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Hybrid Fuzzy-Genetic Algorithm for Solving Multi-Objective Transportation Problems under Uncertainty

[1]Jyoti Jain and [2]Dr. Rishikant Agnihotri

[1]Research Scholar, Department of Mathematics, Kalinga University, Raipur, Chhattisgarh, India
[2]Professor, Department of Mathematics, Kalinga University, Raipur, Chhattisgarh, India

Corresponding Author: Jyoti Jain

Abstract

Transportation problems are fundamental in operations research and logistics, often involving conflicting objectives such as cost minimization, time reduction, and environmental impact. Traditional optimization techniques fall short in handling multiple objectives under uncertain and imprecise data. This study proposes a novel hybrid methodology that integrates Fuzzy Programming (FP) with Genetic Algorithms (GA) to solve Multi-Objective Transportation Problems (MOTPs) under uncertainty. The fuzzy model handles vagueness in the data while the genetic algorithm optimizes conflicting objectives. A set of real-world case studies demonstrates the model's effectiveness in producing robust, adaptive, and optimal solutions. This research significantly advances the decision-making process in transportation systems under uncertainty and sets the foundation for future intelligent logistics optimization frameworks.

Keywords: Fuzzy Programming, Genetic Algorithm, Multi-Objective Transportation Problem, Uncertainty, Optimization, Hybrid Algorithm, Decision Making, Logistics

1. Introduction

Transportation systems are the backbone of global economic activities, affecting costs, service levels, and environmental sustainability. The classical transportation problem aims to determine the optimal distribution of a product from several suppliers to several consumers, minimizing the total transportation cost. However, in real-world applications, transportation decisions often involve multiple conflicting objectives and are made under uncertain or imprecise information. These challenges necessitate the development of intelligent optimization frameworks.

Multi-objective optimization problems (MOOPs) consider multiple, often conflicting objectives, such as minimizing cost and time while maximizing reliability or minimizing carbon emissions. Traditional linear programming fails to adequately address such problems under uncertainty. Fuzzy set theory offers a powerful mathematical framework to model uncertainty and imprecision in data. Genetic Algorithms (GAs), inspired by the theory of evolution, are highly effective in exploring large, complex solution spaces in multi-objective optimization.

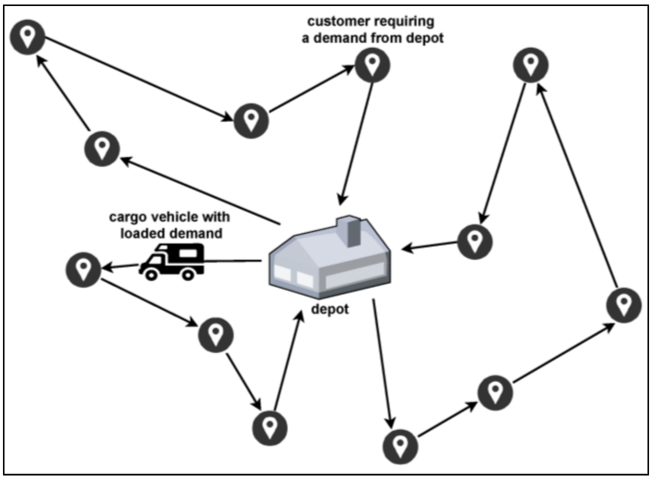

Fig 1: Optimising Transportation System.

This paper integrates fuzzy programming and genetic algorithms into a hybrid methodology to solve MOTPs. By doing so, we aim to enhance the adaptability, robustness, and efficiency of transportation decision-making systems under uncertainty.

2. Aims and Objectives

The primary aim of this research is to design, develop, and validate a hybrid fuzzy-genetic algorithmic model to solve multi-objective transportation problems under uncertainty. The specific objectives are:

- To formulate a multi-objective transportation problem incorporating fuzzy logic for uncertainty handling.
- To design a genetic algorithm framework that effectively explores the solution space of the fuzzy model.
- To integrate the fuzzy model with the GA for hybrid optimization.
- To validate the proposed hybrid algorithm with real-world case studies.
- To compare the performance of the hybrid algorithm with conventional and fuzzy-only approaches.

3. Review of Literature

The review of literature includes a comprehensive examination of existing research in fuzzy optimization, genetic algorithms, and transportation problems under uncertainty.

J. Merline and W. Ritha in the paper titled "Multi-objective Two stage Fuzzy Transportation Problem," Vinotha defined fuzzy membership of the objective function and used fuzzy geometric programming to find the best solution to a multi-objective two stage fuzzy transportation problem where demands and supplies are trapezoidal fuzzy numbers.

In "Fuzzy programming technique to solve bi-objective transportation problem," Bodkhe S.G., Bajaj V.H., and Dhaigude R.M. employed the fuzzy programming technique with hyperbolic membership function to solve the bi-objective transportation problem where the objectives are regarded as fuzzy. V.J. Sudhakar and V Navaneetha Kumar found a workable solution to the multi-objective two stage fuzzy transportation problem. Fuzzy membership of the objective function is defined in the paper Solving Multi-objective Two Stage Fuzzy Transportation Problem by Zero Suffix Method, and supplies and demands are represented as trapezoidal fuzzy numbers for this approach.

In the paper An Exact Solution Approach for Multi-Objective Location-Transportation Problem for Disaster Response, Rachida Abounacer, Monia Rekik, and Jacques Renaud proposed an adaptive epsilon-constraint method and demonstrated that it produces the set of exact pare to front of a complex three-objective location-transportation problem. In the publication Solving Multi-Objective Transportation Problem by Spanning Tree-Based Genetic Algorithm, Mistuo GEN and Yinzhen LI proposed a novel method for resolving a multi-objective transportation problem that involves a spanning tree-based genetic algorithm.

Yousria Abo-Elnaga, Bothina El-Sbky, and Hanadi Zahed transformed the MOT problem into an unconstrained optimization problem using a weighting approach, an active set strategy, and a multiplier method. They then solved the problem using a trust-region algorithm in their paper, Trust Region Algorithm for Multi-Objective Transportation, Assignment, and Transshipment Problems.

In their paper, Fuzzy Goal Programming Technique to solve Multiobjective Transportation Problem with some Non-linear Membership functions, M. Zangiabadi and H. R. Maleki employed a unique kind of nonlinear (hyperbolic and exponential) membership functions to solve the multi-objective transportation problem.

Das et al. (1999) [1] concentrated on the process of solving the multi-objective transportation problem in which the decision maker expresses the source and destination parameters as interval values and the cost coefficients of the objective functions. To minimize as the interval objective function, they converted the problem into a traditional multi-objective transportation problem. The decision maker's preference between interval profits is represented by the order relations they defined. They changed the interval source and destination parameters in the constraints to deterministic ones. Finally, they used fuzzy programming to solve an equivalent transformed problem.

A fuzzy compromise programming method for the multi-objective transportation problem was introduced by Li et al. (2000) [2]. The proposed technique is characterized by the synthetic consideration of many objectives, with a global evaluation for all objectives and a marginal evaluation for individual objectives. When determining the weights of objectives, the decision-maker's preferences are taken into consideration. After every aim has been evaluated globally, a compromise programming model is developed. To find a non-dominated compromise solution where the synthetic membership degrees of the global evaluation for all objectives are at their maximum, the fuzzy compromise programming model is solved using a standard optimization technique.

To find the best compromise solution for a multi-objective transportation problem, Wahed et al. (2001) [3] proposed a fuzzy programming technique. The effectiveness of the approach was evaluated by calculating the degree to which the compromise solution resembled the ideal solution using a family of distance functions.

Sakawa et al. (2001) [4] addressed real-world issues with labor assignment and production at a subcontract company and a manufacturer of housing materials. He developed two types of two-level programming problems: one that maximizes the profits of the subcontract company and the manufacturer of the house materials, and another that maximizes the profits of both. He found a good solution to the two-level linear and linear fractional programming problems by using interactive fuzzy programming.

The stability and effective resolution of a multi-objective transportation problem with fuzzy coefficients, fuzzy supply quantities, and/or fuzzy demand quantities were examined by Ammar et al. (2005) [5]. An interactive fuzzy goal programming method was presented by Wahed et al. (2006) [6] to identify the best compromise solution for the multi-objective transportation problem. By using the minimal operator, the suggested method considers the imprecise character of the input data and assumes that each objective function has a fuzzy target. To find an effective solution that is near the best lower bound of each goal function, the strategy focuses on reducing the worst upper bound. Through the update of both the ambition levels and the membership values, the solution mechanism regulates the direction of the search.

4. Research Methodologies

Surveys and experiments are typically carried out for human perception problems to gather information for a particular fuzzy application. Although the general population is typically used for these surveys and trials, a group of specialists may be used in their place. The selection of participant groups is a crucial issue in the fuzzy application of the study of transportation problem user perception. Users' perceptions of a transportation system are not necessarily the same as those of professionals. Furthermore, the opinions of real users of a transportation system-rather than those of specialists who do not really utilize the system-are the ones that researchers would like to examine. In these conditions, the opinions of professionals and the public were compared to see if they were statistically the same or different.

Instead of using numerical approaches, the studies that assess how users perceive transportation problems rely on language methodologies. Surveys or focus groups, video-based studies, and in-vehicle field approaches are the three data collection techniques that have been used to examine user perceptions of transportation problems. But after the data is gathered, a lot of academics apply basic computations to minimize user inputs from linguistic scales or ranks.

Using those traditional techniques to analyze user perception data has certain drawbacks. The creation of a new technique that offers a more suitable study of transportation problem user perception is required to get around these restrictions. The limitations of their approach to evaluating service quality were pointed out by the Tamil Nadu State Transport Authority on Highway Capacity and Quality of Service. They claimed that it is crucial to have a suitable technique for analyzing linguistic data that reflects human perception.

Although fuzzy sets have been used in a variety of contexts, there was no universal approach to applying these techniques to user perceptions of transportation problems. Furthermore, many studies using fuzzy sets did not address how to determine the fuzzy membership function. The most crucial component of the fuzzy approach is this membership function, which enables the fuzzy approach to assess ambiguous and unclear issues. Membership functions were either determined intuitively in that research or were taken from other similar studies without regard to the issue. Data collection and creation were another weakness of the analyzed studies. To facilitate the usage of fuzzy sets in transportation engineering, it was necessary to look at these problems. Transportation-related user perception studies were conducted using the overall approach created by the methods. The application revealed issues and limitations with the developed fuzzy techniques and their specifics. The fuzzy ways to analyzing user perception of transportation problems are further improved with the help of these discoveries.

5. Results and Interpretation

One of the dynamic route guidance tools that is being utilized more in the transportation industry to provide information to enhance and make the trip safer and more efficient is the variable message sign. The most crucial factor that needs to be mentioned is reducing the amount of time that drivers spend traveling. In situations where precise mathematical modeling is difficult or unattainable, but a skilled human operator can manage the process, fuzzy control has shown promise. By using fuzzy aggregate to measure driver satisfaction, it is possible to accurately depict the complexity and diversity of human perception. To assess each driver's happiness with delay and travel duration, a fuzzy weighted average was calculated using two sets of fuzzy membership functions. The overall satisfaction of the driver group was then estimated by adding all the individual satisfactions. To illustrate the value of the created fuzzy technique, those total satisfactions were contrasted with traffic operational effects and a traditional weighted average.

Numerous traffic management strategies, tactics, and policies have been developed and put into practice thanks to recent technological advancements and ITS. Road transport has become safer, more efficient, and more convenient for both people and cargo thanks to the combination of ITS, computing, and communications technology. Roads now have electronic tolling and VMS, passenger cars have navigation and emergency alert systems, and public transportation vehicles have location and communication systems, all of which demonstrate the development of ITS. Cities' transportation infrastructure has also improved thanks to systems that automatically monitor, track, and assist in better road traffic management. This broad range of domains and uses attests to the fact that ITS are now widely accepted by both the public and the transportation industry. Due to their inability to accurately capture the complexity and diversity of human perception, current approaches for assessing the quality of service offered by a variable message sign (VMS) may not produce findings that accurately reflect drivers' pleasure. A novel approach using fuzzy set theory was created to address those issues. This approach was used to reanalyse the findings of an earlier survey on the quality of VMS services. Two membership functions were created specifically for this application. Five linguistic assertions are used in these two membership functions to indicate the relative relevance and level of satisfaction of six performance criteria.

The fuzzy weighted average notion was used to assess the quality of VMS service as perceived by a single driver. An arithmetic fuzzy mean was used to aggregate the 140 driver quality metrics that were calculated in the state of Tamil Nadu and convert them into a single percentage value. Considering human perception variance and the relative relevance of the six criteria, the defuzzified final number shows how satisfied a set of participating drivers are with the VMS service. The quality of VMS services as subjectively perceived by people and influenced by a variety of external factors can be assessed using the suggested method while considering the complex and subjective nature of human thought. The intelligent transportation subfield known as Advanced Traveler Information Systems (ATIS) involves a lot of interactions between the systems and people, whether they are passengers or drivers. The Variable Message Sign (VMS) is a crucial component of an ATIS that transmits information to travelers. There are two commonly used techniques for assessing the service quality using VMS. One method is to investigate the operational consequences of traffic in order to assess the quality of the service in an indirect manner. How much, for instance, does the average vehicle speed rise or average delay decrease when ATIS is installed along the road? While examining these effects is rather simple, assessing drivers' perceptions of the devices' service quality and their level of satisfaction with the service they receive using these efficacy metrics is challenging.

They were able to examine how drivers perceive the quality of services in relation to various attributes of each service type by using the five perception scales. For instance, VMS employed criteria like readability (for reading) and visibility (for detection). After calculating the percentage of each perception scale, they came to the following conclusion: The drivers believed that the information displayed by the VMS was of high quality and that it was generally straightforward to read and comprehend. They merely added up the proportion of "agree" and "strongly agree" answers for each criterion to arrive at those conclusions. This makes it impossible to adequately explain the perceptional difference between the "agree" and "strongly agree" responses. Additionally, the straightforward summarization of the drivers' answers to different questions may overlook the variations in the significance of each criterion as judged by the drivers and eliminate their distinct individual traits and preferences for assessing the drivers' qualitative assessment of the system. The inability to quantify the total service quality as viewed by all drivers, considering the drivers' preferences and the relative relevance of the various categories, is another weakness of this study. Fuzzy sets were used to re-analyze the VMS service quality survey findings to address those issues. Five fuzzy application phases were carried out for the re-analysis.

6. Discussion and Conclusion

The fuzzy technique was used to assess the VMS service's quality. It is challenging to quantify since human perceptions of service quality are influenced by several factors and are best expressed qualitatively rather than quantitatively. One important metric for assessing how well transportation infrastructure is doing is the quality of service. Because human thought is complex and subjective, and because human perception cannot be captured by binary or numerical data, there are limitations to the assessment of the service quality of transportation services. The suggested approach makes it possible to evaluate service quality numerically. Two fuzzy membership functions were identified via a survey to implement this approach. The interval estimate method was used to create the initial membership function, which reflects five linguistic statement scales. Saaty's eigenvector approach was used to determine the second fuzzy membership functions, which indicate the significance of the weight of six criteria for assessing the quality of VMS services.

The fuzzy weight average was used to assess each driver's perception of the quality of the VMS service. The defuzzified final result represents the drivers' perceived level of satisfaction with the VMS service. This figure accounts for human perception variance and the relative relevance of the six criteria. Fuzzy sets can be used to assess how users perceive the quality of transportation services, which is one of its benefits.

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