Journal of Information & Optimization Sciences
ISSN 0252-2667 (Print), ISSN 2169-0103 (Online)
Vol. 47 (2026), No. 6, pp. 2193–2204
DOI : 10.47974/JIOS-2103

Optimizing resource allocation in disaster response : A multi-criteria decision-making approach using analytic hierarchy process

Nafisur Rahman †
Farheen Siddiqui *
Jawed Ahmed §
Md. Tabrez Nafis ‡
Department of Computer Science and Engineering
School of Engineering Sciences & Technology
Jamia Hamdard (Deemed to be University)
Hamdard Nagar
New Delhi 110062
Delhi
India

Abstract

Efficient allocation of resources is essential in disaster response to reduce the adverse effects of catastrophic events and expedite recovery. The complexity of these situations requires strong decision-making methods that can handle multiple criteria and uncertainty. This article shows how the Analytic Hierarchy Process (AHP) might be employed to address resource allocation difficulties in disaster response. AHP is a method for decision-making that assesses and ranks different options based on specific criteria and their respective significance. It offers a structured method for decision-making by organizing problems hierarchically and using pairwise comparisons. Integrating AHP into resource allocation improves decision-making by offering a systematic framework to evaluate the Resource Allocation options based on various criteria. This article showcases how AHP may optimize resource allocation decisions.

Subject Classification: *90B50, 90B30, 91B06.*

Keywords: *Multi-criteria decision-making, Analytic hierarchy process, Resource allocation, Disaster response.*

† *E-mail:* **nafiis@gmail.com**
* *E-mail:* **fsiddiqui@jamiahamdard.ac.in (Corresponding Author)**
§ *E-mail:* **jawed2047@gmail.com**
‡ *E-mail:* **tabrez.nafis@gmail.com**

1. Introduction

In disaster response, effective resource allocation plays a pivotal role in mitigating the effects of catastrophic events and facilitating timely and efficient recovery efforts. Disaster circumstances require employing strong decision-making methods [1] that can handle various criteria [2] and uncertainties due to their complexity. Applying the Analytic Hierarchy Process (AHP) [3] is a viable method to address resource allocation difficulties in disaster response situations.

AHP allows decision-makers to methodically assess and rank different options [4] based on a number of criteria and their respective significance. AHP gives a systematic method for decision-making in complex and uncertain scenarios. It breaks down the decision into levels and compares options. Using this, stakeholders can make informed decisions by taking into account various factors such as distance to disaster zones, available resources, transportation capacity, and urgency.

There are many advantages of incorporating AHP in the problem of resource-allocation during disaster response. It gives decision-makers a way to distribute resources based on strategic goals and priorities. With AHP, stakeholders can identify the most productive and efficient courses of action considering the constraints and uncertainties arising in crisis scenarios.

The flexibility of AHP takes into account stakeholders' preferences and expert input in the decision-making. This enhances the validity and reliability of resource allocation decisions.

2. Related Work

Multi-Criteria Decision-Making techniques have been used widely in the problems relating to the fields of Soft Computing, Optimization, and Interdisciplinary Mathematics. The various techniques include Analytic Hierarchy Process (AHP) [3], Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [4], Simple Additive Weighting (SAW) [5], Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) [6], Grey Relational Analysis (GRA) [7], and many more.

Over the years, these techniques have been applied extensively in diverse areas including but not limited to Engineering, Mathematics, Computer Science, Environmental Science, Business Management, and Social Sciences. For example, searching the Scopus database of articles using suitable search queries containing Multi-Criteria Decision-Making and other relevant keywords shows that more than twenty five thousand (more than ninety percent written in the last decade) articles have been written on the subject over the years. However, very few (less than twenty in all) relate to disasters. The central points of some of these follow here.

Hosseini, Fuente, and Pons [8] have employed Integrated Value Model for Sustainable Assessment as an MCDM technique to evaluate the sustainability value of Temporary Housing Units used for displaced people in the aftermath of natural disasters. Yu, Yu, and Lu [9] have proposed a model, based on TOPSIS, to estimate the intensity of agricultural meteorological disasters. Abdullah, Siraj, and Hodgett [10] have given an insight into how different MCDM techniques, mostly, AHP and TOPSIS, have been applied to manage water related disasters like flood and drought. Ortiz-Barrios et al. [11] have proposed a six-step procedure that evaluates the hospital disaster preparedness and detects the weaknesses to be tackled to respond to disasters. They have used MCDM techniques like, Fuzzy AHP and TOPSIS for the purpose. Atmaca, Aktaş, and Öztürk [12] have used four different MCDM techniques including AHP to select and evaluate the suitability of emergency assembly areas in the aftermath of a disaster. Wang, Lyu, and Sun [13] have proposed a model to optimize emergency resource allocation by simultaneously considering time, cost, and loss as the criteria.

We see that the works mentioned above are related to disasters but none except Brans and Vincke [6] has considered the problem of Resource Allocation in Disaster Response. Wang, Lyu, and Sun [13] work is in line with the specific needs of emergency rescue to the COVID-19 epidemic. This prompted us to work on the pertinent but generalized problem of optimized Resource Allocation in Disaster Response.

3. Problem Overview

This article targets the critical issue of resource allocation and deployment in disaster response situations. Decision-makers must efficiently allocate scarce resources, such as persons, equipment, and supplies, to meet various pressing needs in such circumstances. Without a systematic strategy, it is possible to make less than ideal decisions that could exacerbate the issue. We intend to tackle this difficulty by examining the use of AHP as a methodical decision-making approach. Our work aims to improve the efficiency and effectiveness of disaster response operations by prioritizing resource allocation choices according to their efficacy and alignment with strategic objectives.

4. Methods

We propose a sequential, step-by-step framework of activities to address the problem of Optimizing [14] Resource Allocation in Disaster Response. We have applied AHP as the underlying technique for Multi-Criteria Decision-Making (MCDM). Figure 1 represents the sequential flow of activities described in the sub-sections that follow. Figure 2 represents the scenario of Disaster Response in the event of an earthquake.

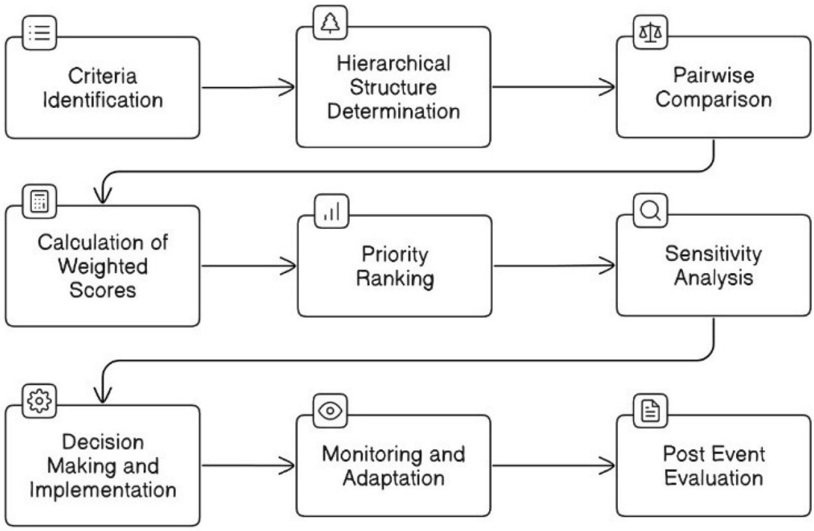

Figure 1

Step-by-step framework of activities to Optimize Resource Allocation in Disaster Response.

4.1 *Criteria Identification*

Before we perform the evaluations and decide the priorities, we identify the criteria that are most important. For example, we have identified four most important criteria as under:

Criterion 1: Proximity to Disaster Site (P)
Criterion 2: Resource Availability (R)
Criterion 3: Transportation Capabilities (T)
Criterion 4: Urgency of Need (U)

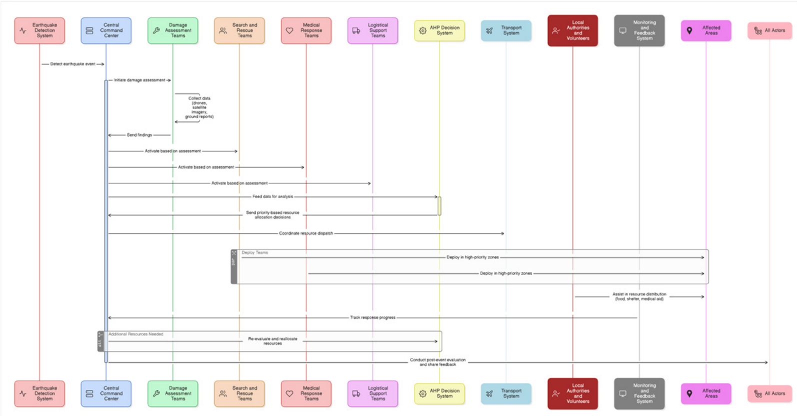

Figure 2

Sequence Diagram depicting the scenario specific workflow of Disaster Response in the event of an earthquake.

4.2 *Hierarchical Structure Determination*

A Hierarchical Structure is determined to align the criteria and sub-criteria with the overall objective. The different hierarchical levels, as shown in Figure 3, are:

Level 1: Overall Objective (Resource Allocation)

Level 2: Criteria (Proximity, Availability, Transportation, Urgency)

Level 3: Sub-criteria (e.g., Types of Resources, Distance to Disaster Site)

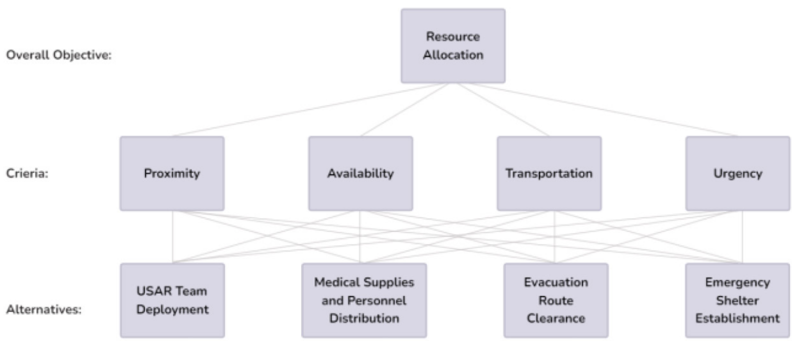

Figure 3

AHP Hierarchy of overall objective, criteria, and alternatives

4.3 *Pairwise Comparison*

In this step, we compare each criterion against every other criterion individually. Then we assign relative importance using a scale, such as 1-9. For example, Proximity is moderately more significant than resource availability with a ratio of 7 to 2. Similarly, Proximity is considerably greater in importance than transportation capabilities, with a ratio of 7 to 2. Also, Proximity is slightly more significant than urgency of need, with a ratio of 3 to 1. This is done for all pairwise comparisons.

4.4 *Calculation of Weighted Scores*

The normalized weights [15] are determined for each criterion using the pairwise comparison matrix. Then the weighted scores are found out by multiplying the criteria weights by the sub-criteria scores [16].

4.5 *Priority Ranking*

The aggregate scores are determined for each resource allocation option based on their respective weights. Then the items are ranked according to their total priority scores.

4.6 *Sensitivity Analysis*

Sensitivity analysis [17] can be conducted to see how the results are affected by variations in criteria weights or resource availability. Then, the assessment, about how different scenarios affect the priority ranking, is done.

4.7 *Decision Making and Implementation*

Now, the resource allocation option with the top priority ranking [18] is chosen. Accordingly, resources according to the selected plan, considering logistical limitations and operational feasibility.

4.8 *Monitoring and Adaptation*

The execution of the allocation strategy is monitored to and make necessary adjustments according to immediate input and evolving conditions. The efficiency [5] of resource allocation is consistently assessed and modified as needed.

4.9 *Post-Event Evaluation*

A post-event assessment is perform to determine the effectiveness of the allocation strategy and pinpoint areas that need enhancement. The insights gained and optimal strategies are recorded for upcoming crisis management endeavors.

By employing AHP in a methodical step-by-step manner, decision-makers can assess and rank resource allocation choices in crisis response and disaster management. This paves the way for a more efficient and effective distribution of resources during catastrophes.

5. Results and Discussions

We make pairwise comparison matrices for the criteria related to allocation and deployment of resources in disaster response and management using AHP.

5.1 *Pairwise Comparison*

A scale in the range of 1 to 9 is used with 1 representing equal importance and 9 representing tremendous importance. Table 1 shows the pairwise comparison.

Table 1

Pairwise Comparison Matrix.

Criteria	P	R	T	U
P	1	3/2	3	2
R	2/3	1	2	3/2
T	1/3	1/2	1	3/2
U	1/2	2/3	2/3	1

5.2 *Calculating Normalized Weights*

The sum of each column is calculated and then each element is divided by the sum of its respective column to create the normalized matrix. Then the criteria weights are determined by calculating the average of each row. Table 2 shows the Normalized Pairwise Comparison. Figure 4 gives the visualization for normalized criteria waits thus obtained. Figure 5 shows the bar chart for Normalized Criteria-Weights.

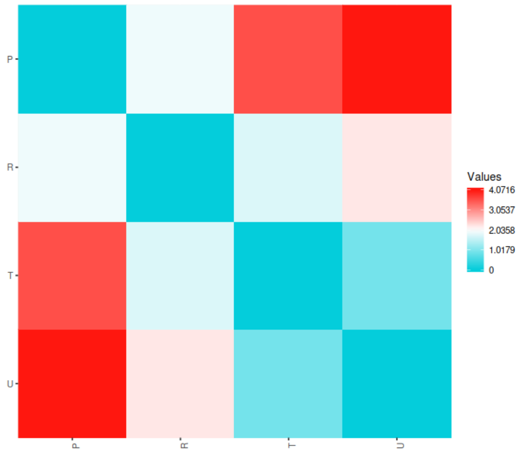

Figure 4

Heatmap representing the Distance Matrix for pairwise comparison

Table 2

Normalized Pairwise Comparison Matrix.

Criteria	P	R	T	U	Weight
P	0.40	0.41	0.45	0.33	0.40
R	0.27	0.27	0.30	0.25	0.27
T	0.13	0.14	0.15	0.11	0.13
U	0.20	0.18	0.10	0.17	0.16

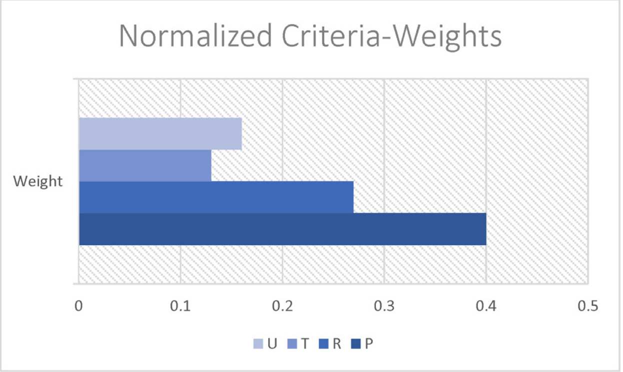

Figure 5

Bar chart representing the Normalized Criteria-Weights

5.3 *Consistency Analysis*

We multiply the original pairwise comparison matrix by the priority vector to get the weighted sum vector as shown in Table 3.

Table 3

Weighted Sums.

Criteria	Weighted Sum
P	1.52
R	1.04
T	0.64
U	0.63

Then we divide each element of the weighted sum vector by the corresponding priority weight and get the consistency values for each criterion as mentioned in Table 4.

Table 4

Consistency Values

Criteria	Consistency
P	3.80
R	3.85
T	4.92
U	3.94

The principal eigenvalue λ_{max} is the average of the consistency values and comes out to be 4.13.

The consistency index [19] is then calculated as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{4.13-4}{4-1} = \frac{0.13}{3} = 0.043$$

Finally, we calculate the consistency ratio using the random index (RI) for $n = 4$, which is 0.90.

$$CR = \frac{CI}{RI} = \frac{0.043}{0.90} = 0.048$$

The Consistency Ratio (CR), in this case, is 0.048. It is less than 0.10, indicating that the matrix is consistent.

5.4 *Priority Ranking*

We now compute the weighted scores for each resource allocation option and establish their overall priority ranking according to the combined scores.

Consider two resource allocation choices, Option A and Option B, with hypothetical weighted scores based on sub-criteria evaluations:

Table 5

Resource Allocation Options Evaluation Matrix.

Options	P	R	T	U	Overall Score
A	0.6	0.7	0.8	0.9	0.38
B	0.5	0.8	0.7	0.6	0.26
C	0.7	0.6	0.9	0.8	0.13
D	0.8	0.5	0.6	0.7	0.17

As evident from Table 5, Option A is the preferred resource allocation choice according to the AHP framework since it has the best total weighted score in this scenario. Decision-makers can methodically assess and rank resource allocation choices in crisis response and catastrophe management to ensure the efficient and effective distribution of resources to impacted regions.

6. Conclusion

Our study demonstrates how Analytic Hierarchy Process (AHP) might be used for resource allocation and deployment in crisis response situations. AHP offers a clear and organized method for decision-making, evaluating and ranking resource allocation choices based on multiple criteria. This aids decision-makers in making well-informed and efficient decisions in complex and uncertain circumstances.

This study highlights the importance of using structured decision-making methods like AHP in disaster response. By harnessing AHP's analytical features, decision-makers can efficiently allocate resources, improve resource utilization, and strengthen community resilience and sustainability during difficult situations. As we continue to face increasingly complex and dynamic challenges in the realm of disaster response, the adoption of robust decision-making frameworks like AHP will be essential in shaping more effective and resilient response strategies in the future.

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Received February, 2026