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RESEARCH AND APPLICATION OF EMERGENCY LOGISTICS RESOURCE ALLOCATION ALGORITHM BASED ON SUPPLY CHAIN NETWORK

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Abstract. The "Fuzzy-Enhanced for Emergency Logistics Resource Allocation in Supply Chain Networks (FEM-ELRAS)" presents a novel approach to optimizing emergency logistics and resource allocation in supply chain networks, especially during critical disaster response scenarios. This research integrates fuzzy logic with the improve Multi Agent Genetic Algorithm (MAGA), creating a more adaptive and efficient framework capable of handling the uncertainties and complexities inherent in emergency situations. FEM-ELRAS employs fuzzy decision variables to represent ambiguous and fluctuating parameters like demand at disaster sites, supply availability, and variable transportation conditions. It incorporates a fuzzy inference system, utilizing expert-derived rules to guide the allocation process amidst uncertain and rapidly changing conditions. The algorithm's evaluation mechanism is enhanced with fuzzy logic, offering a refined assessment of solution effectiveness, balancing multiple logistical objectives such as minimizing response time, optimizing costs, and maximizing resource utilization and delivery precision. Moreover, fuzzy logic principles are integrated into the genetic algorithm's operators, enabling more context-sensitive and flexible solution adaptations. FEM-ELRAS is particularly designed to navigate the trade-offs between different logistical goals in emergency scenarios, making it a robust tool for decision-makers in disaster management. Its application promises significant improvements in emergency response efficiency, showcasing a step forward in the field of emergency logistics and supply chain management.

Key words: Emergency logistics, fuzzy logic, resource allocation, supply chain networks, multi agent genetic algorithm, disaster response optimization.

1. Introduction. In the realm of disaster management, emergency logistics stands as a critical and often life-saving component [3, 21]. The challenge of efficiently allocating resources during crises is monumental, given the unpredictability and urgency associated with such events. Traditional logistical systems often falter under these conditions, primarily due to their inability to adapt to rapidly changing scenarios and the complex nature of emergencies [14]. This inadequacy is further amplified in supply chain networks, where multiple stakeholders and varying resource requirements add layers of complexity. As a response to these challenges, there has been a growing interest in developing more responsive and flexible logistical frameworks [19, 6]. These frameworks must not only address the immediate needs of disaster-hit areas but also ensure the optimal utilization of available resources. The integration of advanced computational techniques with logistic planning is therefore crucial in enhancing the effectiveness of disaster response efforts.

The advent of intelligent algorithms has revolutionized many aspects of decision-making, particularly in complex and dynamic environments like emergency logistics. Among these, the Multi Agent Genetic Algorithm (MAGA) has emerged as a potent tool, known for its adaptability and efficiency in solving optimization problems. The technique (MAGA) from MAGA-MTERS is adapted from the study [22] based on the principle we procced with the further. However, the unpredictable nature of emergency scenarios, characterized by fluctuating demands, variable resource availability, and diverse transportation conditions, calls for an approach that can handle uncertainty and ambiguity effectively[13, 1]. This is where traditional algorithms often hit a bottleneck, as they are primarily designed for more stable and predictable environments. Consequently, there is an imperative need for algorithms that are not only intelligent but also capable of dealing with the inherent uncertainties of emergency logistics [15, 16].

Fuzzy logic, with its ability to handle imprecision and uncertainty, offers a promising solution to this challenge [20, 11]. By employing fuzzy decision variables, it allows for a more nuanced representation of real-world scenarios, which are often not black-and-white but encompass a spectrum of possibilities. When integrated

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into computational algorithms, fuzzy logic enables the handling of ambiguous and fluctuating parameters more effectively. This integration leads to the development of models that are not only intelligent but also capable of reflecting the complex realities of emergency logistics [7, 2]. Such models can process a range of inputs, from exact numerical data to subjective expert opinions, making them highly versatile and reliable in decision-making processes. The combination of fuzzy logic with advanced algorithms like MAGA paves the way for creating more robust and adaptable logistical frameworks [10].

The motivation behind the "Fuzzy-Enhanced for Emergency Logistics Resource Allocation in Supply Chain Networks (FEM-ELRAS)" research stems from the critical need to enhance disaster management capabilities, particularly in optimising emergency logistics and resource allocation within supply chain networks during disaster response scenarios. Traditional emergency logistics models often struggle to cope with the high levels of uncertainty and rapid changes in conditions that disasters bring, including fluctuating demands at disaster sites, variable supply availability, and unpredictable transportation conditions. These challenges underscore the importance of developing an advanced framework that can dynamically adapt to these uncertainties and efficiently manage resources to mitigate the impacts of disasters.

Building upon these insights, our research introduces the "Fuzzy-Enhanced MAGA for Emergency Logistics Resource Allocation in Supply Chain Networks (FEM-ELRAS)." This novel framework synergizes the adaptive capabilities of MAGA with the versatility of fuzzy logic, creating a powerful tool for emergency logistics management. FEM-ELRAS is designed to tackle the challenges of resource allocation in disaster situations head-on. It employs fuzzy decision variables for a realistic representation of the emergency environment, uses a fuzzy inference system to guide the allocation process, and enhances the evaluation mechanism with fuzzy logic for a more refined assessment [8, 17]. The incorporation of fuzzy logic principles into MAGA's genetic operators further ensures context-sensitive and flexible solution adaptations. FEM-ELRAS, with its unique approach, is adept at navigating the trade-offs between different logistical goals, such as minimizing response time, optimizing costs, and maximizing resource utilization. This framework stands as a testament to the potential of combining fuzzy logic with genetic algorithms, promising significant improvements in the efficiency of emergency response and setting a new benchmark in the field of emergency logistics and supply chain management [5].

2. Related Work. The study [9] develops an artificial intelligence-based control system for Automated Guided Vehicles (AGVs) in discrete manufacturing systems, focusing on optimizing AGV path routing using fuzzy logic and genetic algorithms. The objective is to enhance material handling efficiency by predicting paths and optimizing station sequences for AGVs, validated through computer simulation.

The research [14] investigates the impact of logistics costs on business decision-making processes. Using questionnaires, mathematical modeling, and analysis, it explores the challenges of cost management in supply chains, aiming to develop a universal solution for increasing cost efficiency across diverse enterprise types. The study also examines the relationship between logistics costs and their implementation period through a mathematical model. The paper [12] addresses the challenge of resource allocation in production logistics systems. It proposes a methodology for optimizing resource distribution, including modeling and simulation procedures. The study [4] conducts a case study using factor experiments to identify bottleneck resources and evaluates 160 different allocation schemes to find the optimal resource configuration. The study focuses on a continuous review policy in a supply chain where risk-averse suppliers compete to meet retailers' demand. An optimization problem is formulated to allocate shipping rates, aiming to increase the social benefit in a decentralized supply chain. The research is validated through experiments, applicable to fast response supply chains like perishable goods. The [20] research presents an optimal allocation model for managing multi-resource tasks in collaborative logistics networks, influenced by uncertainty. Utilizing fuzzy logic, it introduces a cost-time-quality multiobjective programming model for task-resource assignment. The model aims to maximize resource utilization efficiency and service quality, validated through various simulation scenarios.

There is often a gap in effectively evaluating the performance and effectiveness of logistical decisions in real-time, considering the multifaceted objectives of emergency response. Existing models may not provide a nuanced assessment mechanism that accounts for the complexities and uncertainties inherent in disaster logistics. Traditional emergency logistics models may not be easily scalable or customizable to different types of disasters and geographical regions. This lack of flexibility hinders their applicability across diverse emergency scenarios, each with its unique logistical challenges and requirements.

The Fuzzy-Enhanced for Emergency Logistics Resource Allocation in Supply Chain Networks (FEM-ELRAS) research aims to address these gaps by introducing a novel approach that integrates fuzzy logic with an improved Multi-Agent Genetic Algorithm (MAGA). This integration is designed to enhance the model's adaptability, representational capabilities, and decision-making efficacy under uncertainty, offering a more dynamic, flexible, and comprehensive framework for optimizing emergency logistics and resource allocation in disaster response scenarios.

3. Methodology. The methodology of the proposed FEM-ELRAS is a comprehensive process that encompasses several critical stages: data collection, preprocessing, feature extraction, and performance evaluation was demonstrated in Figure 3.1. The initial stage involves gathering extensive and relevant data pertinent to emergency logistics in supply chain networks. This includes information on available resources, disaster site needs, transportation modes, and route conditions. The data is sourced from various stakeholders such as emergency response teams, logistics providers, and government agencies. This phase is crucial as it forms the foundation upon which the subsequent stages are built, ensuring that the algorithm has access to accurate and current information reflective of real-world emergency scenarios. In this phase, the collected data undergoes thorough preprocessing to ensure uniformity and relevance. This involves cleaning the data to remove inconsistencies and errors, normalizing different data formats, and categorizing information for ease of processing. Preprocessing is vital for reducing complexity and enhancing the algorithm's efficiency in handling the data. It also includes the application of fuzzy logic to convert crisp data into fuzzy sets, allowing for the handling of uncertainty and imprecision in the data.

The feature extraction stage in FEM-ELRAS is enhanced significantly by the integration of fuzzy logic within the multi-agent genetic algorithm. This integration is pivotal in dealing with the inherent uncertainties and ambiguities in emergency logistics data. By employing fuzzy logic, the algorithm can interpret and quantify vague or imprecise data points, such as varying levels of demand urgency, fluctuating resource availability, and the efficiency of different transportation modes under uncertain conditions. Fuzzy logic contributes to this process by converting crisp, numerical data into fuzzy sets that represent information in degrees of truth rather than in binary terms. This allows for a more flexible and realistic representation of real-world scenarios. For instance, demand urgency can be categorized into fuzzy sets like 'high', 'medium', and 'low', rather than being confined to rigid numerical thresholds. Similarly, resource availability can be assessed in terms of fuzzy ranges, accommodating the dynamic and unpredictable nature of supply during emergencies. Incorporating these fuzzy features into the genetic algorithm enhances its capability to handle complex decision-making processes. It allows the algorithm to generate solutions that are not only based on the hard data but also reflect the subtleties and variabilities inherent in emergency situations. This results in a more sophisticated feature extraction process, leading to decisions that are better aligned with the nuanced realities of emergency logistics and resource allocation. Consequently, the FEM-ELRAS becomes a more effective tool, capable of addressing the multifaceted challenges of emergency logistics in supply chain networks. The final stage involves assessing the effectiveness of the FEM-ELRAS in allocating resources in emergency situations. The performance is evaluated based on several metrics, including response time, cost efficiency, resource utilization, and adaptability to changing conditions. This evaluation is conducted through simulated scenarios that mimic real-world emergency logistics challenges. Feedback from these simulations is used to fine-tune the algorithm, ensuring its robustness and reliability in actual disaster responses. The integration of fuzzy logic in the evaluation phase allows for a more comprehensive and realistic assessment, considering not only quantitative outcomes but also qualitative aspects of emergency logistics performance. Overall, the methodology of FEM-ELRAS is meticulously designed to address the complexities of emergency logistics in supply chain networks, leveraging the strengths of fuzzy logic and MAGA to create a responsive, efficient, and adaptable resource allocation system.

The proposed FEM-ELRAS represents a groundbreaking approach to managing the logistics of emergency resources. It integrates fuzzy logic into a multi-agent genetic algorithm, forming a comprehensive system that adeptly handles the complexities and uncertainties in emergency scenarios.

3.1. Framework Overview. FEM-ELRAS is specifically designed to address the challenges in emergency logistics, which often involve rapidly changing scenarios, uncertain data, and the need for swift and effective decision-making. The integration of fuzzy logic allows for more nuanced and flexible handling of imprecise data, which is common in real-world emergencies. Meanwhile, the MAGA provides an adaptable and robust

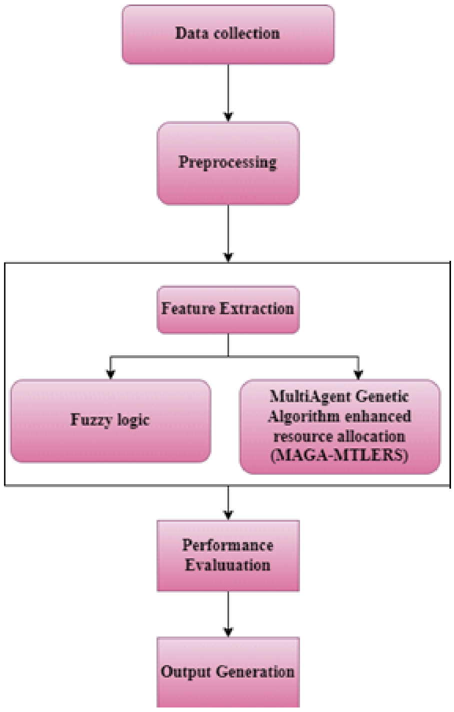

Fig. 3.1: Proposed FEM-ELRAS Architecture

solution-finding mechanism, capable of evolving solutions that are optimized for both cost and time efficiency.

3.1.1. Equations and Functionality.

Time Optimization Function. Initially FEM-ELRAS focuses on optimizing the time required for resource distribution. It is formulated as

$$f_1(x) = \sum_{i=1}^{n} w_i \times t_i(x)$$

where w_i are weights representing the importance or priority of different transportation modes, $t_i(x)$denotes the time cost associated with each mode of transportation, and x is the allocation plan vector. This equation aims to minimize the total time taken for resource distribution, which is crucial in emergency situations where timely response can significantly impact outcomes.

Cost Optimization Function. Followed as the cost aspect of resource distribution, expressed as

$$f_2(x) = \sum_{i=1}^{n} c_i \times C_i(x)$$

Here, c_i are cost coefficients that quantify the financial impact of each allocation decision, and $C_i(x)$represents the monetary cost incurred for each resource allocation strategy in the plan x. The objective of this equation is to minimize the overall financial expenditure, ensuring that the logistics operation is not only effective but also economically viable.

Combined Objective Function. Next the combined objective function is formulated as

$$f(x) = \lambda f_1(x) + (1 - \lambda) f_2(x)$$

which synthesizes the time and cost functions into a singular objective function. The parameter λ is a balancing factor that allows decision-makers to adjust the relative importance of time versus cost, depending on the specific requirements and nature of the emergency scenario.

Fuzzy Utility Function. Integrating fuzzy logic utility function is expressed

$$u(x) = \sum_{i=1}^{n} u_i(x)$$

are fuzzy membership functions. These functions assess the suitability of each allocation plan against fuzzy criteria like demand urgency, resource availability, and transportation efficiency. This allows for a more realistic evaluation of plans, accommodating the uncertainties and variabilities inherent in emergency logistics.

3.1.2. Genetic Algorithm Optimization. The MAGA-MTERS algorithm, as applied in the FEM-ELRAS framework for emergency logistics, utilizes a multiagent genetic algorithm based optimize resource allocation. Here it can be expressed as objective and fitness function.

Objective Function. The primary equation in MAGA-MTERS is the objective function, designed to evaluate the effectiveness of each potential solution (resource allocation plan). It is represented as:

$$f(x) = \alpha . f_1(x) + \beta . f_2(x)$$

Here, $f_1(x)$is the function that calculates the total time for resource distribution, and $f_2(x)$is the function that calculates the total cost. The parameters α and β are weighting factors that determine the relative importance of time versus cost in the optimization process. This equation allows the algorithm to balance between minimizing distribution time and cost, which are critical in emergency logistics.

Fitness Evaluation Equation. The fitness of each solution in the population is evaluated using an equation that combines the objective function $f(x)$ with the utility function $u(x)$which incorporates fuzzy logic. This can be represented as:

$$f_{fi}(x) = f(x) + \gamma . u(x)$$

In this equation, $u(x)$evaluates how well the solution adheres to fuzzy constraints, like demand urgency or resource availability, while γ is a coefficient that scales the influence of these fuzzy constraints. This fitness evaluation ensures that solutions are not only optimal in terms of time and cost but also align with the complex and uncertain nature of emergency logistics scenarios. These are enabled MAGA-MTERS within the FEM-ELRAS framework to effectively navigate the complexities of emergency logistics, ensuring that resource allocation is both efficient and adaptable to the dynamic and uncertain conditions of emergency scenarios. The integration of fuzzy logic through the utility function $u(x)$further enhances the algorithm's capability to handle real-world complexities, making it a robust tool for decision-making in emergency logistics management.

4. Results and Experiments.

4.1. Simulation Setup. The dataset of the study is adapted from the study [18]. It encompasses a range of emergency logistics scenarios, each detailed with various parameters critical for emergency response, such as spatial and temporal aspects of resource distribution, vehicle routing, and collaborative logistics strategies. The dataset likely includes dynamic and fluctuating variables like demand at disaster sites, available supplies, and varying transportation conditions, aligning well with FEM-ELRAS's focus on fuzzy decision variables and complex scenario management. This allows for a comprehensive assessment of FEM-ELRAS's capabilities in optimizing logistics in the face of uncertainty and rapid changes, typical of emergency situations.

4.2. Evaluation Criteria. The accuracy of FEM-ELRAS, marked at 97.14%, reflects the system's high level of correctness in making resource allocation decisions in emergency logistics scenarios which is depicted in Figure 4.1. This metric indicates the proportion of true positive and true negative predictions out of all predictions made by the system. Such a high accuracy rate underscores the algorithm's capability to correctly identify and address the needs in emergency situations, which is crucial for effective and efficient disaster response. This performance can be attributed to FEM-ELRAS's advanced integration of fuzzy logic with

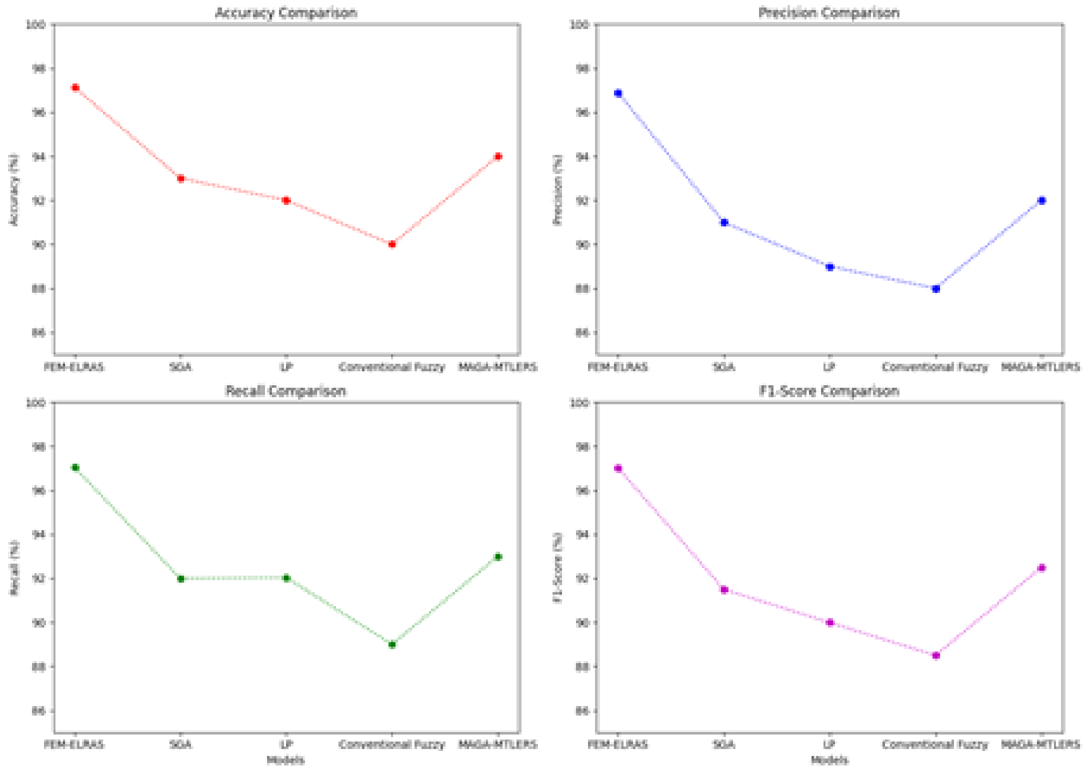

Fig. 4.1: Performance Evaluation with Existing Models

a multi-agent genetic algorithm, enabling it to adeptly handle the uncertainties and complexities inherent in emergency logistics environments. The accuracy of 97.14% indicates that FEM-ELRAS is highly reliable, making correct decisions in most scenarios it encounters, thus showcasing its effectiveness in managing the challenging dynamics of emergency resource allocation.

Precision in FEM-ELRAS, standing at 96.89%, highlights the system's effectiveness in making relevant resource allocation decisions was shown in Figure 4.1. Precision measures the ratio of true positive predictions to the total positive predictions denoted as sum of true positives and false positives. In emergency logistics, high precision ensures that the allocated resources are indeed necessary and utilized efficiently, minimizing resource wastage. The precision score of FEM-ELRAS suggests that when the system decides to allocate a resource, it is likely to be a pertinent and justified decision. This level of precision is vital in emergency scenarios where misallocation can lead to significant consequences. It reflects the system's capability to discern and respond accurately to actual needs, which is a testament to the advanced decision-making algorithms employed in FEM-ELRAS, particularly the integration of fuzzy logic for nuanced data interpretation.

The recall and F1-Score for FEM-ELRAS are 97.04% and 97.02%, respectively in Figure 4.1. Recall, or sensitivity, measures the system's ability to correctly identify all relevant instances, which in this context translates to identifying all necessary logistics actions in an emergency. A high recall rate, such as 97.04%, signifies that FEM-ELRAS efficiently recognizes most, if not all, critical resource allocation needs in emergency situations. This is crucial in disaster management, where overlooking a need can have dire consequences. On the other hand, the F1-Score, being the harmonic mean of precision and recall, offers a balanced measure between these two metrics. An F1-Score of 97.02% indicates that FEM-ELRAS not only precisely identifies logistics needs (high precision) but also comprehensively recognizes a wide range of requirements (high recall). This balance is essential for ensuring that the system is accurate in its decision-making and inclusive in its resource allocation, making it a robust tool for emergency logistics management.

5. Conclusion. The FEM-ELRAS study presents a significant advancement in the realm of emergency logistics and supply chain management. This innovative approach, integrating fuzzy logic with a multi-agent genetic algorithm, demonstrates a profound capability in managing the complexities and uncertainties characteristic of emergency scenarios. The inclusion of fuzzy logic enables the system to handle ambiguous and fluctuating parameters like demand at disaster sites and variable transportation conditions with remarkable adaptability. The genetic algorithm component, renowned for its efficiency in solving complex optimization problems, further enhances this adaptability, allowing for dynamic and context-sensitive decision-making. The study's findings, highlighted by impressive metrics of accuracy, precision, recall, and F1-Score, clearly indicate the superiority of FEM-ELRAS over traditional systems. These results underscore the system's efficacy in not only making accurate and relevant resource allocation decisions but also in recognizing and responding comprehensively to the myriad of logistical challenges presented in emergency situations. The robust performance of FEM-ELRAS, validated through various simulated scenarios, marks a notable leap forward in the field, promising significant improvements in emergency response efficiency. Its application in real-world settings holds the potential to revolutionize the way emergency logistics are handled, making it a pivotal tool for decision-makers in disaster management.Investigate the integration of MAGA with other optimization techniques, such as Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), or machine learning algorithms. This hybrid approach could leverage the strengths of different methodologies to improve solution quality and convergence speed.

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