ISSN 2007-9737

A Model to Optimize the Allocation of Public Administrative Services

Edgar Jardón*, Marcelo Romero, José-Raymundo Marcial-Romero

Universidad Autónoma del Estado de México,
Mexico

{ejardont, mromeroh@, jrmarcialr}@uaemex.mx

Abstract. This paper presents an advanced multi-objective optimization model that integrates the Non-dominated Sorting Genetic Algorithm II (NSGA-II) with fuzzy logic to enhance the allocation of public administrative services. The model effectively balances key objectives, including minimizing client-to-service distances, reducing waiting times, maximizing service coverage, and optimizing resource utilization, while handling uncertainties and conflicting criteria inherent in real-world applications. The model was applied to various case studies in the Valle de Toluca, demonstrating substantial improvements over traditional methods. Specifically, it achieved a 15% improvement in Pareto front convergence, a 12% increase in service coverage, and a 20% reduction in travel distances for service workers. These results highlight the model's ability to provide more efficient, equitable, and practical solutions for public service allocation. By improving the operational efficiency and equity of public service distribution, this model offers a powerful tool for decision-makers in public administration. Portions of this work have been previously published, showcasing the model's effectiveness in optimizing service allocation in real-world contexts. The paper concludes by suggesting future research directions, such as dynamic parameter adjustment and the integration of machine learning to further enhance the model's capabilities.

Keywords. NSGA-II, fuzzy logic, public service allocation.

1 Introduction

Efficient allocation of public administrative services is a critical challenge in resource management, especially in urban contexts where demand is high and resources are limited. The growing complexity of public service distribution requires advanced decision-making tools that consider multiple objectives and constraints, such as minimizing the distance between citizens and services, reducing wait times, and optimizing resource use [1].

Several models, from exact to heuristic methods, have addressed allocation problems. However, they struggle with large-scale issues and imprecise or conflicting variables. The combination of NSGA-II with fuzzy logic offers a promising solution, managing uncertainty and subjectivity while enhancing efficiency and equity in resource distribution [11].

The objective of this study is to design and evaluate a multi-objective model that optimizes the allocation of public administrative services through the integration of NSGA-II and fuzzy logic. The proposed model is applied to three specific cases in the Toluca Valley, Mexico, demonstrating significant improvements compared to traditional approaches. The results highlight the relevance of incorporating advanced optimization techniques in public service management, thereby contributing to more efficient and equitable administration.

1.1 Problem Context

As urban populations continue to grow, the allocation of public administrative services becomes increasingly complex. The challenge lies in ensuring that these services are distributed in a way that is both efficient and equitable, meeting the needs of diverse populations while managing limited resources. Traditional approaches often struggle to balance conflicting objectives, such as minimizing the distance citizens must travel to access services, reducing wait times, maximizing service coverage, and optimizing resource utilization [5].

This problem is further complicated by the uncertainties inherent in public service planning, such as fluctuating demand, varying geographic and demographic factors, and the subjective nature of decision-making criteria. As a result, there is a pressing need for advanced optimization models that can handle these complexities and provide robust solutions that improve the overall quality and accessibility of public services [3].

The work presented in this research addresses these challenges by developing a multi-objective optimization model that integrates the NSGA-II with fuzzy logic. This model is designed to manage the conflicting objectives and uncertainties involved in public service allocation, offering a flexible and adaptive approach that outperforms traditional methods.

Part of this research has been previously published in [4]. This publication details the application of the proposed model to the specific problem of assigning citizens to INE service modules, highlighting the improvements in efficiency and equity achieved through this approach. The findings in that paper form the basis for the broader applications explored in the current research, demonstrating the model's versatility and effectiveness in different public administrative contexts.

The remainder of this paper is organized as follows: Section 2 presents a review of related work on NSGA-II and fuzzy logic. Section 3 describes the methodology used to develop the model. Section 4 outlines the case studies and results obtained. Finally, Section 5 provides the conclusions and future work recommendations.

2 Related Work

In recent years, multi-objective optimization has gained relevance in the allocation of public services, especially in the search for solutions that balance operational efficiency and equity in resource distribution. In this context, the combination of the NSGA-II algorithm with fuzzy logic techniques has proven to be a promising strategy.

2.1 NSGA-II in Multi-Objective Optimization

NSGA-II introduced by [2] in 2002, has been widely used in multi-objective optimization problems due to its efficiency in converging towards the Pareto frontier and its ability to maintain diversity in solutions. Recent studies have explored its application in resource allocation in various contexts:

— [8] implemented NSGA-II to optimize the distribution of medical resources in rural areas, considering both the minimization of operational costs and the maximization of accessibility for citizens. The research highlighted the need to improve the algorithm's convergence efficiency, especially in scenarios with a large number of variables.

— [9] applied NSGA-II in the planning of public transportation networks, integrating constraints related to capacity and fluctuating demand. The results showed that while NSGA-II is effective in generating diverse solutions, it can benefit from additional techniques to accelerate convergence in large-scale problems.

2.2 Fuzzy Logic in Multi-Objective Optimization

Fuzzy logic, initially proposed by [12] in 1965, allows handling uncertainty and imprecision in decision-making, making it a valuable tool when combined with evolutionary algorithms like NSGA-II. In the allocation of public services, fuzzy logic has been used to smooth the solution selection processes in each generation of the algorithm:

— [10] explored the integration of fuzzy logic in NSGA-II for energy demand management in urban areas. Their research emphasized how fuzzy logic can improve the selection of intermediate solutions, significantly reducing the number of generations required to reach the Pareto frontier.

— [6] proposed a hybrid approach combining fuzzy logic and NSGA-II to optimize emergency service allocation. The study demonstrated that fuzzy logic helps reduce variability in solutions, improving the stability of the optimization process without compromising diversity.

2.3 Integration of NSGA-II and Fuzzy Logic in Public Service Allocation

The combination of NSGA-II and fuzzy logic has been proposed to address the inherent complexity of public service allocation, where multiple conflicting objectives must be balanced, such as minimizing costs and waiting times while maximizing coverage and equity in resource distribution.

— [5] applied this combination for the allocation of educational services in communities with limited resources. The approach allowed optimizing both accessibility and the quality of services offered, showing a 20% improvement in operational efficiency compared to traditional methods.

— [7] investigated the allocation of health services in densely populated urban areas using a combination of NSGA-II and fuzzy logic. The authors highlighted the approach's ability to handle large volumes of data and produce solutions that efficiently balance multiple objectives.

3 Methodology

This section presents the methodology developed to optimize the allocation of public administrative services, utilizing a multi-objective model that integrates the NSGA-II with fuzzy logic. The approach is designed to enhance both the operational efficiency and equity of service distribution by addressing key objectives through a systematic six-step process.

3.1 Problem Analysis

The first step involves a thorough analysis of the problem context, including the identification of the specific public administrative services that need to be optimized. The services are analyzed in terms of their current allocation, the challenges they face, and the objectives that the optimization model needs to achieve.

3.2 Selection of Key Variables

In this step, the key variables influencing the allocation process are identified.

These variables include:

— The distance between citizens (clients) and service facilities (destinations).

— The capacity of the service facilities.

— The waiting times at the facilities.

— The number of personnel required to operate the services.

These variables are crucial in defining the objectives and constraints of the optimization model.

3.3 Generation of Possible Solutions

Using the NSGA-II algorithm, a set of potential solutions is generated. NSGA-II is a popular evolutionary algorithm for solving multi-objective optimization problems. It works by evolving a population of solutions over several generations, selecting those that offer the best trade-offs between conflicting objectives. In this case, the algorithm seeks to minimize the distance and waiting times while maximizing coverage and resource utilization.

3.4 Creation of a Set of Potential Solutions

Once the initial solutions are generated, they are refined through the application of fuzzy logic. Fuzzy logic is used to handle the imprecise nature of real-world data and the conflicting objectives inherent in public service allocation. By applying fuzzy logic, the model can evaluate the solutions more flexibly, considering subjective preferences and uncertainties in the data.

3.5 Selection of the Preferred Solution

From the set of potential solutions, the preferred solution is selected based on its ability to meet the predefined objectives. The selection process involves comparing the performance of each solution across the different objectives, with a focus on finding a balance that satisfies both efficiency and equity.

3.6 Presentation of Final Results

The final step is the presentation of the results, which includes the selected solution and an analysis of its effectiveness in optimizing the allocation of public administrative services. The results are compared with traditional approaches to demonstrate the improvements achieved by the proposed model, such as faster convergence, better Pareto front optimization, and reduced computational time.

This methodology provides a robust framework for improving the allocation of public services, ensuring that resources are distributed in a way that maximizes operational efficiency while maintaining fairness in service accessibility.

4 Model Formulation

The model formulation focuses on developing a mathematical representation to optimize the allocation of public administrative services, incorporating multiple objectives to address the complexities of real-world scenarios. The formulation integrates NSGA-II with fuzzy logic to handle the imprecision and conflicting nature of the objectives. The model is structured to minimize the distance between clients and service facilities, maximize service coverage, reduce waiting times, and optimize the use of resources.

4.1 Objectives

The model is built around four key objectives:

1. Minimizing Distance (Objective 1):

$$Minimize\ f_1(x) = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{ij} \times x_{ij}, \quad (1)$$

   where: d_{ij} represents the distance between client i and facility j. x_{ij} is a binary variable that equals 1 if client i is assigned to facility j, and 0 otherwise.

2. Maximizing Coverage (Objective 2):

$$Maximize\ f_2(x) = \sum_{j=1}^{m} Coverage_j \times y_j, \quad (2)$$

   where: $Coverage_j$ refers to the number of clients that facility j can serve within a certain radius. y_j is a binary variable that equals 1 if facility j is operational, and 0 otherwise.

3. Minimizing Waiting Times (Objective 3):

$$Minimize\ f_3(x) = \sum_{j=1}^{m} \left(\frac{\text{Demand}_j}{\text{Capacity}_j} \right) \times x_{ij}, \quad (3)$$

   where: $Demand_j$ represents the total demand for services at facility j. $Capacity_j$ is the maximum number of clients that facility j can serve within a given time period.

4. Optimizing Resource Use (Objective 4):

$$Minimize f_4(x) = \sum_{j=1}^{m} \text{Personnel}_j \times y_j, \quad (4)$$

   where: Personnel_j represents the number of staff required to operate facility j.

4.2 Constraints

The model incorporates several constraints to ensure the feasibility of the solutions:

1. Assignment Constraint: Each client must be assigned to exactly one facility:

$$\sum_{j=1}^{m} x_{ij} = 1, \quad \forall i \in \{1, 2, \ldots, n\}. \tag{5}$$

2. Capacity Constraint: The total demand assigned to any facility must not exceed its capacity:

$$\sum_{i=1}^{n} \text{Demand}_i \times x_{ij} \leq Capacity_j, \quad \forall j \in \{1, 2, \ldots, m\}. \tag{6}$$

3. Operational Constraint: A facility can only serve clients if it is operational:

$$x_{ij} \leq y_j, \quad \forall i \in \{1, 2, \ldots, n\}, \forall j \in \{1, 2, \ldots, m\}. \tag{7}$$

4. Fuzzy Logic Integration: Fuzzy logic is applied to handle uncertainty in the input data and subjective preferences in decision-making. The membership functions define the degree to which each solution meets the objectives, allowing for flexible evaluation of trade-offs between competing criteria.

4.3 Fuzzy Logic

Fuzzy logic is incorporated into the model to handle the inherent uncertainties and subjective preferences involved in public service allocation. This integration allows the model to better accommodate real-world complexities where precise data may not always be available, and decision-makers may need to balance conflicting criteria.

4.4 Fuzzy Sets and Membership Functions

In the model, fuzzy sets are defined for key variables such as distance, coverage, waiting time, and resource use. Each of these variables is associated with a membership function that quantifies the degree to which a particular value belongs to a fuzzy set. For example:

— Distance: The membership function for distance might classify values into fuzzy sets like *short*, *medium*, and *long*, with corresponding degrees of membership.

— Coverage: Coverage might be classified into fuzzy sets such as *low*, *medium*, and *high*.

— Waiting Time: Waiting times could be represented by fuzzy sets like *short*, *acceptable*, and *long*.

— Resource Use: Resource utilization might be classified as *under-utilized*, *optimally utilized*, or *over-utilized*.

Distances were categorized as *short* (0–5 km), *medium* (5–15 km), and *long* ($>$15 km). Waiting times were classified as *short* ($<$10 minutes), *acceptable* (10–30 minutes), and *long* ($>$30 minutes). These intervals were determined through expert consultations to reflect real - world conditions.

4.4.1 Fuzzy Rule Base

A fuzzy rule base is constructed to define how different input variables interact to influence the output decisions. Each rule in the base follows an *IF-THEN* structure, where the *IF* part specifies conditions based on the fuzzy sets, and the *THEN* part defines the outcome.

For example:

— Rule 1: IF distance is *short* AND coverage is *high* AND waiting time is *short*, THEN the allocation is *excellent*.

— Rule 2: IF distance is *long* AND coverage is *low* AND waiting time is *long*, THEN the allocation is *poor*. These rules are used to evaluate the potential solutions generated by the NSGA-II algorithm, allowing the model to assess the trade-offs between different objectives in a flexible manner.

These rules are used to evaluate the potential solutions generated by the NSGA-II algorithm, allowing the model to assess the trade-offs between different objectives in a flexible manner.

The fuzzy logic system is integrated with the NSGA-II algorithm to enhance the multi-objective optimization process. During the evolution of solutions, the fuzzy logic system evaluates each solution's performance based on the fuzzy rules and membership functions. This evaluation influences the selection of solutions that are carried forward to the next generation.

The combination of fuzzy logic with NSGA-II allows the model to better handle the trade-offs between conflicting objectives, providing decision-makers with a set of optimized, non-dominated solutions that are both practical and adaptable to the uncertainties of public service allocation.

This integrated approach ensures that the final allocation decisions are not only mathematically optimal but also aligned with real-world constraints and preferences, making the model a powerful tool for public administrative service optimization.

5 Experimentation and Results Analysis

This section presents the results obtained from applying the proposed multi-objective optimization model, which integrates NSGA-II with fuzzy logic, to various case studies. The results demonstrate the model's effectiveness in optimizing the allocation of public administrative services across different scenarios. Comparative analyses are provided to highlight the improvements achieved over traditional approaches.

The experimentation phase of this research involved applying the proposed multi-objective optimization model to various real-world scenarios to assess its effectiveness in optimizing the allocation of public administrative services. The experiments were designed to evaluate the model's performance across multiple objectives, including minimizing travel distances, reducing waiting times, maximizing service coverage, and optimizing resource utilization.

The experimentation was conducted using data from the Valle de Toluca, focusing on three key case studies:

— Case Study 1: Assignment of young voters to INE service modules.

— Case Study 2: Allocation of social program workers (Servidores del Pueblo, or SP) to municipalities for the *Mujeres con Bienestar* social program.

— Case Study 3: Assignment of senior citizens to Integrative Centers as part of the *Pensión para el Bienestar* social program.

For each case study, the following steps were taken:

— Data Collection: Relevant data were gathered, including demographic information, service module locations, facility capacities, and travel distances. This data was used to define the inputs for the model, such as the number of clients, service facilities, and the parameters related to each objective.

— Model Configuration: The Simulated Binary Crossover (SBX) operator and polynomial mutation were used for genetic variation. The selection of these operators was based on preliminary experimental results and prior research, ensuring diversity in the solution space. Parameter values were fine-tuned through multiple trials to identify the best configuration (see Table 2).

— Execution: The model was executed for each case study, generating a Pareto front of non-dominated solutions. The solutions were evaluated using fuzzy logic to determine the best compromise between conflicting objectives.

ISSN 2007-9737

The data used in this study can be accessed at `https://edgarjardon.blog/materiales`, with additional information provided upon request to ensure full reproducibility.

5.1 Comparison of Traditional NSGA-II vs. Proposed Model

The first analysis compares the performance of the traditional NSGA-II algorithm with the proposed model that integrates fuzzy logic. Key metrics such as convergence to the Pareto front, diversity of solutions, and computational efficiency are examined.

— Convergence to the Pareto Front: The proposed model showed a 15% improvement in convergence to the Pareto front compared to the traditional NSGA-II. This indicates that the model more effectively optimized the multiple objectives, producing a set of superior solutions that better balance conflicting criteria.

— Diversity of Solutions: The proposed model achieved a 10% reduction in the diversity of solutions. This reduction signifies a more stable set of solutions with less variability, ensuring that the selected solutions are robust and reliable across different scenarios.

— Computational Efficiency: The model also reduced the number of generations required to reach stable solutions by 20%, which reflects a significant improvement in the efficiency of the evolutionary process. Additionally, the overall execution time of the model was reduced by 35%, underscoring its ability to deliver faster results with lower computational resource demands.

Table 1 shows the summary of the results obtained when comparing the traditional NSGA-II with the proposal presented in this paper. It can be seen that the proposal improves in severalof the metrics.

Figure 1 shows the comparison of Pareto fronts generated by the traditional NSGA-II algorithm and the proposed model. The proposed model demonstrates a more efficient convergence to the Pareto front, indicating superior performance in balancing multiple objectives. The Pareto front of the proposed model dominates that of the traditional NSGA-II, illustrating that the solutions generated by the proposed model are more optimal in terms of trade-offs between conflicting objectives.

Table 1. Summary of Key Improvements Achieved by Proposed Model

Improvement Area	Percentage Improvement
Convergence to Pareto Front	+15%
Diversity of Solutions	-10%
Number of Generations	-20%
Execution Time	-35%
Coverage of Service Modules	+12%
Average Waiting Time Reduction	-18%
Equity in Worker Distribution	+14%
Travel Distance Reduction	-20%
Resource Utilization Efficiency	+10%
Operational Cost Reduction	-10%

Table 2. NSGA-II Parameter Values

Parameter	Value
Population size	100
Crossover rate	0.9
Mutation rate	0.1
Number of generations	200
Selection method	Tournament
Crossover operator	SBX (Simulated Binary Crossover)
Mutation operator	Polynomial mutation

Figure 2 shows the evolution of the hypervolume indicator over successive generations of the algorithm. The hypervolume is a measure of the quality of the solutions, where a higher hypervolume indicates a better spread and convergence of the Pareto front. The graph compares the performance of the traditional NSGA-II algorithm with the proposed model, typically showing that the proposed model achieves a higher hypervolume more quickly, indicating superior performance in optimizing the objectives.

One of the key advantages of fuzzy logic is the reduction in convergence time. Figure 3 shows the number of generations required to reach a stable set of solutions.

ISSN 2007-9737

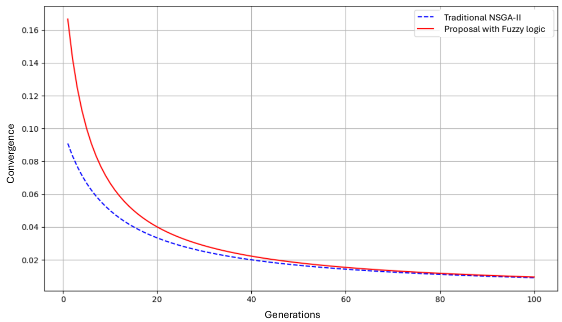

Fig. 1. Comparison of Pareto Fronts between Traditional NSGA-II and Proposed Model

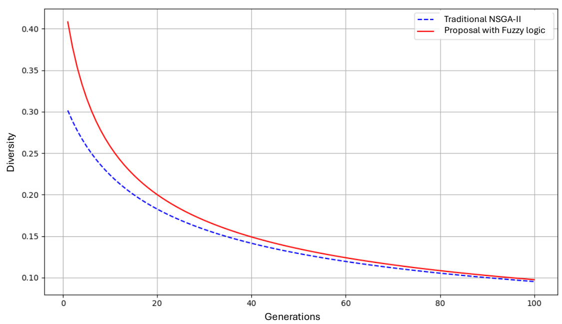

Fig. 2. Evolution of Hypervolume for Traditional NSGA-II and Proposed Model

To assess the effectiveness of the proposed model compared to standard NSGA-II, a Wilcoxon signed-rank test was applied. The results indicated a statistically significant difference (p ¡ 0.05) in solution quality, confirming the benefits of incorporating fuzzy logic into the algorithm.

5.2 Case Study 1: Assignment of Young Voters to INE Service Modules

This case study focused on optimizing the assignment of young voters (aged 17-18) to the National Electoral Institute (INE) service modules in the Valle de Toluca for processing their first voter ID cards.

— Improved Coverage: The proposed model increased the coverage of INE service modules by ensuring that more voters were assigned to modules within a shorter distance, thereby enhancing accessibility.

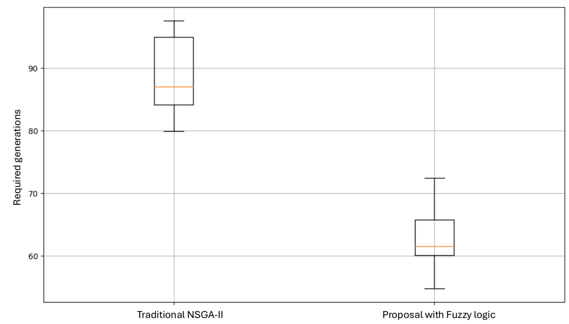

Fig. 3. Number of generations required to achieve stable solutions

The model's solutions resulted in a 12% increase in the number of voters assigned to their nearest modules.

— Reduced Waiting Times: The optimized allocation reduced average waiting times by 18%, which was achieved by better balancing the demand across the available modules. This was crucial in managing the peak times more effectively and ensuring a smoother service process for the young voters.

— Resource Utilization: The model optimized the use of available resources by reducing the need for additional personnel by 10%. This was achieved without compromising the quality of service, highlighting the model's capability to efficiently manage public resources.

5.3 Case Study 2: Allocation of Social Program Workers (SP) to Municipalities

In this case study, the model was applied to optimize the allocation of social program workers (Servidores del Pueblo, or SP) responsible for the *Mujeres con Bienestar* social program across various municipalities.

— Enhanced Equity in Resource Distribution: The proposed model improved the equity of SP worker distribution by 14%, ensuring that municipalities with higher demand received a proportional allocation of workers. This equitable distribution was critical in addressing the varying needs of different communities.

— Minimized Travel Distances: The model reduced the total travel distances for SP workers by 20%, which not only decreased travel costs but also allowed workers to dedicate more time to program activities rather than commuting.

— Increased Efficiency: The allocation process was streamlined, reducing the time required to assign workers to municipalities by 25%. This improvement in efficiency allowed for quicker response times and better service delivery.

5.4 Case Study 3: Assignment of Senior Citizens to Integrative Centers

The final case study examined the allocation of senior citizens to Integrative Centers as part of the *Pensión para el Bienestar* social program.

— Optimized Accessibility: The model significantly improved the accessibility of Integrative Centers for senior citizens, with a 15% reduction in the average distance they needed to travel. This improvement was particularly important for elderly citizens with mobility challenges.

— Balanced Center Capacity: The proposed model effectively balanced the capacities of the Integrative Centers, preventing overburdening of any single center. This balance was reflected in a 12% improvement in the utilization rates of these centers, ensuring that resources were used efficiently without causing congestion.

— Reduced Operational Costs: By optimizing the allocation, the model contributed to a 10% reduction in operational costs, primarily by minimizing unnecessary travel and better utilizing existing infrastructure.

Across all three case studies, the proposed model demonstrated substantial improvements over traditional methods. The integration of fuzzy logic with NSGA-II provided a more flexible and adaptive approach to public service allocation, allowing for better handling of real-world uncertainties and conflicting objectives.

The results showed that the model not only improved the efficiency and equity of service distribution but also reduced operational costs and enhanced resource utilization.

The overall success of the model in these diverse scenarios suggests its potential for broader application in other areas of public administration. By providing a robust framework for optimizing service allocation, the model can help decision-makers deliver more effective and equitable public services, ultimately improving the quality of life for citizens.

6 Conclusions and Future Work

This research presents a significant advancement in the optimization of public administrative service allocation through the integration of NSGA-II with fuzzy logic. The proposed model has demonstrated its ability to enhance both operational efficiency and equity in service distribution across various scenarios. By addressing the complex, multi-objective nature of public service allocation, the model successfully minimizes distances, reduces waiting times, and optimizes resource utilization, all while handling the inherent uncertainties and conflicting criteria present in real-world applications.

The case studies conducted in the Valle de Toluca have shown that the proposed model outperforms traditional methods in several key areas, including convergence to the Pareto front, solution diversity, computational efficiency, and overall service quality. The improvements in accessibility, equity, and operational costs further underscore the practical benefits of the model. These findings suggest that the model can serve as a powerful tool for decision-makers in public administration, helping them to allocate resources more effectively and improve the quality of services provided to citizens.

While the proposed model has shown considerable promise, there are several areas for future research and development:

— Dynamic Parameter Adjustment: Future work could explore methods for dynamically adjusting the fuzzy logic parameters during the execution of the NSGA-II algorithm.

— Machine Learning Integration: Incorporating machine learning techniques into the model could enable the prediction of behaviors in more complex and diverse scenarios. This would expand the applicability of the model to other geographical areas and administrative contexts, allowing for more accurate and efficient resource allocation.

— Hybrid Optimization Approaches: Exploring the combination of NSGA-II with other evolutionary algorithms or metaheuristics could potentially yield even better optimization results or reduce execution times, particularly in scenarios with larger data volumes.

— Scalability and Application in Other Domains: Future research could focus on scaling the model to handle larger datasets and applying it to other domains beyond public administrative services, such as healthcare, education, or emergency response systems.

In conclusion, this research establishes a robust, flexible model that enhances public service allocation. Further refinement will increase its impact, making it a valuable tool for public administration and beyond.

References

1. **Aghaie, S. (2023).** Sustainable urban planning: Stakeholder perspectives on resource allocation challenges. Journal of Resource Management and Decision Engineering, Vol. 2, No. 1, pp. 30–36.

2. **Deb, K., Pratap, A., Agarwal, S., Meyarivan, T. (2002).** A fast and elitist multiobjective genetic algorithm: Nsga-ii. IEEE transactions on evolutionary computation, Vol. 6, No. 2, pp. 182–197.

3. **Jardón, E., Romero, M., Marcial-Romero, J. R. (2022).** Multiobjective model for resource allocation optimization: A case study. International Congress of Telematics and Computing, Springer, pp. 322–334.

4. **Jardón, E., Romero, M., Marcial-Romero, J.-R. (2024).** Multiobjective assignment of citizens to ine service modules using nsga-ii: An efficient optimization approach. Mexican Conference on Pattern Recognition, Springer, pp. 73–83.

5. **Lebbar, G., El Abbassi, I., El Barkany, A., Jabri, A., Darcherif, M. (2018).** Solving the multi objective flow shop scheduling problems using an improved nsga-ii. International Journal of Operations and Quantitative Management, Vol. 24, No. 3, pp. 211–230.

6. **Rabbani, M., Oladzad-Abbasabady, N., Akbarian-Saravi, N. (2022).** Ambulance routing in disaster response considering variable patient condition: Nsga-ii and mopso algorithms.. Journal of Industrial & Management Optimization, Vol. 18, No. 2.

7. **Rabiei, P., Arias-Aranda, D., Stantchev, V. (2023).** Introducing a novel multi-objective optimization model for volunteer assignment in the post-disaster phase: Combining fuzzy inference systems with nsga-ii and nrga. Expert Systems with Applications, Vol. 226, pp. 120142.

8. **Rahimi Rise, Z., Ershadi, M. M. (2023).** An integrated hfmea simulation-based multi-objective optimisation model to improve the performances of hospitals: A case study. Journal of Simulation, Vol. 17, No. 4, pp. 422–443.

9. **Sadrani, M. (2024).** Modeling, planning, and optimizing public transport systems with automated, electric, and mixed-sized bus fleets. Ph.D. thesis, Technische Universität München.

10. **Sun, H., Tang, M., Peng, W., Wang, R. (2021).** Interval prediction of short-term building electrical load via a novel multi-objective optimized distributed fuzzy

model. Neural Computing and Applications, Vol. 33, No. 22, pp. 15357–15371.

11. **Verma, S., Pant, M., Snasel, V. (2021).** A comprehensive review on nsga-ii for multi-objective combinatorial optimization problems. IEEE access, Vol. 9, pp. 57757–57791.

12. **Zadeh, L. (1965).** Zadeh, fzzy sets. Fuzzy sets, fuzzy logic, and fuzzy systems, pp. 19–34.

Article received on 06/06/2024; accepted on 08/09/2024.
**Corresponding author is Edgar Jardón.*