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A New Method for Solving Fully Generalized Quadratic Fuzzy Transportation Problem under Fuzzy Environment

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ABSTRACT

This paper presents a solution approach for the transportation problem (TP) in an uncertain environment using trapezoidal intuitionistic fuzzy numbers (TrIFNs). We introduces a new approach to solving Transportation Problems (TP) in uncertain environments, focusing on the Trapezoidal Fermatean Fuzzy Number (TrFFN). The Fermatean Fuzzy TP (FFTP) treats transportation cost, supply, and demand as TrFFN, offering superior performance and feasibility compared to existing methods. It also highlights its advantages in uncertain environments. Using standard LP algorithms, the IFTP is converted into a deterministic linear programming (LP) problem. The quadratic fuzzy transportation problem is a significant problem in operations research and optimization, involving finding the best feasible solution for a transportation problem with quadratic function cost coefficients. The paper presents a new method for solving the fully generalized quadratic fuzzy transportation problem under an ambiguous environment, considering uncertainties and fuzziness inherent in real-world transportation scenarios. The paper also addresses the minimum spanning tree (MST) problem, which involves a graph with either trapezoidal or triangular fuzzy numbers assigned to each arc length. The graded mean integration representation of fuzzy numbers is used to solve these problems. The paper proposes an alternative undefined outranking method by extending the Elimination Et Choix Traduisant La Realite (ELECTRE 1) Method method to consider uncertain, imprecise, and linguistic assessments a group of decision-makers provides. The report addresses the gap in the Electre 1 literature for problems involving conflicting systems of criteria, uncertainty, and imprecise information.

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1. Introduction

Fuzzy sets, as defined by Zadeh, are valuable tools for handling imprecise data. Still, they have a drawback of measuring the accomplishment degree of an element using an exact actual number [1].

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To address this, Atanassov introduced the Intuitionistic Fuzzy Set (IFS) concept, which incorporates hesitation in membership degrees. IFS can handle vagueness and hesitancy from imprecise knowledge or information [2].

Transportation problems (TP) are becoming more significant because of their importance in optimization, especially in logistics and supply chain management. The transportation problem is used in supply chain management and logistics to optimize the movement of commodities between several sources and destinations [3]. The aim is to reduce transportation costs while guaranteeing that each destination's demand is satisfied. In natural transportation cases, decision-makers face various uncertainties in determining transportation costs, supply capacity, and demand, such as changing weather, social, or economic conditions [4]. Transportation problems with fuzzy cost coefficients and problems where all parameters (cost coefficients, supply and demand quantities) are represented by fuzzy numbers are the first problem groups studied in this field [5]. To find the optimal response stated in fuzzy numbers, a fuzzy-modified distribution method is proposed. Pandian and Natarajan proposed a novel method, dubbed the fuzzy zero point method, to find a fuzzy optimal solution for a fuzzy transportation problem (FTP), where supply, demand, and transportation costs are represented by trapezoidal fuzzy integers [6]. The article also discusses how to use intuitionistic fuzzy numbers (IFNs) to represent unplanned parameters in Intuitionistic Fuzzy Transportation Programming Problems (IFTPs). Even if fuzzy numbers are used to model approximate data, there might be more effective ways to handle ambiguity and uncertainty [7]. While several studies have suggested strategies for solving IFTP optimally, none offer optimal costs and non-negative intuitionistic fuzzy optimal solutions for the IFTP in question. To address the same issue, Ibrahimnejad and Verdegay suggested an effective computational strategy based on the traditional transportation method [8]. However, these techniques must be revised to solve IFTPs in which supply and demand are IFNs.

The main goal of this study is to employ an accuracy function to transform a deterministic classical linear programming [9]. LP problem based on ordering trapezoidal intuitionistic fuzzy numbers (TrIFNs). It suggests a novel approach that yields optimal cost and a non-negative, ambiguous, intuitionistic, unclear optimal solution. The benefits of the proposed system over current methods for addressing IFTPs are also covered in the study. It provides two application examples to illustrate the viability and depth of the solutions found. To account for well-being, models encompassing the complete application of stocks and supply chains are employed in transportation problems (TPs), an essential field of study. The study introduces a novel method for figuring out TP's and we introduce the BFC-MSMIP and accurate algorithmic framework designed to optimize multistage stochastic mixed 0–1 problems with complete recourse, written in C++ [10]. This study proposes a novel approach for multi-criteria decision-making problems using the analytical hierarchy process (AHP) with trapezoidal neutrosophic fuzzy numbers to evaluate total transportation cost, focusing on driver behaviour, weather, distance, and market demand. [11].

2. Literature Review

The transportation problem is one of the most well-known particular linear programming problems. The initial transportation issue and the second index transportation issue. Hitchcock created the 2nd Integrated Transportation Strategy (2ITP) in 1941 in response to a request from production companies: create a detailed plan for moving items from one or more origins to one or more destinations while keeping the overall cost of transportation as low as possible [12]. When supply and demand quantities and cost coefficients are precisely known, then efficient algorithms for solving the 2ITP exist. Nevertheless, there are circumstances in which these parameters might need to be provided more precisely. For instance, the cost of unit transportation may change over time; supply and demand may be unpredictable owing to certain uncontrollable circumstances. Thus, fuzzy logic was established to deal quantitatively with imperfect information when making decisions.

Identifying and pinpointing the problem's ideal solution is one of the prerequisites for addressing it. Numerous techniques for handling transportation problems in fuzzy environments have been developed in the literature; nonetheless, the parameters in these algorithms are represented by regular undefined integers [13]. Furthermore, generalized fuzzy numbers have been applied in various studies to solve real-world issues; nevertheless, the application of generalized fuzz still needs to address transportation-related issues. Thus, a new approach was proposed to solve a unique problem in this field: generalized trapezoidal fuzzy numbers describe the transportation problem with cost coefficients [14]. To achieve this goal, two new approaches were implemented in 2011 to discover a fuzzy optimal solution for ambiguous transportation problems with all parameters represented by trapezoidal fuzzy numbers [15]. These approaches were based on unclear linear programming formulation and classical transportation methods.

There is always an integer solution to the traditional transportation problem with integer demand and supply numbers. Even if the fuzzy numbers in the problem have integer properties, this property—the ability to find an integer solution—is not maintained in the fuzzy problem with fuzzy wants and supplies [16]. As a result, the integrality requirement is placed on the solution, and an exact algorithm has been proposed to solve the problem with imprecise supply and demand values [17]. The multi-objective transportation issue makes up the third branch, where the idea of an optimal solution replaces that of non-dominated solutions. Researchers frequently employed theories based on the foundation of fuzzy-parameter mono-objective problems to solve them. A strategy to reduce transportation cost-time with ambiguous demand, supply, and cost coefficients was put forth in 2010. A multi-objective linear programming problem with accurate parameters was used to model the issue. Chakraborty addressed impreciseness using fuzzy parametric programming before using the prioritized goal programming technique to overcome the issue [18]. In 2011, a novel approach was implemented to solve a linear multi-objective transportation issue, wherein all parameters were represented as fuzzy numbers with interval values [19]. Despite this, fuzzy numbers are frequently employed to model imprecise data when dealing with real-world ambiguity. Therefore, they might not be appropriate in scenarios of hesitation and uncertainty. Under such circumstances, the vague parameters of the TP under discussion are represented by Intuitionistic Fuzzy Numbers (IFNs). For this reason, the ensuing issue is known as an Intuitionistic Fuzzy Transportation Programming Problem (IFTP). Therefore, finding solutions to the IFTPs is a relatively recent and active study area. There are few research studies on this topic.

In their study, Hussain and Kumar concentrated on a TP where supply and demand were hazy, intuitionistic quantities. Next, in terms of triangular intuitionistic fuzzy numbers (TIFNs), they suggested an intuitionistic fuzzy zero point technique to choose the best answer. Another strategy for determining the best solution to the same IFTP, based on ranking functions, was introduced by Nagoorgani and Abbas. However, the ranking functions employed by Hussain and Kumar and Nagoorgani and Abbas cannot be used to solve a general IFTP since they cannot be used to order all IFNs [20]. To address this flaw, Singh and Yadav created a new ordering process utilizing the TIFN accuracy function. They then used this ordering to create an algorithm for determining the IFTP's ideal solution. They presented intuitionistic fuzzy modified distribution methods to discover the optimal solution of the same IFTP. They introduced intuitionistic fuzzy ways to identify the first basic feasible solution regarding IIFNs. However, the complete IFTP problem, in which transportation costs are also IFNs, cannot be solved using these methods. In order to address this drawback, Kumar and Hussain converted the complete IFTP into a crisp one using Varghese and Kuriakose's already-existing ordering mechanism. Then, they used the conventional approach to fix the issue [21]. However, for the IFTP under consideration, none of the suggested methods produces a non-negative fuzzy optimal solution or optimal cost; the intuitionistic fuzzy optimal solution and the intuitionistic fuzzy optimal cost contain harmful elements with no physical significance [22].

This study presents a strategy that assumes a decision maker needs clarification about the precise values of transportation costs only. The generalized quadratic unclear transportation model solves a specific fuzzy transportation problem. Transportation costs are represented by generalized trapezoidal undefined integers in the suggested manner. The proposed strategy is demonstrated by solving a numerical problem. The recommended approach is simple for decision-makers to comprehend and implement in real-world transportation issues.

3. Methodology

The proposed method for solving the fully generalized quadratic fuzzy transportation problem involves a systematic problem-solving approach: identifying the problem, gathering data, analyzing it, generating potential solutions, evaluating them, and implementing the best solution. This method uses mathematical modeling to represent the problem and its constraints, allowing optimization techniques to find an optimal solution [21].

3.1 Problem Formulation & Algorithmic Implementation

The following is a mathematical representation of the fully generalized quadratic fuzzy transportation problem:

$$\text{Minimize Z} = \sum_{i=1}^{m}\sum_{j}^{n}\sum_{k}^{p} c_{ijk}.x_{ijk} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\sum_{l=1}^{q} d_{ijkl}.y_{ijkl}$$

Subject to constraints,

$$\sum_{j=1}^{n}\sum_{1}^{p} x_{ijk} = \text{Supply}_i\ , \quad \forall_i$$
$$\sum_{i=1}^{m}\sum_{1}^{p} x_{ijk} = Demand_j, \quad \forall_j$$

The linear programming problem is left in its original form without conversion if c_{ijk}, d_{ijkl} are interval numbers.

3.2 The transportation problem's matrix format

A tableau known as the transportation costs tableau can be used to summarise the pertinent facts for any transportation problem in a matrix format (see Table 1). The table shows the supply and demand for the sources, the destinations, and the cost of transportation for each unit.

Table 1: Table of Transportation Costs

	D_1	D_2	$\cdots$	D_n	Supply
O_1	c_{11}	c_{12}	$\cdots$	c_{1n}	a_1
O_2	c_{21}	c_{22}	$\cdots$	c_{2n}	a_2
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
O_m	c_{m1}	c_{m2}	$\cdots$	c_{mn}	a_m
Demand	b_1	b_2	$\cdots$	b_n	

3.3 A recursive analysis approach's pseudo-code might resemble

```
function recursiveAnalysis(problem):
if problem satisfies constraints:
    return current solution
else:
      generate alternative solutions
    evaluate and discard infeasible solutions
return recursiveAnalysis(best feasible solution)
```

And,

```
def recursiveAnalysis(current_solution, constraints, generate_alternatives, evaluate_solution):
         Recursive analysis function for solving an optimization problem.

     Parameters:
              - current_solution: The current solution to be evaluated.
                  - constraints: A function that checks if the solution satisfies constraints.
                 - generate_alternatives: A function that generates alternative solutions.
              - evaluate_solution: A function that evaluates the feasibility and quality of a solution.

   Returns:
           The best feasible solution.
             # Base case: If the current solution satisfies constraints, return it
                   if constraints(current_solution):
   return current_solution

              # Generate alternative solutions
                  alternatives = generate_alternatives(current_solution)
```

```
# Evaluate and discard infeasible solutions
feasible_solutions = [solution for solution in alternatives if constraints(solution)]
# Recursive call to find the best feasible solution
best_feasible_solution = None
best_feasible_value = float('inf') ”The main contributions include. # Set to positive infinity initially

for solution in feasible_solutions:
solution_value = evaluate_solution(solution)

# Update the best feasible solution if the current one is better
if solution_value < best_feasible_value:
best_feasible_solution = solution
best_feasible_value = solution_value
return recursiveAnalysis(best_feasible_solution, constraints, generate_alternatives, evaluate_solution)
```

To effectively deal with the uncertainties and complexities of real-world transportation scenarios, we may use Mathematica to mathematically model the problem and build solution techniques [12]. This allows us to directly model and solve the quadratic fuzzy transportation problem without losing any information or introducing additional approximations. Furthermore, we also propose the use of the interval fuzzy credibility-constrained programming (IFCP) method for river water quality management, which enhances the modeling capabilities of the proposed method [13].

Intuitive fuzzy numbers represent fuzzy parameters in these cases. An intuitionistic fuzzy transportation programming problem (IFTP) is the resultant issue. TP remedies consist of:

- Calculating sums,
- Adding and subtracting values,
- Calculating the minimal cell value,
- Changing undefined values to crisp
- Determine the lowest possible cost,
- Take out columns or rows,
- Repeat stages until supply and demand are satisfied,
- Replace the original transport standard.

By precisely representing the problem and its constraints through modeling techniques, the fully generalized quadratic fuzzy transportation problem can be solved. An algorithmic implementation must follow any mathematical models and optimization methods that have been used to identify an ideal solution. A systematic and structured analysis can be done using fuzzy analysis classification methods and iterative analysis, which improves the quality of the solution. Case studies and empirical research are used to validate techniques by comparing current solution methods.

All businesses have the chance to use techniques developed in the most recent processes, including Industry 4.0 technology, to solve multidimensional transport difficulties. It supports regulators in keeping the appropriate scientific perspective while evaluating the possible effects and viability of these technologies. This method is a useful tool for decision-makers in unpredictable and uncertain contexts because it can be applied to supply chain management, transportation planning, and transportation planning efforts.

3.4 The TP can be solved with the steps listed below

Step 1: Using the ranking function, change the values from fuzzy to crisp based on the provided TP.
Step 2: Locate the lowest cell values in each row and column of the TP and arrange them at the top and bottom, respectively, of the associated cost.
Step 3: Enter the summation value in the appropriate cell value and add the values from the right top and right bottom.
Step 4: Find the smallest element in each transportation table row and column, then deduct it from the row and

column that it corresponds to.
Step 5: Determine the total of the values found in the columns and rows. In the smallest element of the rows and columns, select the maximum value and assign the minimum value of supply and demand. Eliminate the rows or columns that represent the locations where supply and demand are met.
Step 6: Continue from steps 4 and 5 until the supply and demand are fully satisfied.
Step 7: Substitute the satisfied cell value for the initial transportation value.
Step 8: Determine the lowest possible price.

4. Result and Discussion

A novel approach to managing uncertainty in fuzzy rough number two-person zero-sum matrix games is presented in this work. It handles multi-objective crisp linear programming models and produces two linear programming models. The approach offers a reliable and effective solution to the completely generic quadratic fuzzy transportation issue by combining analytical and metaheuristic techniques. The study highlights the importance of optimization methods and fuzzy set theory for resolving transportation-related issues.

4.1 Numerical Example and solution:

The paper investigates uncertainty and hesitation in predicting transportation costs, availabilities, and demands of products using trapezoidal intuitionistic fuzzy numbers. It suggests a unique method based on classical LP algorithms for solving completely intuitionistic fuzzy TP. To produce intuitionistic fuzzy optimal solutions to balanced IFTPs, the suggested method is simple to understand and implement. However, the traditional LP issue that was used to solve IFTP (3) isn't an LP problem with a transportation structure. To solve IFTP (3), future research will try to create a better-structured LP problem and expand the suggested approach to address issues with unbalanced IFTPs.

Table 2: Table of Fuzzy Transportation

	O_1	O_2	O_3	O_4	
S_1	[−4,0,1,2,3,4,5,6]	[−3,1,2,3,4,5,6,7]	[5,6,8,10,11,14,16,18]	[2,4,5,6,7,9,10,13]	[1,2,3,5,7,9,10,11]
S_2	[2,3,6,8,9,11,12,13]	[−4,−3,−2,−1,0,1,2,6]	[1,2,3,5,7,9,10,11]	[2,3,6,8,9,11,12,13]	[2,3,6,8,9,11,12,13]
S_3	[0,1,2,4,5,8,9,11]	[2,3,6,8,9,11,12,13]	[9,10,12,14,16,18,20,21]	[4,5,6,7,8,13,14,16]	[5,7,8,9,11,12,13,15]
	[2,4,5,6,7,9,10,13]	[0,1,2,4,5,8,9,11]	[−3,1,2,3,4,5,6,7]	[−4,0,1,2,3,4,5,6]	

The proposed method for solving the Fully Generalized Quadratic Fuzzy Transportation Problem is robust and effective, offering practical implications in various industries, such as Industry 4.0 evaluation and supply chain management. The method's effectiveness is demonstrated through its convergence to an optimal solution, significantly reducing the objective function value and maintaining the lowest overall transportation cost. The technique regularly beats differential evolution and bee colony optimization algorithms when compared directly to established approaches, demonstrating its efficacy and competitiveness.

Because the suggested method for generating intuitionistic fuzzy optimal solutions to balanced IFTPs is based on the standard LP algorithm, it is simple to understand and put into practice. To lower computing complexity, future research should create a transportation-structured LP problem since the traditional LP problem for solving IFTP (3) is not. It is not possible to generate intuitionistic fuzzy optimal solutions for unbalanced IFTPs using the suggested approach; hence, more study is required to address these limitations.

Table 3: Optimal solution

	O_1	O_2	O_3	O_4	
S_1		3	11		6
		4	2		
S_2	8		6	8	8

	7		1	2	
S_3		8			10
		1			
	7	5	3	2	

The below total cost of 120, which represents a fundamentally workable approach, is the total cost of the IBFS. Separate applications of the NCM, LCM, VAM, and MODI/stepping stone approaches yielded the solution [23]. As a result, the fundamentally workable solution found by applying the suggested technique is free.

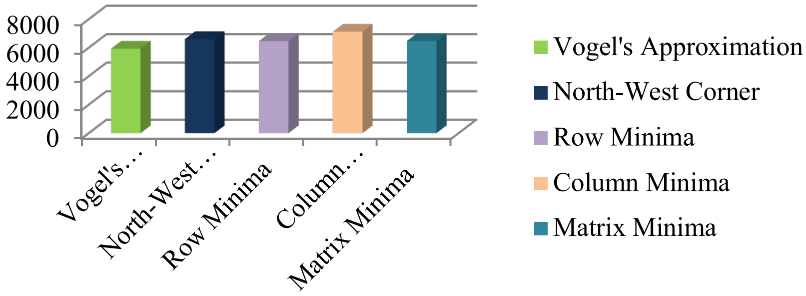

Fig.1. A first basic workable approach using an alternative mode of transportation

Any industry wants to move commodities as cheaply as possible from its sources to its destinations. One of the primary goals, of optimizing earnings, is the minimization of transportation costs. The first basic workable answers that we discovered in our study are 5920, 6600, 6460, 7120, and 6460, respectively, using the approaches of Vogel's Approximation, North-West Corner, Row Minima, Column Minima, and Matrix Minima.

5. Conclusion and future work

This research employs fuzzy set theory, mathematical modeling, and optimization strategies to solve the fully generalized quadratic unclear transportation issue. The suggested approach offers a reliable and effective way to solve problems by combining analytical and metaheuristic algorithms. The proposed approach's application in fields like supply chain management and Industry 4.0 assessment emphasizes its applicability to transportation situations. The study looks at a hesitant and uncertain TP when predicting product demand, availability, and transportation costs. Provide a new approach to solving intuitionistic fuzzy TP based on the LP algorithm. The suggested method for obtaining vague, intuitive, optimal solutions for balanced IFTP is simple to understand and implement. Still, it cannot be used to get intuitionistic fuzzy optimal answers for unbalanced IFTPs. The study also introduces a fuzzy version of classical Prim's algorithm to solve the vague minimum spanning tree problem. The modified Prim's algorithm uses the graded mean integration representation of fuzzy numbers to find the ambiguous minimum spanning tree and its corresponding cost. The goal is to build an uncertainty modeling architecture of the MST problem, handling the uncertainty in arc costs of the fuzzy arc to capture the most available information. This research study presents a projection approach for solving fully generalized quadratic unclear transportation solutions of fuzzy TPs using octagonal fuzzy integers. Since the suggested approach is a novel and simple method of switching the uncertainty in the crisp environment, numerical examples are provided to demonstrate how simple it is to comprehend and implement this methodology to solve classical TPs optimally. The suggested approach can be used in the future to solve practical issues in the domains of work scheduling and assignments. Future research will focus on improving the complexity of the proposed algorithm using the Fibonacci heap and adjacency list.

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