ISSN: 1672 - 6553

JOURNAL OF DYNAMICS AND CONTROLL

VOLUME 9 ISSUE 7: 236 - 248

ANT COLONY METAHEURISTIC FOR THE INTEGRATED BIN PACKING-VEHICLE ROUTING WITH COVERAGE AREAS APPLIED TO SUPPLY LOGISTICS

Jose Rodriguez – Melquiades

Department of Informatic, University National of Trujillo, Peru

JOURNAL OF DYNAMICS AND CONTROL
DOI: https://doi.org/10.71058/jodac.v9i7017

ANT COLONY METAHEURISTIC FOR THE INTEGRATED BIN PACKING-VEHICLE ROUTING WITH COVERAGE AREAS APPLIED TO SUPPLY LOGISTICS

Jose Rodriguez – Melquiades

Department of Informatic, University National of Trujillo, Peru

ORCID: https://orcid.org/0000-0002-4763-4663

Corresponding author: jrodriguez@unitru.edu.pe

Abstract: *The population growth in urban areas has generated intense commercial activity in cities, so the delivery of consumer products and others must be done as fast as possible. In this context, an integrated Bin Packing-Vehicle Routing proposal is presented, with quantification of the CO2 generated by vehicles under a sales approach within a coverage area solved through the Ant Colony Optimization metaheuristic. The process, in a first level, consists of packing items in a group of bins located in a collection center. At level 2, by means of capacitated vehicle routing, the items are distributed to sales centers located in strategic places of a city, which will have the capacity to serve a group of customers located within a coverage area of the respective urban area. The proposal implemented in Python shows that its implementation provides good results as it happened when it was applied in the city of Trujillo, Peru.*

Keywords: Bin packing, vehicle routing, Ant Colony Optimization, coverage area

1. Introduction

Population growth in cities around the world has made it difficult for those in charge of developing plans related to the supply of various goods to meet the fundamental demands of the populace. Thus, the employment of urban logistics—which has developed into intelligent logistics—is required [1]. Our suggestion is only applicable to city logistics.

In this situation, academic involvement is required to provide computationally based solutions to aid in decision-making. Therefore, from the perspective of city logistics, the expected success requires the use of theoretical knowledge such as packing, vehicle routing, and computational procedures.

In the modern world, it is essential to pack items in collection centers so they can be sent to sales centers or delivered to consumers'

DOI: https://doi.org/10.71058/jodac.v9i7017

homes based on demand generated during delivery or when the customer visits the sales center through a routing process. Therefore, the Ant Colony Optimization metaheuristic is used to computationally solve an integrated packaging-routing proposal. This method not only optimizes the process but also has the ability to quantify the CO2 emissions that vehicle emit when traveling through urban regions. The proposal is depicted graphically in Figure 1.

The article is structured as described below. Section 1 presents the actual situation in the context of the subject of the study. A review of the research that has been done and is relevant to the current idea is presented in Section 2, and it includes recent publications in specialized journals. Section 3 presents the metaheuristic based on Ant Colony Optimization, developed to solve the problem shown graphically in Figure 1. Section 4 shows and discusses the results obtained when the proposal was applied to two scenarios for the city of Trujillo in Peru. Finally, the conclusions in section 5, and the bibliographical references.

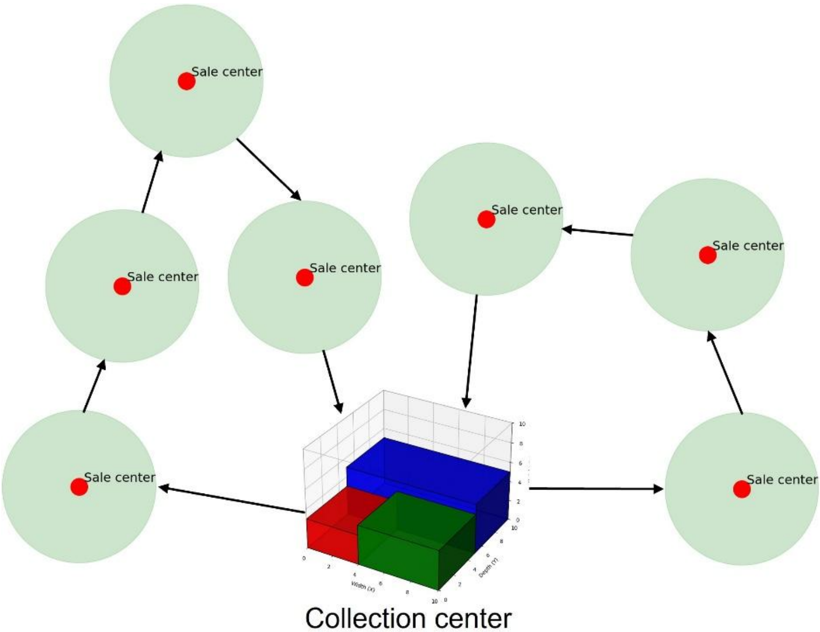

Figure 1. Bin packing-Routing to sale centers with customers within coverage area

2. Review of specialized literature

DOI: https://doi.org/10.71058/jodac.v9i7017

2.1. Bin Packing and vehicle routing problem

Bin Packing is a combinatorial optimization problem that consists of grouping and depositing a group of items in a bin according to its capacity, i.e., given a number of identical bins with capacity $w \in Z^{+}$ and a set $N = \{1, 2, \ldots, n\}$ of items, where each item $j \in N$ is associated with a weight $w_j \leq W$. Therefore, to pack all the objects and place them in bins in a minimum amount without exceeding their capacities, several optimization models and algorithms have been proposed, as shown in [2] who proposes a mixed integer linear programming model and a heuristic, to solve this problem with time windows for each bin.

Optimizing the transportation service is crucial because it improves service quality and increases the competitiveness of the organization that implements it, claims [3]. The method starts with the adoption and usage of a suitable packaging procedure, for which they developed an application that was evaluated in the context of a logistics service provider.

In [4], the Bin Packing problem is defined, classified as an NP-Hard problem, and its applications are discussed. Bin packing is closely related to logistics and frequently appears as a specific subproblem of some more complex logistic problems. Therefore, they discuss both the exact and approximate computational strategies used to solve this class of problems in [5], where they construct a benchmark class to be used in algorithmic proposals.

Vehicle routing is NP-Hard, which is a combinatorial optimization problem that involves offering a minimum cost service to a group of customers under the condition that the process starts and ends at a depot and that every customer will be visited exactly once in order to receive service. This is why [6] discusses its variants, a taxonomy, and metaheuristics developed during the last ten years for this type of problem, considering their importance to solving logistic problems. Similarly, generalized vehicle routing in all of its variations is studied in [7], which classifies them into seven groups and explains their corresponding exact and approximate solution algorithms.

According to [8], a bibliometric analysis of the proposals submitted between 1959 and 2022 shows their importance in resolving logistics related problems. A survey done recently [9] discusses a number of proposals to satisfy multi-commodity demands. In [10], the significance of vehicle routing is reaffirmed in its different forms, particularly when it comes to intelligent delivery. [11] proposes an important variant known as open vehicle routing, and [12] presents an application.

DOI: https://doi.org/10.71058/jodac.v9i7017

2.2. Integrated Bin Packing-vehicle routing

One activity that promises to produce positive outcomes is the integration of Bin Packing and vehicle routing for use in logistics problems. For example, [13] proposed an integrated two-level model based on mixed integer programming, which is validated using both artificially created scenarios and real instances applied to logistics.

In order to address logistical challenges, an integrated packing and routing problem was recently proposed. This problem involves simultaneous packing and transportation decisions, and a set of heuristic procedures as well as an automatic algorithm using an artificial neural network were investigated with the goal of guiding it towards machine learning for logistics optimizations. In addition, [14] presented a binary integer linear programming model.

Delivery of commodities has become more robust as a result of the COVID-19 epidemic. In this context, [15], when applied to the cold chain's last mile delivery, suggests an optimization model known as the Joint Optimization of Sustainable Order Packing and Multi-Temperature Delivery Problem. In this model, orders are received, packaging is developed in the best possible way, and transportation is established for product delivery through quick and efficient routing to guarantee customer satisfaction. Modular coordination is crucial since, with the vehicle available, loading goods with specified qualities will be successful [16]. Similarly, reduce costs associated with the process of delivering cities in a timely way is a desirable goal in the last mile.

3. Metaheuristics for Integrated Bin Packing-Ruteo in an Urban Context

The challenge of packaging items and delivering them to sales centers via capacitated vehicle routing is solved by the metaheuristic discussed in this section. One important aspect that isn't included in the literature is that these centers will cater to clients who live within their specific coverage area. As a result, the consumer has two choices: either purchase items in person at their local sales center or have items delivered to their home. Our proposal can be easily considered through delivery, but it is limited to in-person sales. In order to make decisions about environmental care, this study also measures the CO2 emissions produced during the routing stage.

3.1. Ant Colony Optimization

DOI: https://doi.org/10.71058/jodac.v9i7017

The following is the pseudo-code of the proposal, which is based on the discussions in the previous section, to accomplish the desired goal through the city under study's road network. This will help guarantee that packaged items are delivered on time and then transported to the sales centers via capacitated vehicle routing. Customers who live within a so-called coverage area will be served by such centers.

The algorithm, which is separated into two parts, is first given data on how many items should be placed in the bins and how many cars, each with a specific capacity, will be moving throughout the road network, among other considerations. Finally, the EVALUATESOLUTION function returns the final cost sum utilizing the BinAssignments and vehicleRoutes parameters. In addition to the ANTCOLONYOPTIMIZATION and INITIALIZEPHEROMONES functions.

Algorithm

```
Input: NumItems; NumBins; NumVehicles; VehicleCapacity; red vial G;
    SalesCenter; coordinates and coverage areas for SalesCenter; time
    window for SalesCenter; SalesCenter demand; depot coordinates.
for all pairs (i, j) of locations do
    if i ≠ j then
        Calculate distance(i, j) to the shortest distance in G
        if there is no route then
            distance(i, j) ← ∞
        end if
    end if
end for

function EvaluateSolution(BinAssignments, VehicleRoutes)
    for all vehicles on a route do
        Calculate time and distance from depot
        for all Pairs of consecutive nodes in the route do
            Add distances, time and emissions
            Check penalties for time windows
        end for
        Calculate total load and penalty if capacity is exceeded
        Calculate return to depot
    end for
    return total sum of costs
end function
```

JOURNAL OF DYNAMICS AND CONTROL
DOI: https://doi.org/10.71058/jodac.v9i7017

```
function InitializePheromones        ▷ Arrays for bins and routes
    Initialize arrays of PheromonesBin and PheromonesRoute
    return PheromonesBin, PheromonesRoute
end function

Assign vehicles ← bins

function AntColonyOptimization
    Initialize Pheromones
    BestSolution ← ∅; BestCost ← ∞
    for t = 1 : Iterations do
        Solutions ← [ ]
        for k = 1 : NumAnts do
            Generate BinAssignments using pheromone probability
            Group SalesCenter by bin; Assign route to vehicle by bin
            Merge SalesCenter and reassign routes    ▷ overwrites previous
            Calculate Cost
            if Cost < BestCost then
                Update better solution and cost
            end if
            Add solution to list
        end for
        PheromonesBin ← PheromonesBin × (1 - EvaporationRate)
        PheromonesRoute ← PheromonesRoute × (1 - EvaporationRate)
        for all solutions do
            Reinforce pheromones proportional to Q/Cost
        end for
        Save best cost of this iteration
    end for
    return BestSolution
end function

Show the best assignment of items to bins
Show assignment of bins to vehicles
Create interactive map and show depot and SalesCenter
for all SalesCenter do
    Draw coverage zone
end for
```

DOI: https://doi.org/10.71058/jodac.v9i7017

```
for all vehicles do
    Calculate shortest path between each pair of nodes
    Add distance, time, emissions; Draw route on map
end for
Display bins and items in 3D
```

3.2. Results and discussion

A laptop with Core (TM) i7-855ou CPU 1.8 Ghz with 8.00 Gb RAM was used to evaluate the proposal, where the Python programming language was used to solve the case study.

The Province of Trujillo, located in the La Libertad Region, is made up of 11 Districts, which, due to their high population density, need to be served in order to supply them with basic products in the most optimal and timely manner possible. In this sense, the proposal of the present research constitutes an ideal alternative, whose implementation will be a great contribution through the algorithm presented in the previous section 3.1.

3.2.1. Case 1

Table 1 shows the data to be processed by the proposed algorithm, where each bin has a capacity of 30 units, and 8 sales centers with their time windows, randomly chosen which are located in the central part of their respective coverage zones whose radius is 450 meters. Other data are shown in Table 1. Finally, the values 0.2 and 0.275 corresponding to the EmissionRate of CO_2 per vehicle in grams per liter and CC the fuel consumption in liters per km traveled by the vehicle. The total CO_2 emission generated by the travel process was calculated using the formula:

$$\text{emissions} = \text{TotalDistance} \times (\text{EmissionRate}/\text{VehicleCapacity}) \times \text{CC}$$

Table 1. Data used for case 1 in the proposal

Dates	NumItems	NumBins	NumVehicles	VehicleCapacity
Quantity	10	3	3	8

After 200 iterations and 30 ants employed in each iteration to build solutions, where the pheromone deposited is in the ratio of Q/cost, Q is a constant that scales the amount of pheromone deposited by an ant according to the quality of the solution, and whose EvaporationRate of the pheromone in each iteration is

DOI: https://doi.org/10.71058/jodac.v9i7017

0.5; we have the 10 items packed and placed in three available bins, as shown in Figure 2.

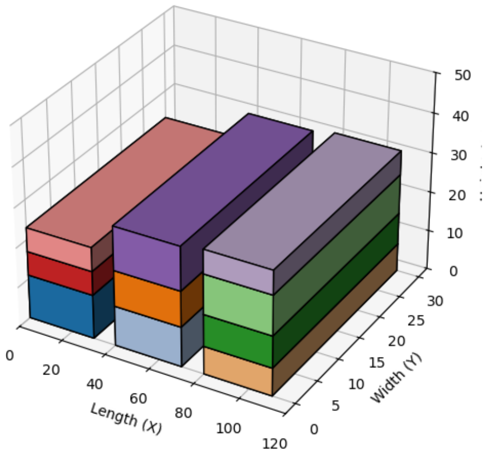

Figure 2. Three bins each with their items in Case 1

Once the items are packed and placed in the bins, they are transported to the sales centers following a vehicle routing process, where each of the three vehicles begins its journey from the collection center Loc0 to each of the sales centers assigned to it Loc_i, i = 1,…,8. Finally, each customer within its coverage area will go to its respective sales center to purchase the desired items. See Table 2 and Figure 3, where the distance is given in meters, the carbon dioxide in grams and the travel time in minutes.

Table 2. Transportation of bins to sales centers in Case 1

Vehicle	Route	Distance	CO2	Time
0	Loc0 → Loc6 → Loc5 → Loc2 → Loc0	9406.5	64.7	12.3
1	Loc0 → Loc7 → Loc8 → Loc4 → Loc0	7204.7	49.5	11.2
2	Loc0 → Loc1 → Loc3 → Loc0	2600.1	17.9	4.3

DOI: https://doi.org/10.71058/jodac.v9i7017

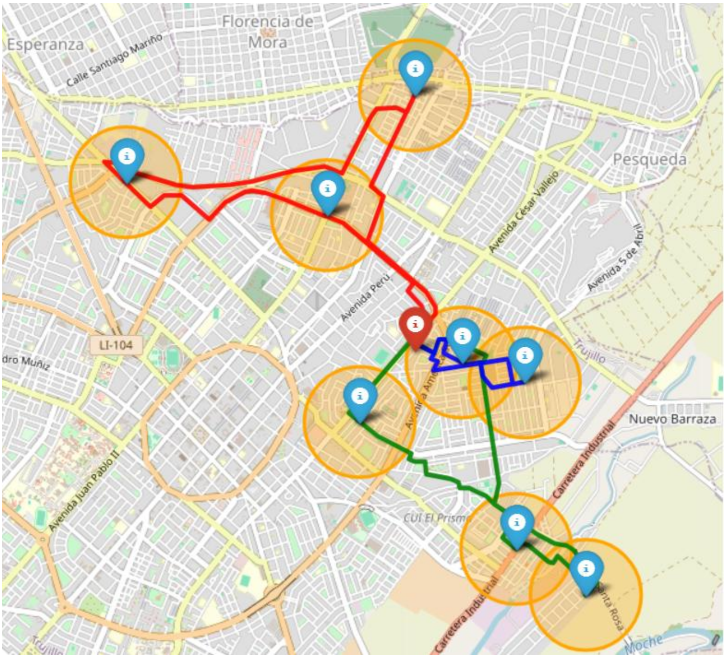

Figure 3. Routing delivering bins to the sales centers in Case 1

3.2.2. Case 2

In this new case, the sales centers have been increased to 11 and their respective time windows, in addition the NumItens; NumBins; NumVehicles and VehicleCapacity are now 30; 4; 4 and 10, respectively. The other information already specified in Case 1 remains constant. The computationally executed proposal returns the results in Figure 4, Table 3 and Figure 5.

DOI: https://doi.org/10.71058/jodac.v9i7017

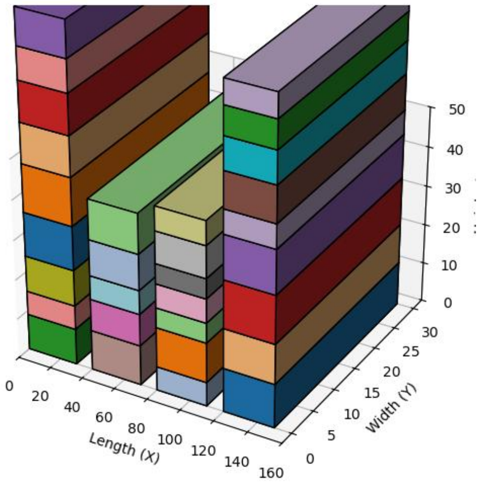

Figure 4. Four bins each with their items in Case 2

Table 3. Transportation of bins to sales centers in Case 2

Vehicle	Route	Distance	CO2	Time
0	Loc0 → Loc7 → Loc11 → Loc9 → Loc0	8673.2	47.7	13.9
1	Loc0 → Loc10 → Loc1 → Loc3 → Loc0	4155.0	22.9	6.9
2	Loc0 → Loc5 → Loc2 → Loc6 → Loc0	9956.1	54.8	14.3
3	Loc0 → Loc8 → Loc4 → Loc0	6190.7	34.0	10.0

The two case studies presented show the potential of the proposal to provide timely attention, since the sales centers will always be stocked to meet the demand of people located within the coverage area without generating agglomeration, who visit such centers to purchase their products in person or there is also the possibility of making purchases in the non-face-to-face modality, where orders are delivered to the buyers' homes. Although this last type of service was not algorithmically modeled in this proposal, we consider that it can be put into practice since the structure is already developed.

DOI: https://doi.org/10.71058/jodac.v9i7017

Additionally, since the route is traveled by vehicles, then it was also possible to quantify the distances traveled in meters and the travel time in minutes, so it was possible to determine the amount of CO2 emissions, as shown in Tables 2 and 3. This makes the proposal also a contribution to environmental protection.

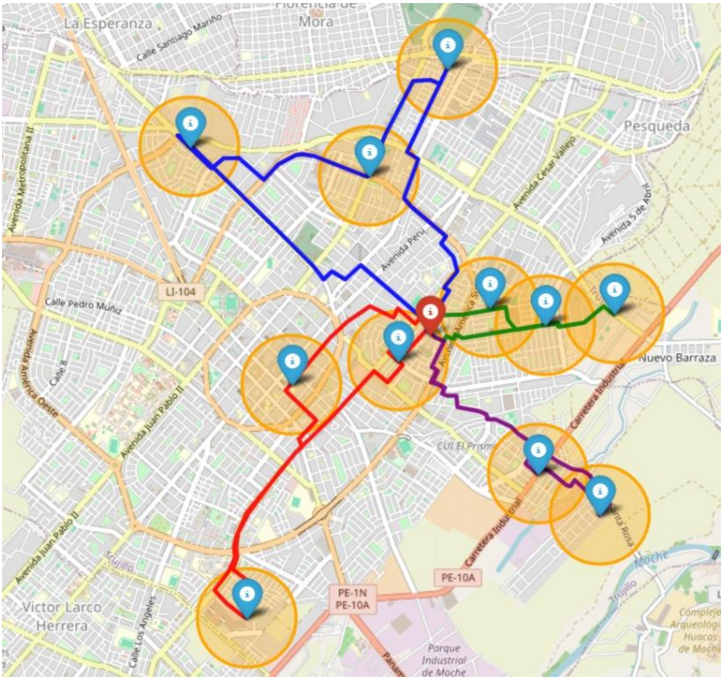

Figure 5. Routing delivering bins to sales centers in Case 2

4. Conclusion

The article shows the ant colony optimization metaheuristic based on integrated bin packing-vehicle routing in the urban context. The operational activity of packing and routing applied to the supply of items in an urban area consisted of two levels, where the first is the process of packing and placing the items in the bins and the second its transportation for distribution to the sales centers through the road network in an optimal way. In addition, in the article the proposal quantifies the generation of CO2 for decision making in the care of the environment.

DOI: https://doi.org/10.71058/jodac.v9i7017

The proposal is based on the estimated premise of the demands generated by customers, located within a coverage area, to the sales centers. This premise constitutes valuable information to place the items in the bins, to then build a routing plan as shown in the proposed metaheuristic.

The computational results in the cases when the research was applied to the city of Trujillo in Peru, show the potential of the proposal because the results are obtained quickly, which is a favorable indication for situations with larger scenarios that can occur when, for example, a company expands its business to other sectors of the city.

References

[1] *R. Gonçalves, L. Domingues, "Artificial Intelligence Driving Intelligent Logistics: Benefits, Challenges, and Drawbacks," in Procedia Computer Science, Elsevier, vol. 256,* ***(2025)****, pp. 665-672. Available: http://doi.org/10.1016/j.procs.2025.02.165*

[2] *K. Fleszar, "A new MILP model and fast heuristics for the variable-sized bin packing problem with time windows," in Computer & Industrial Engineering, Elsevier, vol. 175, 108849,* **(*2023*).** Available: http://doi.org/10.1016/j.cie.2022.108849

[3] *K. Kolezarić, D. Božić, M. Šafran, "Transport Service Optimization by Bin Packing Problem Implementation," in Transportation Research Procedia, Elsevier, vol. 73, pp. 58-65,* ***(2023).*** *Available: http://doi.org/10.1016/j.trpro.2023.11.892*

[4] *Y. Hadad, B. Keren, "A Two-Stage Bin Packing Algorithm for Minimizing Machines and Operators in Cyclic Production Systems," in Algorithms, MDPI, vol. 18, issue 6, 367,* ***(2025).*** *Available: http://doi.org/10.3390/a18060367*

[5] *G. Dósa, A. Éles, A. R. Goswami, I. Szalkai, Z. Tuza, "Solu-*

DOI: https://doi.org/10.71058/jodac.v9i7017

tion of Bin Packing Instances in Falkenauer T Class: Not So Hard," in Algorithms, MDPI, vol. 18, issue 2, 115, ***(2025).*** *Available: http://doi.org/10.3390/a18020115*

[6] *S. Elatar, K. Abouelmehdi, M. E. Riffi, "The vehicle routing problem in the las decade: variants, taxonomy and metaheuristics," in The 14th International Conf. on Ambient Systems, Networks and Technologies, Leuven, Belgium, pp. 15–17,* ***(2023).***

[7] *A. A. Jolfaei, M. Alinaghian, R. Bahrami, E. B. Tirkolaee, "Gen- eralized vehicle routing problem: Contemporary trends and re- search directions," in Heliyon, CellPress, 9, e22733,* ***(2023).*** *Avail- able: http://doi.org/10.1016/j.heliyon.2023.e22733*

[8] *Q. Ni, Y. Tang, "A Bibliometric Visualized Analysis and Classification of Vehicle Routing Problem Research," in Sustainability, MDPI, vol. 15, issue 9, 7394*, **(2023).** *Available: http://doi.org/10.3390/su15097394*

[9] *W. Gu, C. Archetti, D. Cattaruzza, M. Ogier, F. Semet, M. G. Speranza, "Vehicle Routing Problem with multiple commodities: A survey," in European Journal of Operational Research, Elsevier, vol. 317, 1, pp. 1-15,* ***(2024).*** *Available: http://doi.org/10.1016/j.ejor. 2023.11.032*

[10] *T. Jastrzab, M. Myller, L. Tulczjew, "Standardized validation of vehicle rounting algorithms," in Appl Intell, Springer Nature, vol. 54, pp. 1335-1364,* ***(2024),*** *Available: http://doi.org/10.1007/s10489-023-05212-0*

[11] *T. Gasset, F. Paillalefr, S. Payacan, G. Gatica, G. Herrera-Vidal, R. Linfati, J. R. Coronado-Hernández, "Route Optimization for Open Vehicle Routing Problem (OVRP): A Mathematical and Solution Approach," in Appl. Sci., MDPI, vol. 14, issue 16, 6931,* ***(2024)****, Available: http://doi.org/10.3390/app14166931*

[12] *J. Rodriguez-Melquiades, L. Ramirez Cerna, "Reverse logistics based on green open vehicle routing for waste collection in the urban context," in Pesquisa Operacional , 43, e269174, pp 1-33,* ***(2023),*** *Available: http://doi.org/10.1590/0101-7438.2023.043.00269174*

[13] *C. Liu, "An integrated mixed integer program model for the two- level capacitated vehicle routing problem with extensions," in Optimization and Control, arXiv, arXiv: 2210.07051,* ***(2022),*** *Available: http://doi.org/10.48550/arXiv.2210.07051*

[14] *C. Liu, J. Lyu, K. Fang, "Integrated packing and routing: A model and its solutions," in Computers and Operations Research, Elsevier, vol. 172, 106790,* ***(2024),*** *Available: http://doi.org/10.1016/j.cor.2024.106790*

[15] *Y. P. Tsang, H. Ma, K. H. Tan, C.K.M. Lee, "A joint sustainable order-packing vehicle routing optimisation for the cold chain e- fulfilment," in Ann Oper Red, Springer Nature,* ***(2024),*** *Available: http://doi.org/10.1007/s10479-024-05949-y*

[16] *N. Perić, A. Kolak, V. Lešić, "Modular Coordination of Vehicle Routing and Bin Packing Problems in Last Mile Logistics," in logistics, MDPI, vol. 9, issue 2,* ***(2025),*** *Available: http://doi.org/10.3390/logistics9020070*