICEIS 2020) - Volume 1*, pages 460-467
ISBN: 978-989-758-423-7

not at the address to receive your order.

Lockers are collection points, where goods are available for a certain period of time and users can collect them on an appropriate time. User interaction with the locker is done through a self-service interface that requires user authentication to ensure the security of orders.

Lockers can be located anywhere that facilitates their access, such as shopping malls, restaurants, gas stations and also in residential areas as long as there is demand from customers.

The installation of the locker in places that have parking, toilets, among other facilities, helps in popularizing the locker. It can also bring advantages to existing businesses close to the locker, as the circulation of customers can generate consumption and consequently profit for traders.

The location is the most important and challenging feature of the implementation of the self-collection, because, in addition to the investment in the construction of the locker, it is essential for its popularization. In this work, we consider that each locker has a coverage distance, that is, we consider that users with addresses in the coverage area would accept that their orders were delivered to the locker.

Wang et al. (2017) highlight the closure of several lockers in Singapore between 2015 and 2017, the main indication being that the location of the lockers did not favor its popularization. The Locker Alliance (LA) was proposed by the government of Singapore in 2019 and consists of a network of lockers distributed across residential areas and metro stations to help to optimize last mile delivery. Lyu and Teo (2019) propose methods to define the location of the network lockers and the demand to be aimed at them.

In door-to-door delivery, it is necessary to consider additional time for interaction with the consumer and the possibility that the consumer is not available to receive his goods. Building lockers, we can reduce operating costs due to the condensation of several deliveries at the same point, reducing the distance covered, eliminating the interaction time with the consumer and consequently reducing the delivery time. The supply of the lockers can also be done at periods with less traffic, using the same vehicle for different work shifts. With the decrease in delivery vehicles circulating during heavy traffic hours, we have a small reduction in the emission of gases harmful to the environment (Edwards et al., 2009).

In this work, the objective is to determine which lockers will be built, the routes to supply them and the routes to meet the demand of customers who have not been allocated to lockers.

We can consider this problem as a variation of the location-routing problem since it is necessary to determine the location of the lockers and create routes to meet the demands. Customers' demands can be met in two different ways: by door-to-door delivery or through the collection from lockers. Given a set of potential locations for building lockers and a set of customers with their respective demands, it is necessary to create two groups of routes: the delivery routes and supply routes, and the associations between customers and lockers. The built-in lockers must also be served through supply routes.

2.1 RELATED WORKS

The last mile problem with the use of lockers is discussed by Wen and Li (2016). The paper presents a model using lockers in vehicle routing, considering relevant aspects such as CO_2 emission, customer time window and congestion. Actual data from Mingguangcun in Beijing is used to apply the proposed model. In this case study, it was possible to conclude that the use of lockers contributes to a better solution, because, relaxes the restriction of time window and reduces traffic congestion.

Faugere and Montreuil (2016) analyzed the business model of twelve companies using lockers and/or access points in order to identify different characteristics in their services. The data were obtained through the companies' websites and online press. The entities involved in the process, and the impacts generated by them, are observed: customers, salespeople, delivery personnel, cities, and the environment. The results consist of the classification of the business models used by the companies and their general characteristics.

Through the observed points, it was possible to conclude that the use of lockers generates a decrease in the delivery time. However, it is a good solution only if they are conveniently located for customers. For logistics providers, they may have a reduced fleet since delivery points are condensed in the lockers, also eliminating multiple trips due to the absence of the customer at the time of delivery. For sellers, the price of deliveries is expected to be reduced in the long term. Finally, reducing gas emissions and congestion is an advantageous consequence for cities and the environment.

Veenstra et al. (2018) proposed to integrate the facility location problem with the vehicle routing problem and lockers service. This integrated problem was applied to the delivery of medicines in the Netherlands. This problem differs from other classic problems due to the possibility of serving a customer in two ways, through the locker or with door-to-door service. A mathematical model and a heuristic are defined to solve the problem. The objective is to minimize total costs, considering the routes and the cost of opening the lockers. Computational tests were performed with two sets of instances: random and based on real data. The branch-and-bound method was applied to the proposed mathematical model, obtaining results for instances with 100 patients and 50 potential lockers with a time limit of 7200 seconds. The proposed heuristic achieves solutions that surpass the optimization software, CPLEX, with only a fraction of the time (4.18% better for the set of random instances and 3.64% better for the instances based on real data). The heuristic proved to be consistent in obtaining the same results considering 10 executions for each instance.

Wang et al. (2017) discussed relevant questions about the use of lockers. The paper uses Singapore's case as an example, where the lockers from POPStation, a leader in this market, are positioned at 2500m from each other. From 2015 to 2017 it was observed that several lockers were closed permanently. According to the authors, the location of the lockers is crucial for its popularization, so they must be positioned in an attractive way for the customer. The competition between various companies and their lockers should also be considered. The article also contributed to the literature because it was the first work related to lockers and your positions, which is based on real and public data. Real distances between locations were also used instead of the Euclidean distance, commonly used in the literature.

Huang et al. (2019) present the problem of vehicle routing using electric cars and stations. The stations can be of three types, the first one, only to recharge cars used on delivery of goods, the second one, only to store goods of customers, such as locker, the third one, a hybrid station, which can be used for both purposes. In the work, two integer programming models are proposed: in the first one, the routes for supplying the lockers and the routes for customer deliveries are separated; in the second one, a hybrid route is allowed. A hybrid heuristic is proposed which, compared to CPLEX, presents good results efficiently and effectively. The results obtained show that the use of lockers combined with door-to-door deliveries can help to reduce the cost of deliveries.

Relevant reasons are presented for calculating the routes separately. Firstly, it is not possible to measure the time that would be spent on each customer. Therefore, on a hybrid route, if a delivery to a customer is delayed, one is forced to delay the delivery to a locker, which will affect multiple users. Second, the hours of interest for deliveries are different: lockers may be located at points with congestion during business hours, so it is interesting to deliver at less busy times, while for door-to-door delivery, deliveries are usually during business hours. Third, the required skills of the driver are different depending on the type of delivery he/she will make: for door-to-door deliveries, the delivery person must have interpersonal skills while for the supply to lockers the driver must have availability in times less conventional.

In this paper, a variation is also proposed that allows for more work shifts. The same vehicle can be used during the day for door-to-door deliveries and, at night, for supplying lockers. In this variation, the vehicle may have more than one route associated with it and the fixed cost of the vehicle is considered only once. In all of the proposed models, the objective is to minimize the total costs including expenses with the construction of the stations and the fixed costs of the vehicles, considered heterogeneous. We do not consider the construction costs, as lockers are built only once and used for years. Considering these costs on a daily delivery would highly overestimate the cost. The instances used to test the methods were created by the authors by combining several instances of the literature. They consider electrical vehicles but characteristics about charging electric cars at stations are not considered, such as charging waiting time, the possibility of changing batteries or charging queue.

As part of The Federated Lockers and Collection Points program, the government of Singapore has proposed the creation of the Locker Alliance (LA) which consists of a network of lockers to complement existing lockers and to improve the performance of deliveries to consumers. Lyu and Teo (2019) aim to determine the best design of the locker network in order to increase its coverage and use. With the increasing in coverage, it is expected that the concentration of existing deliveries in the central business district (CBD) would be reduced by 7.5% due to the possibility of collecting items in locations away from the CBD.

Unlike the current work, the solutions obtained by them are evaluated on the perspective of the attractiveness of the use of lockers, that is, the objective is to optimize the location of the lockers so that the volume of users who choose this type of delivery is maximized. The data collected in the study are from a time when LA did not exist, and therefore, the work takes into account that after the implementation of the network, certain changes will occur in the choice of users. Using real data, a model was developed and calibrated to calculate whether the user would be subject to using the locker, thus, it was possible to measure the effectiveness of the network design concerning the popularity of locker. The supply and delivery routes of users who have not opted for the locker are not addressed in their work.

3 INTEGER PROGRAMMING FORMULATION

We propose here an Integer Linear Programming formulation to formally define the problem.

As input we have the location of the depot, the customers and the candidate positions for lockers. We consider a complete graph, i.e., we know the distance between any pair of locations.

As output we have the the lockers chosen to be used, which customers are associated to each of those lockers, and the routes to delivery items to the lockers and to the customers not served by any locker. All the output is represented by binary variables, but we use also integer variable to keep track of the load in each vehicle, as a way to guarantee that the capacity of lockers and vehicles are satisfied and also avoid isolated sub-tours along the routes.

3.1 Input and Decision Variables

The parameters and the decision variables of the proposed model are presented below.

dep: depot
I: set of customers
I': set of nodes, $I' = \{dep\} \cup I$
J: set of candidate location for lockers
J': set of nodes, $J' = \{dep\} \cup J$
n: number of customers, $n = |I|$
m: number of locker candidate locations, $m = |J|$
q_i: demand of customer i
Q: capacity of vehicles for door-to-door delivery
QL: capacity of vehicles that supply lockers
qL_j capacity of locker j
x_{ij}: binary, 1 if arc (i, j) used, $i, j \in I'$, 0 otherwise
xL_{ij}: binary, 1 if arc (i, j) used, $i, j \in J'$, 0 otherwise
f_{ij}: integer, flow on arc (i, j) on customers' route
fL_{ij}: integer, flow on arc (i, j) on lockers' route
l_i: binary, 1 if customer i is served by a locker, 0 otherwise
a_{ij}: binary, 1 if i is served by locker j, 0 otherwise
c_j: binary, 1 if locker j is used, 0 otherwise
dI'_{ij}: distance between nodes i and j, $i, j \in I'$
dJ'_{ij}: distance between nodes i and j, $i, j \in J'$
dIJ_{ij}: distance between customer i and locker j
r_j: cover distance of locker j

3.2 Objective Function

The objective function is defined below.

$$\min \sum_{i \in I'} \sum_{j \in I'} x_{ij} * dI'_{ij} + (\sum_{i \in J'} \sum_{i \in J'} x_{ij} * dJ'_{ij}) * 0.8 \quad (1)$$

The aim is to minimize the total cost of the routes. We consider the cost proportional to the distance, then the cost of the customers' routes is simply the sum of the distances of the arcs used (first term of (1)). For the lockers supply routes (second term), we consider the cost as 80% of the normal cost, as these routes are favourable due to several conditions: higher flexibility in the period of attendance; no temporary absent and no need to return,, which may happen in the customers' route; possibility of night attendance, in period of no traffic congestion; possibility to reuse the same vehicle used in normal routes during the day, so as to reduce fixed costs of vehicles.

3.3 Constraints

$$(\sum_{j \in I'} x_{ij}) + l_i = 1, \forall i \in I \quad (2)$$

$$(\sum_{j \in I'} x_{ji}) + l_i = 1, \forall i \in I \quad (3)$$

$$\sum_{i \in I'} x_{i,dep} = \sum_{i \in I'} x_{dep,i} \quad (4)$$

$$(\sum_{j \in I'} f_{ji}) - (\sum_{j \in I'} f_{ij}) + (l_i * q_i) = q_i, \forall i \in I \quad (5)$$

$$f_{ij} \leq Q * x_{ij}, \forall i, j \in I' \quad (6)$$

$$\sum_{i \in I} a_{ij} * q_i \leq qL_j, \forall j \in J \quad (7)$$

$$\sum_{j \in J} a_{ij} = l_i, \forall i \in I \quad (8)$$

$$a_{ij} * dIJ_{ij} \leq r_j, \forall i \in I, j \in J \quad (9)$$

$$a_{ij} \leq c_j, \forall i \in I, j \in J \quad (10)$$

$$\sum_{i \in J'} xL_{ji} = c_j, \forall j \in J \quad (11)$$

$$\sum_{i \in J'} xL_{ij} = c_j, \forall j \in J \quad (12)$$

$$\sum_{j \in J'} xL_{j,dep} = \sum_{j \in J'} xL_{dep,j} \quad (13)$$

$$fL_{ij} \leq QL * xL_{ij}, \forall i, j \in J' \quad (14)$$

$$\sum_{i \in J'} fL_{ij} - \sum_{i \in J'} fL_{ji} = \sum_{k \in I} a_{kj} * q_k, \forall j \in J \quad (15)$$

$$x_{ij} \in \{0,1\}, \forall i,j \in I' \quad (16)$$

$$xL_{ij} \in \{0,1\}, \forall i,j \in J' \quad (17)$$

$$f_{ij} \geq 0, \forall i,j \in I' \quad (18)$$

$$fL_{ij} \geq 0, \forall i,j \in J' \quad (19)$$

$$l_i \in \{0,1\}, \forall i \in I \quad (20)$$

$$a_i \in \{0,1\}, \forall i \in I, j \in J \quad (21)$$

$$c_j \in \{0,1\}, \forall j \in J \quad (22)$$

Routes are modeled using flow variables to control nodes demand service and avoid sub-tours. There are two set of routes, one set for in-door service (constraints (2)- (6)) and one set for lockers supply (constraints (11)- (15)). The remaining constraints (7)-(10) define the assignment of customers to lockers and, finally, (16)-(22) the range of variables.

Constraint (2) and (3) define that must be a chosen arc leaving and respectively reaching each customer or else the customer must be served by a locker. Together, they define that each customer must be served by a locker or by exactly one in-door route.

Constraint (4) balance the number of arcs leaving and reaching the depot, so that every route starting at the depot must come back to it. Notice that, although a customer may not be served by more than one route, the depot may be in as many routes as needed.

The demand of each customer is guaranteed by constraint (5), either by the flow of a route or by assigning it to a locker. The following two constraints establish that the capacity of vehicles may not be exceeded in any point of the route neither the capacity of a locker may be surpassed.

Constraints (8)-(10) assure that a customer may be assigned only to lockers nearby (within their covering distance) and at most to one locker. If customer i is assigned to a locker j, the corresponding variables l_i (customer served by locker) and c_j (locker used) are set to 1.

Constraints (11)-(15) control the routes to serve lockers in the same way constraints (2)- (6) control the door-to-door routes. Particularly, (11) and (12) define that, if a locker is used, it must be served by a route (arc arriving and leaving the node); (13) balances the number of arcs leaving and reaching the depot (the number of routes to supply lockers); (14) assure that the capacity of the vehicle is respected and (15) that when visiting a locker the demand of all customers assigned to it must be unload there.

Finally, constraints (16)-(22) define the domain of the decision variables.

4 VND

As detailed later in the experiments, optimal solutions using the proposed formulation are reached only for small instances, with up to 75 customers. Heuristic method is needed to handle larger instances.

The proposed heuristic follows the standard Variable Neighborhood Descent (VND) metaheuristic as proposed by Mladenović and Hansen (1997), using a local search with three neighborhood. To provide an initial solution, a random greedy constructive method was used. The construction is followed by a local search and the two steps are performed 200 times, after which the best solution found is returned.

A solution consists of two parts, a set of routes and a set of assimilations. Each route can be of delivery or supply. Both are represented by a vector of identifiers, of customers or lockers. Where n is the number of lockers, the assimilations consist of n lines, starts with locker identifier followed by the customers assimilates to each locker.

An initial solution is generated by a greedy randomized solution: a subset of candidate lockers is chosen at random, and the customers within the coverage distance of these lockers are sorted by distance to the depot. The further away the customer the sooner it is associated to a locker.

Customers may end up not associated to any locker, some because they are not within the coverage radius of any locker and others because when they are considered the possible lockers cannot serve their demand anymore due to previously assignments. Routes are built to serve those customers using the Clare and Wright saving heuristic (Clarke and Wright, 1964), satisfying vehicle capacities. The lockers are served by separated routes, created with the same method.

The routes of the constructed solution is then improved by a local search using three different neighborhoods: 2-swap, 2-opt and exchange. They are used sequentially, as in the VND metaheuristic.

The 2-swap neighborhood consists in swapping two customers inside a route. A best improvement strategy is used in this stage: the best swap is chosen and performed until there is no possible improvement.

For the 2-opt neighborhood, two nodes are randomly chosen and the visit sequence between those nodes is reversed. Successive improvements are made until a stop criteria is reached. We used as stop condition 500 iteration without improvement.

The third and last neighborhood is the exchange. For each node a, the nearest node b in a different route is determined. If moving node a to the route of b just before or after b improves the cost, it is considered for exchange. Then, the best improvement is made. The process continues until no improvement can be made.

The algorithm of VND-based heuristic can be seen below:

```
for(int i=0;i<ITERATIONS;i++){
  s = constructiveMethod();
  int k = 1;
  while(k<3){
    s' = bestOfNeighborhood(k);
    if (f(s') < f(s)){
      s = s';
      k = 0;
    }else{
      k++;
    }
  }
  if (f(s) < f(s*)){
    s* = s;
  }
}
return s*;
```

5 INSTANCES

We adapt a set of classic instances from the Vehicle Routing Problem (VRP) (Rochat and Taillard, 1995). We chose 8 instances, with 75, 100 and 150 customers, and adapt them by inserting 10 candidates for lockers. The position of these candidates were manually chosen in areas with many customers. The capacity of each locker was defined randomly in the range of 10 to 20 times the average of customers demand, so a locker may serve around 10 to 20 customers.

Table 1 lists some characteristics of each instance: the number of customers (n) and the capacity of the vehicles (Q). We do not impose a limit on the capacity of the vehicles that supply lockers (QL), as the capacity of lockers in the instances used already limit a reasonable capacity.

Table 1: Instances.

ID	#Customers	#Vehicle Capacity
c_tai75a	75	1445
c_tai75b	75	1679
c_tai75c	75	1122
c_tai75d	75	1699
c_tai100a	100	1409
c_tai100b	100	1842
c_tai100c	100	2043
c_tai150a	150	1544

6 RESULTS

The machine used was an i5-7400 CPU @ 3.00GHz with 8GB RAM. The Integer Linear Programming (ILP) model was implemented in Julia, using JuMP as modelling language, and run on Gurobi solver, with time limit of 1 hour. The heuristic was implemented in C++ and run 3 times for each instance. The average value is reported for analysis.

The results of the ILP model are reported in Table 2: solution value, runtime and the linear gap reported by Gurobi. Optimal results were found for only 3 instances, among those with less customers. However, the difficult is not related only to the number of customers. Instance `c_tai75a` has the same number of customers and lockers but the optimal solution was not guaranteed in the time available, finishing with a gap of 3.6%. This may be due to the relative location of lockers and customers. For example, a customer may be located in an area covered by two or more lockers, so may be served by any of them either by a door-to-door route. The higher the alternatives the greater the solution space, which may increase the running time to reach an optimal solution.

Table 2: Results of the ILP formulation.

Instance	Solution	Runtime	gap
c_tai75a	803.613	3600	3.63
c_tai75b	537.113	25	-
c_tai75c	804.118	194	-
c_tai75d	420.707	55	-
c_tai100a	971.408	3600	3.13
c_tai100b	982.592	3600	4.93
c_tai100c	870.561	3600	2.59
c_tai150a	1097.150	3600	16.01

Table 3 show the results of the proposed heuristic. Column gap^{ILP} represents the percentual difference between the solution of the heuristic and the one reached by the ILP in 1 hour. One may notice that the heuristic found the same result for 4 instances. Column gap^{LB} show the percentual difference to the lowew bound found the ILP model, which is the best known still possible result. Besides the two optimal solutions, for three other the gap was less than 4%.

The time to reach the optimal solution is substantially less in comparison to the ILP model, and for the others the gap was less than 5%.

In Figure 1 we can see the comparison between the lower bound and the two approaches proposed in this work. The results obtained by ILP and VND are close for most instances, increasing for larger instances, however, as previously mentioned, the time spent by VND to obtain solutions is significantly less.

Table 3: Results of the heuristic.

Instance	VND	time	gap^{ILP}	gap^{LB}
c_tai75a	803.613	9	-	3.63
c_tai75b	537.113	6	-	-
c_tai75c	813.119	9	1.11	1.11
c_tai75d	420.707	6	-	-
c_tai100a	971.408	22	-	3.13
c_tai100b	1002.820	19	2.02	6.85
c_tai100c	908.177	17	4.14	6.62
c_tai150a	1136.280	54	3.44	18.91

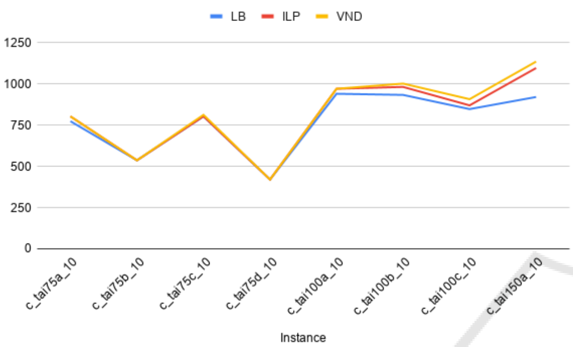

Figure 1: Comparison of the Lower Bound reported by CPLEX and the feasible solutions from ILP and VND for each instance.

The instances used in this work, proposed by Rochat and Taillard (1995), are commonly used for the VRP and some of its variations. Table 4 show on column VRP the best known results for the classic VRP, which may be used to study and foresee the saving that the use of lockers can bring. Solutions using lockers save in average 52% of the transportation costs. The real saving is not that amount, of course, because we are considering that routes to supply locker are 20% cheaper and we are not considering the costs of building and maintaining the lockers. However, the saving is clear, as the fixed costs of locker are spread over years and the costs of the table are a daily cost.

Table 4: Impact of the use of lockers.

Instance	VRP	ILP	VND
c_tai75a	1618.36	803.613	803.613
c_tai75b	1344.64	537.113	537.113
c_tai75c	1291.01	804.118	813.119
c_tai75d	1365.42	420.707	420.707
c_tai100a	2041.34	971.408	971.408
c_tai100b	1940.61	982.592	1002.820
c_tai100c	1406.21	870.561	908.177
c_tai150a	3055.23	1097.150	1136.280

Table 5 shows, for each instance, the number of customers that are served by lockers in the best solution found by each method. One might intuitively think that the optimal solution would include the maximum possible number of customers to lockers. However, this is not always the case, as shown by the results for the instance `c_tai100c`: the heuristic solution is 4% costly, despite having more customers associated to lockers. This happens because, in some scenarios, the cost to visit a locker may be higher than the cost to include the costumers associated to it in other route. Hence, even disregarding installation costs, lockers should not be build deliberately, as there would be still supply costs.

Table 5: Customers served by lockers.

Instance	Customers	ILP	VND
c_tai75a	75	62	62
c_tai75b	75	69	69
c_tai75c	75	58	57
c_tai75d	75	72	72
c_tai100a	100	82	82
c_tai100b	100	83	83
c_tai100c	100	59	61
c_tai150a	150	125	121

7 CONCLUSION

Due to the increasing popularity of e-commerce the last mile step in the delivery of goods has become more important and relevant in the delivery planning. The use of lockers has gained attention as an alternative to reduce costs, to optimize the delivery time and is also beneficial to the environment, as it contribute to reduce gas emission.

In this work we study methods for a vehicle routing combined with a facility problem for delivering goods using lockers. To define and solve the problem we propose an integer linear programming model, implemented and solved by Gurobi. Due to the complexity of the formulation, a heuristic is also proposed to handle larger instances. The heuristic is based on the VND metaheuristic and uses 3 neighborhoods to improve a greedy initial solution.

Experimental tests were made with 8 cases adapted from VRP classical instances. The ILP formulation found the optimal solution for three instances and a linear gap below 5% for other four instances within 1 hour of execution time. The heuristic found solutions close to the ones found by the ILP for most of the instances in few seconds.

We show the impact of the use of the lockers and as future works we plan to incorporate time windows and traffic conditions, as the problem in the real context has such characteristics. We also plan to improve the heuristic by adding more neighborhoods and use good solutions to instead of creating new random solutions on each iteration.

ACKNOWLEDGEMENTS

The authors thank Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) for the financial support of this project.

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