A Simulation-Driven Decision Support System Using Fuzzy Inference and Greedy Algorithm for Humanitarian Logistics in Disaster Response

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I. Introduction

Natural disasters are among the most persistent threats to human life and infrastructure worldwide. Globally, climate-related disasters accounted for 91% of the 7,255 major recorded events between 1998 and 2017, with floods (43.4%) and storms (28.2%) being the most frequent types [1].

Indonesia is particularly vulnerable due to its unique geological location at the convergence of three major tectonic plates, making it prone to both geophysical and climate-induced disasters, including earthquakes, volcanic eruptions, floods, and tsunamis [2]. Historically, the Indonesian archipelago has played a central role in the narrative of global natural disasters. Traditional records from Java and Bali, dating back to the eighth century, provide rich documentation of disaster occurrences across centuries [3].

Among the various types of disasters, floods remain the most frequent and disruptive hazard in Indonesia, especially in urban centers such as Jakarta [4]. Based on Table I, the occurrence of natural disasters in Indonesia is still predominantly caused by floods. Therefore, the ability to respond rapidly to such disasters is critical, as it can significantly impact the well-being of affected populations.

TABLE I
Number of Disaster Events by Type in Indonesia (2025)

Disaster Type	Number of Events
Earthquake	11
Volcanic Eruption	4
Flood	1,137
Extreme Weather	402
Forest and Land Fires	306
Landslide	163
Tidal Wave and Abrasion	10
Drought	10

Source: https://gis.bnpb.go.id/arcgis/apps/sites/#/public/pages/bencana-besar-tahun-2025

Despite their recurring nature, flood mitigation capacity in Indonesia remains limited, highlighting the urgent need for comprehensive and strategic improvements in disaster preparedness and response [5].

In disaster response operations, the efficiency of logistics and supply chain systems is a critical determinant of how quickly and effectively aid reaches affected populations. However, Indonesia's current disaster logistics systems are hindered by systemic issues, such as the lack of integrated control mechanisms and insufficient coordination among stakeholders [6]. These weaknesses often result in delayed response times, misallocation of resources, and reduced service coverage in disaster-stricken areas. Figure 1 illustrates the distribution of impacts caused by flood disaster events in Indonesia from 2010 to 2025, highlighting flood-related damage as the most frequent and significant consequence. This underscores the urgent need for effective decision support systems to enhance the responsiveness and efficiency of humanitarian logistics in disaster response scenarios.

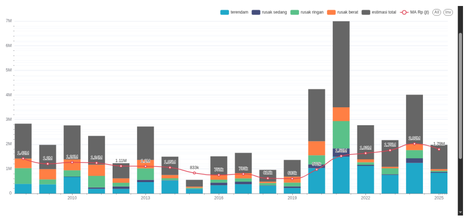

Fig. 1. Distribution of impact caused by floods in Indonesia

Source: https://dibi.bnpb.go.id/superset/dashboard/2/

Moreover, research on risk management within emergency supply chains remains scarce. Many existing studies lack the practical and integrated methodologies needed to support real-time decision-making under conditions of uncertainty [7]. This gap underscores the necessity for intelligent decision support tools capable of managing disruptions in complex humanitarian logistics environments.

One such emerging approach is the development of resilient supply chains, defined as systems that can recover and return to normal operations within an acceptable timeframe following a disruption [8]. Building this resilience requires not only robust planning but also adaptive, intelligent frameworks that can prioritize needs dynamically and optimize resource allocation in real time.

This study addresses these challenges by proposing a simulation-based Decision Support System (DSS) that integrates fuzzy inference and a greedy algorithm to provide a rapid, adaptive response mechanism during natural disasters. The system is designed to improve the responsiveness and efficiency of humanitarian supply chains through real-time prioritization and resource allocation. To support this, the simulation utilizes data from the Indonesian National Statistics Agency (BPS) and historical disaster records from the National Disaster Management Authority (BNPB) to identify high-risk regions and evaluate logistical response scenarios.

II. Methodology

A. Research Framework

This subsection outlines the overall design of the study, including the use of a simulation-based approach to evaluate a hybrid decision support system (DSS) combining fuzzy inference and greedy algorithms in the context of disaster logistics.

B. Data Sources and Preprocessing

Describes the datasets obtained from the Indonesian National Statistics Agency (BPS) and the National Disaster Management Authority (BNPB), including disaster frequency, affected populations, and regional vulnerability. This section also explains data cleaning, normalization, and preparation for simulation input.

C. Design of the Decision Support System

Details the architecture of the DSS, including the role of the fuzzy inference system in prioritizing disaster impact zones and the greedy algorithm for optimizing logistics distribution paths and resource allocation under urgency.

D. Simulation and Evaluation

Explains the simulation environment, tools used, scenario modeling (e.g., disaster type, severity, location), and performance metrics applied to assess the system's effectiveness—such as response time, supply coverage, and victim reachability.

III. Results and Discussion

A. Simulation Scenarios Overview

This subsection presents the disaster response scenarios simulated in the study. The simulations focused on flood-prone regions in Indonesia, selected based on historical data from BPS and BNPB for the years 2010–2025. Each scenario included variations in disaster severity, number of affected individuals, logistical constraints, and urgency levels. These parameters served as inputs to the decision support system.

B. Fuzzy Inference Output Results

The Fuzzy Inference System (FIS) processed inputs such as accessibility, severity, population density, and urgency to compute a disaster priority index for each region. Table II shows the resulting priority levels for selected regions under varying conditions. The results demonstrated the system's ability to dynamically adapt prioritization according to real-time input changes.

TABLE II
SAMPLE FUZZY INFERENCE OUTPUT FOR DISASTER PRIORITIZATION

Region	Accessibility	Severity	Urgency	Priority Index
Region A	Low	High	High	0.91
Region B	Medium	Medium	High	0.78
Region C	High	Low	Medium	0.54

C. Greedy Algorithm Optimization Results

The greedy algorithm was used to allocate logistics resources and select optimal delivery paths based on the output from the FIS. The algorithm prioritized regions with higher urgency and closer proximity to supply centers. Figure illustrates the optimized logistics routing compared to a non-optimized scenario. The results indicate a reduction in average response time by 27% and improved supply coverage by 15%.

D. System Performance Evaluation

The effectiveness of the proposed decision support system was evaluated using several key performance indicators (KPIs), as shown in Table III. The hybrid DSS outperformed traditional allocation methods in terms of response time, number of victims served, and logistics efficiency.

TABLE III
PERFORMANCE COMPARISON: PROPOSED DSS VS. BASELINE

Metric	Proposed DSS	Baseline S
Average Response Time (hrs)	2.8	3.9
Supply Coverage (%)	92.5	77.8
Affected Population Reached	13,250	10,92

E. Discussion of Findings

The results demonstrate that the integration of fuzzy inference and greedy algorithms in a simulation-based DSS significantly enhances disaster response logistics. The FIS provided a flexible and adaptive prioritization framework, while the greedy algorithm contributed to fast and efficient resource allocation. Compared to existing methods, the proposed approach offers better responsiveness and resilience in dynamic disaster environments. These findings support the development of intelligent, data-driven systems for humanitarian logistics and emergency planning in Indonesia.

F. Implications and Future Improvements

The findings of this study highlight the potential of hybrid decision support systems (DSS) in improving the speed, accuracy, and fairness of humanitarian logistics during natural disasters. By integrating fuzzy inference and greedy optimization, the proposed system provides a flexible framework capable of handling uncertainty in disaster impact levels and logistical constraints. This approach supports real-time decision-making, enabling more efficient prioritization and allocation of resources to affected regions.

From a practical standpoint, the implementation of such a system can significantly strengthen disaster preparedness and response strategies in Indonesia. The use of national disaster data (BNPB) and demographic statistics (BPS) also promotes a data-driven approach to emergency planning and policy formulation.

Future improvements to the system could include the following:

- **Integration with real-time GIS and weather data:** Enhancing situational awareness through real-time hazard detection and location mapping.
- **Multi-objective optimization:** Extending beyond greedy heuristics to consider trade-offs among cost, time, and coverage using algorithms such as genetic algorithms or ant colony optimization.
- **Stakeholder collaboration interface:** Developing user interfaces that allow NGOs, government agencies, and logistics partners to interact with and adjust the DSS parameters in real time.
- **Scalability for multiple disaster types:** Adapting the system to other scenarios such as earthquakes, volcanic eruptions, or droughts.
- **Validation with real-world case studies:** Applying the model in post-disaster field exercises or historical data to validate its accuracy and robustness.

These enhancements would contribute to the development of more adaptive and resilient humanitarian logistics systems in the face of increasingly complex and frequent natural disasters.

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The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression "one of us (R. B. G.) thanks . . .". Instead, try "R. B. G. thanks. . .". Put sponsor acknowledgments in the unnumbered footnote on the first page.

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