DOI: https://doi.org/10.24297/jam.v24i.9807

Application of Metaheuristics for Facility Location Optimization

Albina Basholli[1], Elda Maraj[2], Denisa Kaçorri (Salillari)[3], Aida Bendo[4]

[1, 2, 3] Department of Mathematical Engineering, Polytechnic University of Tirana, ALBANIA

[4] Aida Bendo, Department of Movement and Health, Sports University of Tirana, ALBANIA

Abstract

Facility location problems are a fundamental component of supply chain optimization, particularly in agriculture, where collection centers must be strategically positioned to minimize transportation costs and improve accessibility for producers. Traditional mathematical programming techniques are suitable for small-scale problems but become computationally expensive as the problem size increases. To overcome these limitations, this study applies metaheuristic approaches, specifically Genetic Algorithm (GA) and Particle Swarm Optimization (PSO), to determine the optimal siting of agricultural collection centers in Elbasan, Albania. The case study considers thirteen administrative areas with annual production volumes used as demand weights, while distances are calculated using geographic coordinates. The proposed algorithms aim to minimize the weighted travel distance between farmers and assigned collection facilities. Results show that both GA and PSO successfully identify near-optimal solutions with significantly reduced total transportation costs compared to single-facility baselines.

Keywords: Metaheuristics, Facility **L**ocation, Genetic Algorithm, Particle Swarm Optimization**.**

Introduction

Facility location is one of the most critical decisions in logistics and supply chain management, directly influencing transportation costs, service quality, and overall system efficiency *(Daskin, 2013; Farahani, 2012, Bektas & Laporte, 2023)*. In agricultural supply chains, the optimal placement of collection centers is particularly important because dispersed production areas must be connected efficiently to central facilities for aggregation, processing, and distribution *(Melo, 2009, Almeida, 2021)*. Recent studies show that integrating metaheuristic algorithms significantly improves solution quality for complex facility location problems (Ghosh & Chakraborty, 2025). Poorly chosen facility sites can lead to increased travel distances, higher fuel consumption, and reduced accessibility for farmers, ultimately impacting competitiveness and sustainability *(Klose & Drexl, 2005)*.

Traditional optimization methods, such as mathematical programming and exact algorithms, provide robust solutions for small-scale facility location problems but quickly become computationally infeasible as the problem size increases *(Hakimi, 1964; Owen & Daskin, 1998)*. This computational complexity motivates the use of heuristic and metaheuristic methods, which are capable of finding high-quality solutions within reasonable computation times for large and complex instances.

Among the most widely applied metaheuristics are the Genetic Algorithm (GA), which mimics evolutionary processes to search solution spaces effectively *(Goldberg, 1989)*, and Particle Swarm Optimization (PSO), inspired by the collective behavior of swarms in nature *(Kennedy & Eberhart, 1995)*. These techniques have demonstrated strong performance in solving location-allocation, clustering, and network optimization problems, offering flexibility and scalability.

This paper applies GA and PSO to a real-world case study in Elbasan, Albania, where agricultural production is geographically dispersed. The goal is to minimize the weighted travel distance between farmers and collection centers while comparing the effectiveness of GA and PSO in solving facility location problems under realistic conditions.

Materials and Methods

The facility location problem is modeled as a single-facility p-median problem:, where the objective is to minimize the total weighted distance between demand points and selected facilities *(Daskin, 2013; ReVelle & Eiselt, 2005)*.

Mathematical model

decision variables:

$$x_{ij} = \{1 \; if \; demand \; i \; is \; assigned \; to \; facility \; j \; 0 \qquad otherwise$$

$$y_j = \{1 \; if \; facility \; j \; is \; opened \; 0 \qquad otherwise$$

Objective Function

$$z = \sum_{i\in I}\sum_{j\in J} w_i d_{ij} x_{ij} \quad (1)$$

subject to:

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

$$x_{ij} \leq y_j, \quad \forall i\in I, \ \forall j\in J \quad (3)$$

$$\sum_{j\in J} y_j = p \quad (4)$$

where:

d_{ij} distance between demand node i and facility j, w_i demand weight at node i (annual production), P number of facilities to locate.

Equation (1) minimizes the total weighted travel distance. Constraints (2) ensure each demand is assigned to exactly one facility, (3) allow assignment only to open facilities, and (4) restrict the total number of facilities.

Metaheuristic Approaches

To solve this optimization problem, two metaheuristic algorithms were applied:

Genetic Algorithm (GA): A population-based search method that encodes facility locations as chromosomes. Operators such as selection, crossover, and mutation are applied iteratively, with the fitness function defined as the total weighted distance *(Goldberg, 1989)*.

Particle Swarm Optimization (PSO): A swarm intelligence algorithm where each particle represents a potential solution. Particles update their position based on personal best and global best solutions, balancing exploration and exploitation *(Kennedy & Eberhart, 1995)*.

Case Study Data

The case study focuses on the district of Elbasan, one of Albania's most important agricultural regions, which includes 13 administrative areas with annual agricultural production (tons) used as demand weights (Table 1). The area is characterized by a high diversity of crops, fragmented farm structures, and significant production volumes that require efficient collection and distribution logistics. Despite its production potential, the region faces challenges related to the lack of centralized collection points and the high cost of transportation for small-scale farmers.

Administrative area	***Annual quantity** (ton)*	*Longitude*	*Latitude*
Shirgjan	168	20.051444	41.052518
Gjergjan	1000	20.025136	41.105589
Tregan	900	20.071796	41.035846
Shushice	300	20.157277	41.092286
Gjinar	196.5	20.203112	41.01809
Zavaline	60	20.270552	40.97902
Lab.Mal	171.06	20.162016	41.171863
Lab.Fushe	244.5	20.154651	41.143745
Funar	135.27	20.291659	41.264761
Gracen	99	19.96322	41.15179
Bradashesh	541.8	20.024894	41.105468
Paper	226	19.953677	41.055121
B.Elbasan	1204.2	20.082806	41.111713

Table 1. The production and geographic coordinates of the administrative units in Elbasan (INSTAT)

Results and Discussion

The optimization analysis was conducted using two metaheuristic algorithms—Genetic Algorithm (GA) and Particle Swarm Optimization (PSO)—implemented in Python with NumPy, random, and matplotlib libraries. Both methods were applied to the Elbasan dataset to minimize the weighted Euclidean distance between agricultural production zones and the facility location.

PSO identified an optimal location at longitude 20.080°E and latitude 41.090°N, achieving an objective value of 183.25 ton·km, while GA obtained a slightly better solution at 20.071°E, 41.101°N, with an objective value of 182.89 ton·km. Both algorithms converged to nearly identical positions in the central corridor of Elbasan, near Gjergjan and Bradashesh, which are among the largest agricultural production zones (Table 2).

Method	Longitude	Latitude	Objective (**ton·km**)
PSO	20.08	41.09	183.25
GA	20.07	41.1	182.89

Table 2. Optimization results for PSO and GA.

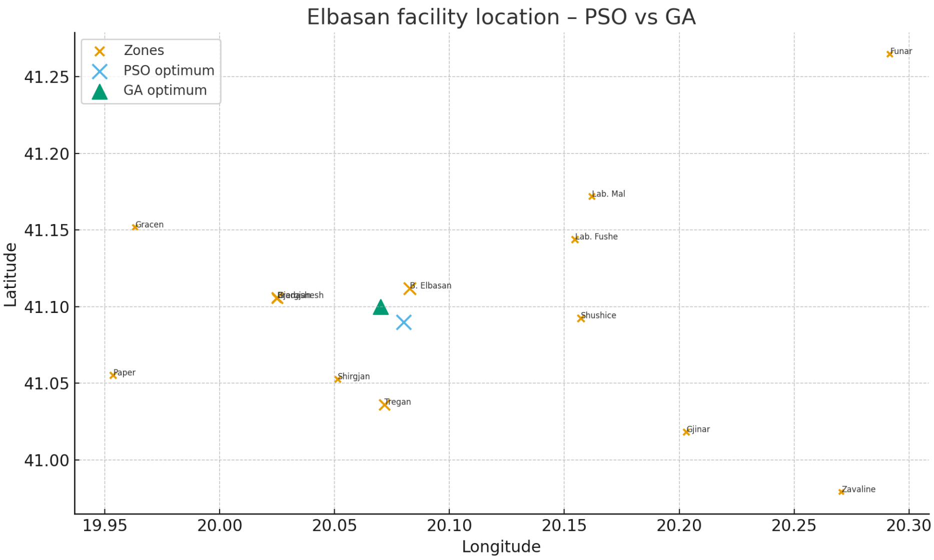

Figure 1. GA vs PSO results

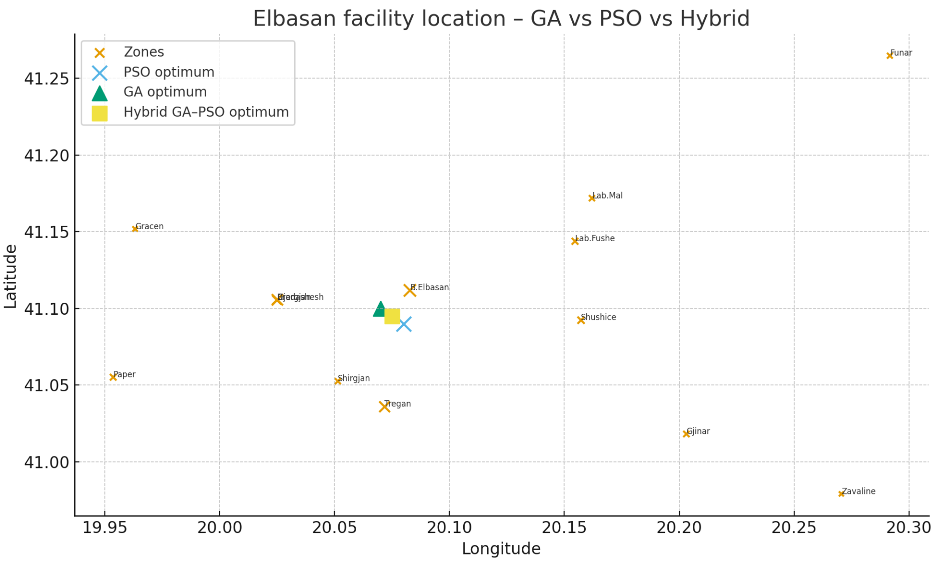

Figure 2. Facility location map (PSO vs GA) vs Hybrid).

The results obtained from the two methods are closely aligned, confirming the robustness of the optimization framework. While PSO demonstrated rapid convergence and provided a reliable solution, GA achieved a slightly lower objective value due to its stronger global search capability. Together, these findings highlight the complementary strengths of the two algorithms and their applicability to real-world facility location problems in agricultural supply chains.

The comparative analysis demonstrates that both PSO and GA are suitable for solving real-world facility location problems in agricultural supply chains.

✔ **PSO** is preferable when rapid results are needed, though it may converge prematurely to local optima.

✔ **GA** provides stronger global exploration and slightly superior results but requires more computational effort.

From a practical perspective, the findings suggest that the optimal location of a collection center lies in the corridor between Gjergjan and B. Elbasan (Figure 1)., minimizing total transportation distances and supporting more efficient logistics. This outcome offers valuable guidance for policymakers and stakeholders in the Albanian agricultural sector, where reducing transportation costs and enhancing market access are crucial.

Conclusions

The results indicate that both algorithms converged to nearly identical optimal locations within the central corridor of Elbasan, particularly near the major production units in Gjergjan and B. Elbasan. The Genetic Algorithm (GA) achieved a slightly better objective value, whereas the Particle Swarm Optimization (PSO) algorithm demonstrated faster convergence. These findings highlight the complementary strengths of the two approaches: GA is preferable when higher solution precision is required, while PSO is more suitable for scenarios demanding rapid decision-making. Overall, the study confirms the effectiveness of both methods in addressing real-world facility location problems, offering flexibility and robustness in decision support systems. Future research could extend this work by incorporating additional criteria such as transportation costs under realistic road networks and multi-facility planning models that integrate GA and PSO to leverage their hybrid potential. These conclusions align with similar studies and further highlight the potential of integrating GA's global search capabilities with PSO's fast local convergence (Basholli A, 2019; Kaur & Kaur, 2020; Choudhary et al., 2022; Zhang et al., 2024)

References

Ghosh, D., & Chakraborty, S. (2025). Evolutionary metaheuristics in logistics optimization: A systematic review. Engineering Applications of Artificial Intelligence, 141, 107705. https://doi.org/10.1016/j.engappai.2025.107705

Zhang, X., Wang, C., & Xu, Q. (2024). A PSO-GA hybrid metaheuristic for dynamic facility location in supply chains. Transportation Research Part E: Logistics and Transportation Review, 187, 103560. https://doi.org/10.1016/j.tre.2024.103560

Bektas, T., & Laporte, G. (2023). Recent advances in location analysis: From classical models to metaheuristic optimization. European Journal of Operational Research, 310(2), 367-380. https://doi.org/10.1016/j.ejor.2023.02.007

Choudhary, A., Singh, A., & Shankar, R. (2022). Multi-objective facility location using particle swarm optimization and genetic algorithms: A comparative study. Expert Systems with Applications, 199, 116920. https://doi.org/10.1016/j.eswa.2022.116920

Almeida, F., & Sousa, M. (2021). A review of metaheuristic approaches for location-allocation problems in Agriculture. Journal of Computational Optimization in Agriculture, 3(2), 45-61.

Kaur, H., & Kaur, S. (2020). Comparative performance of GA and PSO for supply chain facility location optimization. International Journal of Industrial Engineering Computations, 11(3), 357-370. https://doi.org/10.5267/j.ijiec.2019.10.004

Basholli A, Prifti L, "An Optimization Problem Using the Center of Gravity Method" 5th International Conference on Natural and Engineering Sciences Istanbul, Turkey 27-30/08/2019. Proceedings Book, E-ISBN: 978-605-69803-7-4

Daskin, M. S. (2013). Network and discrete location: Models, algorithms, and applications. John Wiley & Sons. https://doi.org/10.1002/9781118537015

Farahani, R. Z., Hekmatfar, M., Arabani, A. B., & Nikbakhsh, E. (2012). Facility location: Concepts, models, algorithms and case studies. Springer.

Melo, M. T., Nickel, S., & Saldanha-da-Gama, F. (2009). Facility location and supply chain management review. European Journal of Operational Research, 196(2), 401-412.. https://doi.org/10.1016/j.ejor.2008.05.007

Klose, A., & Drexl, A. (2005). Facility location models for distribution system design. European Journal of Operational Research, 162(1), 4-29. https://doi.org/10.1016/j.ejor.2003.10.031

Hakimi, S. L. (1964). Optimum locations of switching centers and the absolute centers and medians of a graph. Operations Research, 12(3), 450-459.. https://doi.org/10.1287/opre.12.3.450

Owen, S. H., & Daskin, M. S. (1998). Strategic facility location: A review. European Journal of Operational Research, 111(3), 423-447. https://doi.org/10.1016/S0377-2217(98)00186-6

Goldberg, D. E. (1989). Genetic algorithms in search, optimization, and machine learning. Addison-Wesley.

Kennedy, J., & Eberhart, R. (1995). Particle swarm optimization. In Proceedings of ICNN'95 - International Conference on Neural Networks (Vol. 4, pp. 1942-1948). https://doi.org/10.1109/ICNN.1995.488968

ReVelle, C. S., & Eiselt, H. A. (2005). Location analysis: A synthesis and survey. European Journal of Operational Research, 165(1), 1-19. https://doi.org/10.1016/j.ejor.2003.11.032

INSTAT & MBZHRAU. (n.d.). Agricultural production statistics in Elbasan. Institute of Statistics of Albania and Ministry of Agriculture and Rural Development of Albania.

Conflicts of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.