Application of the Ant Colony Optimization algorithm (ACO) in urban route optimization: an *in silico* case study

Fabricio Marcillo Vera. Member IEEE
Escuela de Hábitat, Infraestructura y Creatividad
Pontificia Universidad Católica del Ecuador, sede Santo Domingo
Santo Domingo, Ecuador
frmarcillo@pucesd.edu.ec

Anderson Meza Vizuete
Escuela de Hábitat, Infraestructura y Creatividad
Pontificia Universidad Católica del Ecuador, sede Santo Domingo
Santo Domingo, Ecuador
ajmezav@pucesd.edu.ec

Argel Velez Villagomez
Escuela de Hábitat, Infraestructura y Creatividad
Pontificia Universidad Católica del Ecuador, sede Santo Domingo
Santo Domingo, Ecuador
aavelezv@pucesd.edu.ec

Sebastián Toscano Araque
Escuela de Hábitat, Infraestructura y Creatividad
Pontificia Universidad Católica del Ecuador, sede Santo Domingo
Santo Domingo, Ecuador
satoscano@pucesd.edu.ec

Kenneth Cevallos Cedeño
Escuela de Hábitat, Infraestructura y Creatividad
Pontificia Universidad Católica del Ecuador, sede Santo Domingo
Santo Domingo, Ecuador
kgcevallosce@pucesd.edu.ec

Andy Alava Gomez
Escuela de Hábitat, Infraestructura y Creatividad
Pontificia Universidad Católica del Ecuador, sede Santo Domingo
Santo Domingo, Ecuador
agalava@pucesd.edu.ec

Andy Roldan Posligua
Escuela de Hábitat, Infraestructura y Creatividad
Pontificia Universidad Católica del Ecuador, sede Santo Domingo
Santo Domingo, Ecuador
adroldan@pucesd.edu.ec

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***Abstract*—This study examined how the Ant Colony Optimization (ACO) algorithm could be used to improve urban route planning, using a simulation based on the classic Traveling Salesman Problem (TSP). Four city locations were represented using Cartesian coordinates, and the distances between them were calculated with the Euclidean formula. The experiment was conducted in Python 3.13.0, applying *NetworkX* and *Matplotlib* for modeling and visualization. The ACO algorithm was configured with four ants and ten iterations, using standard parameters such as pheromone importance, evaporation rate, and heuristic influence. The results showed that the ants generated distinct routes. The most efficient path—C4, C3, C1, C2, C4—was identified early in the process, with a total length of 241.45 km. The variability in the solutions highlighted ACO's ability to explore multiple possibilities within the search space. Compared to other heuristic techniques like Genetic Algorithms, Tabu Search, or Simulated Annealing, ACO showed a more flexible and stable performance, particularly in dynamic urban environments. These qualities suggest that ACO could be a valuable approach for tackling routing problems in cities, especially when conditions such as traffic or delivery constraints are in constant change. While results were promising, future research is encouraged to evaluate ACO in more complex urban scenarios and explore how tuning its parameters might enhance its performance in real-world applications.**

***Keywords*—Ant Colony Optimization, Metaheuristic Optimization, Traveling Salesman Problem (TSP) and Urban Transportation Planning.**

I. Introduction

The ACO algorithm, developed by Marco Dorigo in 1990, is an optimization technique based on collective intelligence focusing on the behavior of ants searching for optimal routes to food sources [1][2]. Some authors have shown that ACO presents a considerable efficiency in solving the traveling salesman problem (TSP), which in turn is defined as a classical combinatorial optimization problem in communication sciences and applied mathematics, also, it consists of finding the shortest path through a set of cities, visiting each one exactly once and returning to the point of origin. Since this problem belongs to the NP-hard class, exact algorithms are inefficient when the number of nodes grows significantly [3]. In an applicative context, ACO's ability to adapt to changes and iterative learning makes it a useful tool for simulated urban contexts. Nowadays, contemporary cities face increasing challenges in the planning and management of their mobility systems, the increase of urban population, vehicular congestion and associated environmental problems, generate a need to optimize urban routes as a facility to improve transportation efficiency and reduce environmental impact [4].

Urban environments nowadays require algorithms capable of finding optimal solutions in reasonable time. The ant colony algorithm, considering its collaborative behavior mechanism in finding efficient routes, presented a vehicle routing problem with flexible time windows, where the use of ACO was proposed for the logistics of a vegetable and food company in China, in order to validate a multi-objective model with 16 delivery points where the results showed that greater savings can be generated in the company's logistics due to the use of ACO with more flexible time sales [4][5].

The objective of this study was to elaborate optimal routes by means of the ant colony optimization algorithm as an alternative for solving TSP through *in silico* experimentation for applicability in urban areas and city-scale solutions.

II. MATERIALS AND METHODS

A. *Conditions of the experiment*

There were four points represented by Cartesian coordinates (cities): C1 (9, 76), C2 (28, 75), C3 (98, 3) and C4 (96, 27) as shown in Figure 1. The distance between each pair of cities was calculated using the Euclidean distance formula, which considers the differences in the X and Y coordinate values.

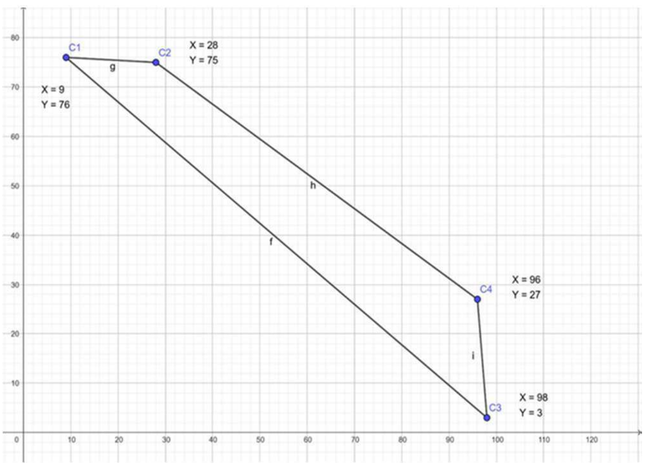

Fig. 1. Diagram of the location of the cities represented.

B. *Algorithm implementation*

It was carried out in two sub-steps: (1) an automated pre-built ant colony algorithm (adapted from: *https://www.datacamp.com/tutorial/swarm-intelligence*) was used, (2) the algorithm was standardized, where, the number of ants= 4, number of interactions= 10, importance of pheromones= 1.0, importance of heuristics= 1.0, pheromone evaporation rate = 5% per interaction, amount of pheromones= 0.0453.

Code used:

```
from aco import AntColony
import matplotlib.pyplot as plt
    import networkx as nx
    def graphic_path(path):
        G = nx.DiGraph()
        edges = [(path[i], path[i+1]) for i in range(len(path)-1)]
        G.add_edges_from(edges)
        pos = {node: node for node in path}
        nx.draw(G, pos, with_labels=True,
node_color='orange', node_size=500, arrowsize=20)
        plt.title("Best path found by ACO")
        plt.show()
    cities = [
        (9, 76),
        (28, 75),
        (98, 3),
        (96, 27),
    ]
    colony = AntColony(
        nodes=cities,
        ant_count=4,
        alpha=1.0,
        beta=1.0,
        pheromone_evaporation_rate=0.05,
        pheromone_constant=0.0453,
        iterations=10,
    )
    best_path = colony.get_path()
    print("Best path found:", best_path)
graphic_path(best_path)
```

C. *Analysis of results*

The results obtained were based on the complete routes generated by calculating their distance measured in kilometers, where the routes with the best accumulated distance were prioritized, the results were analyzed using Python software version 3.13.0 through *NetworkX* and *Matplotlib* libraries.

III. RESULTS AND DISCUSSION

The results obtained showed that the optimal route found was C4, C3, C1, C2, C4. This route represents a closed loop that respects the TSP condition and was selected because it presented the shortest total distance among all the simulations performed. The approximate numerical value of this distance was 241.45 km, calculated from the sum of the Euclidean distances between each pair of consecutive cities on the route as seen in Figure 2.

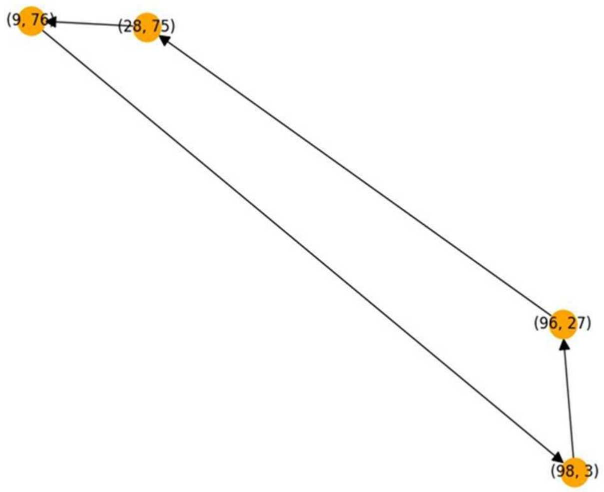

Fig. 2. Scheme of solution obtained.

Further in detail, the ACO algorithm used, ant 1, constructed a path (4, 3, 1, 2, 4) reached a total length of 241.45 km, ant 2, obtained the path (3, 1, 4, 2, 3), with a length of 398.61 km, while the third ant generated the sequence (4, 3, 2, 1, 4), with a total of 243.38 km. Finally, the fourth ant constructed the path (2, 1, 3, 4, 2), whose total length was 276.17 km, as shown in Figure 3.

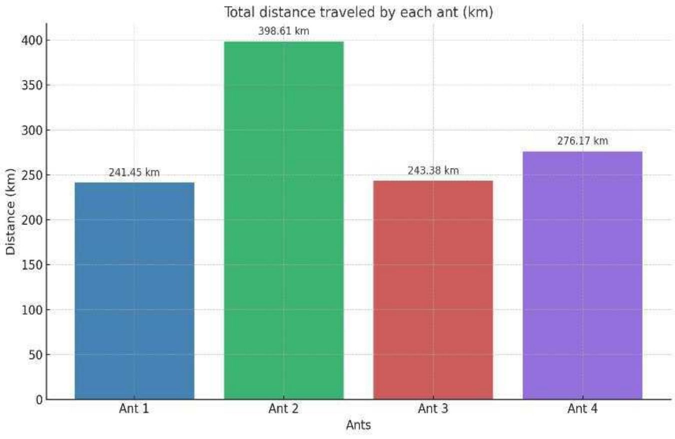

Fig. 3. Bar graph considering distance traveled.

Considering the analysis of variance in the distance traveled by each ant, it was observed that there is a significant difference between the distance traveled by each ant; however, the ant with the longest distance traveled was ant two, and the one with the shortest distance traveled was ant one. The variation observed in the distances traveled by the different ants evidences the algorithm's ability to explore multiple viable solutions within the search space, which is especially useful in complex and nonlinear problems such as urban routing [6], [7]. Compared to other methods, ACO has key advantages that justify its choice in this study. First, unlike genetic algorithms (GA), which operate by crossover and mutation operators on populations of coded solutions, ACO simulates the collective behavior of simple agents (ants) interacting with their environment through the pheromone trail [8], [9]. This feature allows ACO greater adaptability in dynamic search spaces, such as those found in urban environments, where traffic and accessibility conditions can change in real time [10], [11].

Also, compared to tabu search (TS), which employs short-term memory to avoid cycles and explore neighboring solutions, ACO offers more global exploration from the outset, allowing emerging solutions to be strengthened based on positive reinforcement [12], [13]. While TS may be more effective in locally exploiting nearby solutions, ACO maintains a better balance between exploration and exploitation, which is critical when starting from limited information or highly variable scenarios [14], [15], [16], [17]. With respect to simulated annealing (SA), which relies on a thermal analogy to accept suboptimal solutions with some decreasing probability, ACO exhibits greater stability and convergence to optimal or near-optimal solutions with less dependence on fine-tuning of temperature or cooling parameters [18], [19][20], [21].

A case study conducted by Mariusz Korzeń in Poland demonstrated the application of the Ant Colony Optimization (ACO) algorithm in urban contexts, particularly for public transport route planning. The author proposed a modified version of ACO with direct implementation in urban agglomerations that demand sustainable, efficient, and reliable mobility systems. The model incorporated real-world parameters such as driving time, route length, delays, and urban attractiveness, achieving an 11.5% reduction in logistical effort compared to existing routes [22]. These findings suggest that ACO algorithms represent a viable alternative for the organization and optimization of public transport in urban development scenarios, offering potential applicability in Ecuadorian cities facing similar challenges in sustainable mobility.

IV. CONCLUSIONS

The application of the ant colony algorithm (ACO) in urban route optimization proved to be an effective and versatile strategy to solve routing problems with multiple nodes and spatial constraints. From the *in silico* simulation performed, it was observed that ACO was able to generate feasible solutions with significantly different paths from each other, highlighting the algorithm's ability to explore a wide search space. The most efficient path, with a total length of

241.45 km, was obtained in the first iterations, which evidences its potential to converge to optimal solutions even in preliminary stages of execution. However, it is important to note that the efficiency of the algorithm may depend on the fine tuning of its parameters and the size of the problem. Therefore, future work could consider the application of ACO on more complex urban scenarios, integrating variables such as temporal constraints, traffic conditions or logistic priorities.

This study was conducted in a laboratory setting for educational and exploratory purposes. Therefore, in future research, we plan to apply ACO algorithms to complex, real-world urban contexts. Considering the results obtained, these algorithms are a clear alternative for route optimization, focusing specifically on TSP.

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REFERENCES

[1] Z. Cai, "Multi-direction searching ant colony optimization for traveling salesman problems," *Proceedings - 2008 International Conference on Computational Intelligence and Security, CIS 2008*, vol. 2, pp. 220–223, 2008, doi: 10.1109/CIS.2008.151.

[2] H. Guo, Q. Liu, and Z. Dang, "Optimization of Two-dimensional Path Optimization Algorithm Based on Dijkstra Ant Colony Optimization Algorithm," *Proceedings of 2024 2nd International Conference on Signal Processing and Intelligent Computing, SPIC 2024*, pp. 399–402, 2024, doi: 10.1109/SPIC62469.2024.10691583.

[3] G. K. Baydogmus, "A Parallelization Based Ant Colony Optimization for Travelling Salesman Problem," *2022 1st International Conference on Information System and Information Technology, ICISIT 2022*, pp. 166–169, 2022, doi: 10.1109/ICISIT54091.2022.9873092.

[4] C. Ratanavilisagul, "Modified Ant Colony Optimization with pheromone mutation for travelling salesman problem," *ECTI-CON 2017 - 2017 14th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, pp. 411–414, Nov. 2017, doi: 10.1109/ECTICON.2017.8096261.

[5] Z. Yan, S. Cai, and S. Hou, "Non-Dominated Sorting Multi-Objective Ant Colony Optimization Algorithm for Route Planning of UUV Target Search," *Chinese Control Conference, CCC*, pp. 4404–4409, 2024, doi: 10.23919/CCC63176.2024.10662714.

[6] R. Gan, Q. Guo, H. Chang, and Y. Yi, "Improved ant colony optimization algorithm for the traveling salesman problems," *Journal of Systems Engineering and Electronics*, vol. 21, no. 2, pp. 329–333, Apr. 2010, doi: 10.3969/J.ISSN.1004-4132.2010.02.025.

[7] D. Ekmekci, "An Ant Colony Optimization Memorizing Better Solutions (ACO-MBS) for Traveling Salesman Problem," *3rd International Symposium on Multidisciplinary Studies and Innovative Technologies, ISMSIT 2019 - Proceedings*, Oct. 2019, doi: 10.1109/ISMSIT.2019.8932768.

[8] R. S. Jadon and U. Datta, "Modified ant colony optimization algorithm with uniform mutation using self-adaptive approach for travelling salesman problem," *2013 4th International Conference on Computing, Communications and Networking Technologies, ICCCNT 2013*, 2013, doi: 10.1109/ICCCNT.2013.6726752.

[9] V. Murugananthan, M. Y. E. S. Rehan, R. Srinivasan, M. Kavitha, and R. Kavitha, "Traveling Salesman Problem with Ant Colony Optimization," *Proceedings of the 2nd International Conference on Edge Computing and Applications, ICECAA 2023*, pp. 481–485, 2023, doi: 10.1109/ICECAA58104.2023.10212262.

[10] J. Thongpiem, N. Punkong, C. Ratanavilisagul, and S. Kosolsombat, "Hybrid Genetic Algorithm and Ant Colony Algorithm for Solving Travelling Salesman Problem," *2024 IEEE 9th International Conference on Computational Intelligence and Applications, ICCIA 2024*, pp. 69–73, 2024, doi: 10.1109/ICCIA62557.2024.10719116.

[11] U. Janjarassuk, "Hybrid Ant Colony Optimization Method for the Traveling Salesman Problem," *ICBIR 2024 - 2024 9th International Conference on Business and Industrial Research, Proceedings*, pp. 292–295, 2024, doi: 10.1109/ICBIR61386.2024.10875933.

[12] C. Ratanavilisagul and B. Pasaya, "Modified ant colony optimization with updating pheromone by leader and re-initialization pheromone for travelling salesman problem," *ICEAST 2018 - 4th International Conference on Engineering, Applied Sciences and*

Technology: Exploring Innovative Solutions for Smart Society, Aug. 2018, doi: 10.1109/ICEAST.2018.8434500.

[13] L. Meng, Y. Lin, S. Qing, and F. Wenjing, "Research on Generalized Traveling Salesman Problem based on Modified Ant Colony Optimization," *Proceedings of the 31st Chinese Control and Decision Conference, CCDC 2019*, pp. 4570–4574, Jun. 2019, doi: 10.1109/CCDC.2019.8833167.

[14] S. Huang, D. Yang, C. Zhong, S. Yan, and L. Zhang, "An Improved Ant Colony Optimization Algorithm for Multi-Agent Path Planning," *Proceedings - 2021 International Conference on Networking Systems of AI, INSAI 2021*, pp. 95–100, 2021, doi: 10.1109/INSAI54028.2021.00028.

[15] H. Cui and Y. Du, "Ant Colony Algorithm for Solving Multi-objective Optimization Problems in Software Engineering," *International Conference on Intelligent Algorithms for Computational Intelligence Systems, IACIS 2024*, 2024, doi: 10.1109/IACIS61494.2024.10721905.

[16] T. Huang, Z. Q. Zhang, Y. J. Gong, and J. Liu, "nLKH-ACS: A Niching Lin-Kernighan-Helsgaun Based Ant Colony System for Multi-Solution Traveling Salesman Problems," *IEEE Transactions on Evolutionary Computation*, 2024, doi: 10.1109/TEVC.2024.3507777.

[17] X. L. Shi, W. N. Chen, F. F. Wei, and J. Zhang, "A Distributed Ant Colony System with Pheromone Transfer for Multiagent Traveling Salesmen Problem," *IEEE Transactions on Evolutionary Computation*, 2025, doi: 10.1109/TEVC.2025.3562437.

[18] C. Xia, R. Wang, Z. Deng, and Y. Zheng, "Research on cloud computing resource scheduling based on improved ant colony optimization algorithm," *2022 4th International Conference on Frontiers Technology of Information and Computer, ICFTIC 2022*, pp. 295–298, 2022, doi: 10.1109/ICFTIC57696.2022.10075137.

[19] J. Sun, Y. Yu, and L. Xin, "Research on Path Planning of AGV Based on Improved Ant Colony Optimization Algorithm," *Proceedings of the 33rd Chinese Control and Decision Conference, CCDC 2021*, pp. 7567–7572, 2021, doi: 10.1109/CCDC52312.2021.9601807.

[20] S. Thong-Ia and P. Champrasert, "Gene-Ants: Ant Colony Optimization with Genetic Algorithm for Traveling Salesman Problem Solving," *2023 International Technical Conference on Circuits/Systems, Computers, and Communications, ITC-CSCC 2023*, 2023, doi: 10.1109/ITC-CSCC58803.2023.10212945.

[21] S. Yuan, D. Li, H. Li, Y. Chen, and M. Chang, "Fault Diagnosis and Recovery of Transmission Networks Using Improved Ant Colony Optimization Algorithm (ACO)," *Proceedings - 2024 International Conference on Power, Electrical Engineering, Electronics and Control, PEEEC 2024*, pp. 34–38, 2024, doi: 10.1109/PEEEC63877.2024.00012.

[22] W. Qiu, F. Chen, W. Li, M. Korzé, and M. Kruszyna, "Public Transport Planning Using Modified Ant Colony Optimization," *Sustainability 2025, Vol. 17, Page 2468*, vol. 17, no. 6, p. 2468, Mar. 2025, doi: 10.3390/SU17062468.