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A New Approach for Evaluation of Fuzzy Travelling Salesman Problem using Pentagonal Fuzzy Number

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Abstract

The Travelling Salesman Problem (TSP) is a specific kind of task where a salesman commences his journey from a single city, stops in each of the other cities just once, and then returns to the beginning location. The goal of the problem is to determine the salesman's shortest path from a specific city while minimizing the overall cost. Concepts of fuzzy sets are now widely employed to simulate real-world situations with intrinsic uncertainty and imprecision, such as assignment problems and TSP. It is frequently thought that transit time between nodes in conventional TSP solutions depends only on distance. Journey times are actually greatly impacted by variables like traffic and road conditions. To address these limitations, we propose a novel approach to solving the Travelling Salesman Problem (TSP) using pentagonal fuzzy numbers. We demonstrated our proposed algorithm with a numerical example and provide a comparative analysis with an existing algorithm.

Keywords: Fuzzy Numbers; Fuzzy Ranking Method; Pentagonal Fuzzy Number; Travelling Salesman Problem.

1 | Introduction

Problems involving travelling salespeople can be solved using a variety of techniques, including branch and bound methods, simulated annealing, Markov chains, cutting plan algorithms, and linear programming. A classic method for resolving different kinds of TSPs is the Hungarian procedure. There may be situations in which a specific amount of time or money cannot be obtained. RE Bellman, LA Zadeh, 1970, [1] address imprecision and ambiguity by introducing fuzzy set notions. Subsequently, considerable advancements have been made in developing diverse methodologies and utilizing them for various kinds of decision-making problems.

Both the Shortest Path Problem (SPP) and the Travelling Salesman Problem (TSP) are basic graph theory problems that deal with determining the best routes in a network. However, the goals of the two problems are significantly different. For example, the Shortest Path Problem seeks to determine the shortest path between two particular nodes (a source and a destination) in a graph. It does not require visiting all other nodes. In contrast, the Travelling Salesman Problem determines the shortest path that makes exactly one stop at each node in a network before returning to the beginning node. Prashant et al. [19-20, 22-24] proposed different algorithms to solve shortest path problems under a fuzzy environment and obtain an optimal solution.



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It becomes a fuzzy TSP if the cost, time, or distance is not a precise value. Coefficient was used as an LR parameter in the Fuzzy TSP solution by 2012 Amit Kumar et al. [2]. Convert the provided fuzzy parameters into a Haar tuple first and then use element-wise addition to choose the necessary nodes (cities) to meet the route criteria. Introducing "A procedure for ordering fuzzy subsets of the unit interval," R.R. Yager did so in 1981[3]. Since fuzzy TSP is an NP-hard problem, numerous methods are still being developed to solve it.

The Fuzzy numbers are arranged in this study using the Haar wavelet-based method. The benefit of employing this ranking technique is that it introduces a method for resolving the traveling salesman problem in a clear setting and transforms a fuzzy value into a corresponding crisp value. Because it is so simple to acquire the fuzzification from the defuzzified value through up-sampling, the Haar ranking approach [4] is unique.

In 1970, Zadeh and Bellman talked about making decisions in a fuzzy setting. Wen and Lin [5] used a labelling method to address an assignment issue involving fuzzy interval cost. They demonstrated how assignment problems are typically reduced to either bottleneck assignment problems or linear fractional programming problems. Wang [6] solved the fuzzy assignment problem using graph theory. An interactive fuzzy programming technique was introduced by Sakwa et al. [7] to address the two-level assignment problem. Yager's ranking algorithm was employed by Mukherjee and Kajla [8] to solve the assignment fuzzy problem. The fuzzy assignment problem is converted into a crisp assignment problem, which is then resolved using the simplex approach. Fuzzy assignment was resolved by R. Nagarajan and A. Solairaju [9] using the same process, which is the robust ranking approach of Yager. Various versions of fuzzy number ranking have been introduced in the literature [3, 10-15, 21].

In Pandey P. and Singhal A., [12] used a dynamic programming approach to solve traveling salesman problems. M. S. Cheema, H. Saeed, and A. Rehmat. Fuzzy multi-objective linear programming was utilized in 2007 [13].

An Analysis of the Fuzzy Traveling Salesman Issue. The traveling salesman problem can be resolved by applying the fuzzy number approach. Fereidouni Sepideh. A study on the traveling salesman problem was conducted in 2011[14] using multi-objective fuzzy linear programming.

In this study, we examine a fuzzy cost TSP that is more realistic. The approach for solving the traveling salesman problem with fuzzy cost is presented in this paper. The fuzzy expenses are regarded as fuzzy pentagonal numbers. In practical decision-making situations, however, fuzziness is common, and the decision-making unit is constantly in close contact with the environment.

The remaining portion of the document is structured as follows: The preliminary fuzzy set requirements for the article are covered in Section 2. Fuzzy arithmetic is presented in subsections 2.4–2.6. In Section 3, FAP is developed. The expanded Hungarian approach that has been suggested is presented to FAP in Section 4. The fuzzy assignment problem is solved in Section 5 to show how effective the suggested approach concerning existing methods. Lastly, the closing remarks are presented in Section 7.

2 | Preliminaries

Definition 2.1: Fuzzy set: A fuzzy set $\tilde{F}$ in a universe discourse, Y is defined by $\tilde{F} = \{ \langle y, \mu_{\tilde{F}} \rangle \mid y \in Y \}$ where $\mu_{\tilde{F}}(y): y \in Y \rightarrow [0, 1]$ is called the membership function of $\tilde{F}$ and $\mu_{\tilde{F}}(y)$ is the degree of membership to which $y \in \tilde{F}$.

A fuzzy set of tall people has membership values that range from 1 for full membership to 0 for non-membership, so giants may belong to this to a degree of one, while dwarfs belong to this to a degree of zero. In contrast, a crisp set of tall people has membership values that can be either true or false.

Definition 2.2 fuzzy number: An uncertain number, the membership function of $\mu_{\tilde{F}}(y)$, $\tilde{F}$ A subset of the real line R , satisfies the following characteristics:

- (i) The domain of $\mu_{\tilde{F}}(y)$ is piecewise continuous.

- (ii) A is normal, meaning that $\mu_{\tilde{F}}(y) = 1$ for all x in F .
- (iii) $\mu_{\tilde{F}}(\lambda y_1 + (1-\lambda)y_2) \geq \min(\mu_{\tilde{F}}(y_1), \mu_{\tilde{F}}(y_2))$. y_1, y_2 in Y indicates that $\tilde{F}$ is convex.

Definition 2.3 A pentagonal fuzzy number is denoted as $\tilde{F} = (f_1, f_2, f_3, f_4, f_5)$ with membership function

$$\text{define as } \mu_{\tilde{F}}(y) = \begin{cases} \frac{y-f_1}{f_2-f_1} & , \text{ if } f_1 \leq y \leq f_2 \\ 1 & , \text{ if } y = f_3 \\ \frac{f_4-y}{f_4-f_3} & , \text{ if } f_3 \leq y \leq f_4 \\ \frac{f_5-x}{f_5-f_4} & , \text{ if } f_4 \leq y \leq f_5 \\ 0 & , \text{ otherwise} \end{cases}$$

Definition 2.4: The arithmetic operation of pentagonal fuzzy numbers

Consider two pentagonal fuzzy numbers $\tilde{F} = (f_1, f_2, f_3, f_4, f_5)$ and $\tilde{G} = (g_1, g_2, g_3, g_4, g_5)$ then addition and subtraction of two numbers are given by

$$\tilde{F} + \tilde{G} = (f_1 + g_1, f_2 + g_2, f_3 + g_3, f_4 + g_4, f_5 + g_5)$$

$$\tilde{F} - \tilde{G} = (f_1 - g_1, f_2 - g_2, f_3 - g_3, f_4 - g_4, f_5 - g_5)$$

Multiplication of two pentagonal fuzzy numbers is given by

$$\tilde{F} \tilde{G} = (f_1 g_1, f_2 g_2, f_3 g_3, f_4 g_4, f_5 g_5)$$

The division of two pentagonal fuzzy numbers is given by

$$\tilde{F} / \tilde{G} = (f_1 / g_1, f_2 / g_2, f_3 / g_3, f_4 / g_4, f_5 / g_5)$$

Note that only when $\tilde{G}$ contains nonzero components is the pentagonal fuzzy number $\tilde{F}$ divisible by $\tilde{G}$

Definition 2.5: If any fuzzy number is $\tilde{F} = (f_1, f_2, f_3, f_4, f_5)$ then the pentagonal ranking can be obtained by

$$R(\tilde{F}) = \frac{1}{2} \left(\frac{f_3 + f_4 + f_5}{3} + \frac{f_1 + f_2 + f_3}{3} \right)$$

Where $\frac{f_3 + f_4 + f_5}{3}$ is the right spread and $\frac{f_1 + f_2 + f_3}{3}$ is the right spread, and the final ranking is their average.

3 | Fuzzy Travelling Salesman Problem

Assume that someone must go to m cities. He begins in one city, travels to each one once, and then returns to the beginning place.

The q_{ij} to formulate the selected fuzzy traveling salesman problem is as

$$\text{Minimize } T = \sum_{i=1}^m \sum_{j=1}^m w_{ij} q_{ij}$$

Subject to:

$$\sum_{j=1}^m w_{ij} = 1, i = 1, 2, 3, \dots, m$$

$$\sum_{j=1}^m w_{ij} = 1, i = 1, 2, 3, \dots, m$$

4 | Proposed Algorithm

This section used a novel search strategy to solve the fuzzy (TSP) Traveling Salesman Problem and determine the exact total optimal path.

Step 1: If the cost is expressed as a fuzzy number, turn the problem into a network.

Step 2: Convert the fuzzy parameters into crisp values when provided. The whole cost becomes a clear figure.

Step 3: Find the cost totals by row and column. Next, choose the highest Path Finding Indicator. Choose the PFIs with the lowest cost if there is a tie. Choose the minimum price cell and PFI at random if there is another tie. Next, eliminate the associated row and column.

Step 4: Proceed to the final step, step 3, until you find the greatest couple who meet the requirements of the route and finish the tour.

Step 5: Review the routes (cells) you have chosen, then attempt to make a full tour. Choose the next lowest cost (next lowest order) along the chosen PFI if you want to build a sub-tour and then connect the city with the next (second) least cost cell. Creating multiple sub-tours and breaking them up similarly will result in a full tour.

Step 6: Finish the tour based on the chosen cell.

5 | Numerical Example

Consider the fuzzy travelling salesman problem in which a salesman starts traveling from a city, repeatedly visits the nearest unvisited city, and returns to the starting city (see Figure 1).

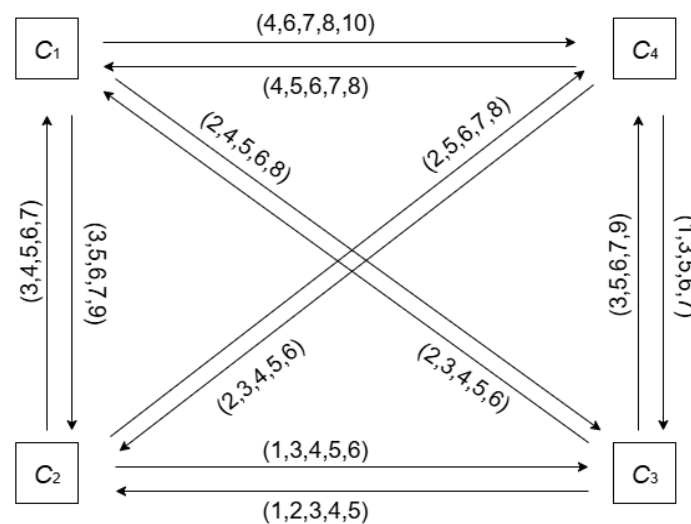


Figure 1. Asymmetric TSP with four different cities.

Table 1. Cost matrix.

City	C_1	C_2	C_3	C_4
C_1	∞	(3,5,6,7,9)	(2,4,5,6,8)	(4,6,7,8,10)
C_2	(3,4,5,6,7)	∞	(1,3,4,5,6)	(2,5,6,7,8)
C_3	(2,3,4,5,6)	(1,2,3,4,5)	∞	(3,5,6,7,9)
C_4	(4,5,6,7,8)	(2,3,4,5,6)	(1,3,5,6,7)	∞

Convert the pentagonal fuzzy numbers (PFN) into crisp values (see Tables 1-2).

Table 2. Crisp value of the cost matrix.

City	C_1	C_2	C_3	C_4
C_1	∞	6	5	6.833
C_2	5	∞	3.833	5.66
C_3	4	3	∞	6
C_4	6	4	4.5	∞

Calculate the total along the column-wise and row-wise items, as shown in Table 3.

Table 3. Calculate the total along the column-wise and row-wise items, accordingly.

City	C_1	C_2	C_3	C_4	Total
C_1	∞	6	5	6.833	17.83
C_2	5	∞	3.833	5.66	14.493
C_3	4	3	∞	6	13
C_4	6	4	5.5	∞	15.5
Total	15	13	14.33	18.49	

Select the 4th column and 2nd row. Now delete the 4th column and the 2nd row. ($C_4 \rightarrow C_2$) (see Table 4).

Table 4. Reduced cost matrix.

City	C_1	C_2	C_3	C_4	Total
C_1	∞	6	5		11
C_2					
C_3	4	3	∞		7
C_4	6	4	5.5		15.5
Total	10	13	10.5		

Select the 2nd column and the 3rd row. Then delete the 2nd column and the 3rd row. ($C_2 \rightarrow C_3$) (see Table 5).

Table 5. Reduced cost matrix.

City	C_1	C_2	C_3	C_4	Total
C_1	∞		5		5
C_2					
C_3					
C_4	6		5.5		11.5
Total	6		10.5		

Select the 3rd column and 1st row. ($C_3 \rightarrow C_1$) Select 1st column and 4th row ($C_1 \rightarrow C_4$).

The paths that have been determined are $C_4 \rightarrow C_2$, $C_2 \rightarrow C_3$, $C_3 \rightarrow C_1$, and $C_1 \rightarrow C_4$.

Based on the chosen routes, the tour was built as follows: $C_4 \rightarrow C_2 \rightarrow C_3 \rightarrow C_1 \rightarrow C_4$.

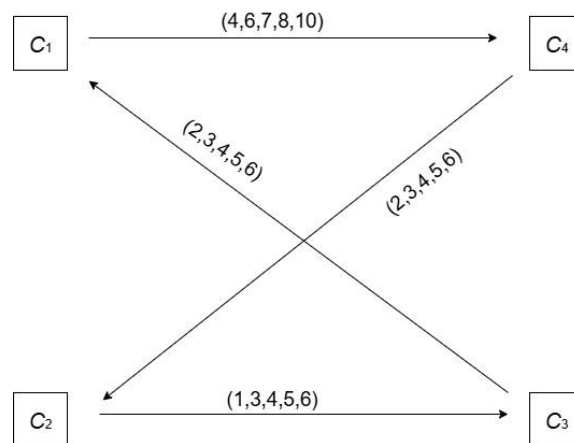


Figure 2. Optimal path of FTSP.

Here is the fuzzy optimal cost: $4+3.833+4+6.833 = 18.66$

6 | Solution of TSP using Existing Traditional Algorithm (Branch and Bound Method)

We used the same fuzzy distances in Table 6 as in Table 2.

Table 6. Crisp value of the cost matrix as in Table 2.

City	C_1	C_2	C_3	C_4
C_1	∞	6	5	6.833
C_2	5	∞	3.833	5.66
C_3	4	3	∞	6
C_4	6	4	4.5	∞

The number of rows = 4 and the number of columns = 4 (see Table 7)

Table 7. Replace ∞ as N (no path).

City	C_1	C_2	C_3	C_4
C_1	N	6	5	6.833
C_2	5	N	3.833	5.66
C_3	4	3	N	6
C_4	6	4	4.5	N

We know that the sum of row minimums gives us the lower bound. Determine the lowest possible element for each row and deduct it from that row (see Tables 8-15).

Table 8. Row reduction.

City	C_1	C_2	C_3	C_4	
C_1	N	1	0	1.833	(-5)
C_2	1.167	N	0	1.767	(-3.833)
C_3	1	0	N	3	(-3)
C_4	2	0	0.5	N	(-4)

So, the row minimum will be 15.833. ($5+3.83+3+4=15.833$)

Determine the lowest possible element for each column and deduct it from that column.

Table 9. Column reduction.

City	C_1	C_2	C_3	C_4
C_1	N	1	0	0.066
C_2	0.167	N	0	0
C_3	0	0	N	1.233
C_4	1	0	0.5	N
	(-1)	(-0)	(-0)	(-1.767)

So, the column minimum will be 2.767. ($1+0+0+1.77=2.767$)

We get the lower bound = $15.833+2.767=18.6$

Compute the penalty of all 0's (penalty = lowest element in that row + lowest element in that column).

Table 10. Reduced cost matrix.

City	C_1	C_2	C_3	C_4
C_1	N	1	0(0.066)	0.066
C_2	0.167	N	0(0)	0(0.066)
C_3	0(0.167)	0(0)	N	1.233
C_4	1	0(0.5)	0.5	N

The greatest penalty in this case is 0.5; it takes place at X_{C_4,C_2} , thus we pick X_{C_4,C_2} to start the branch. It has two branches:

1. If $X_{C_4,C_2}=0$, then there's an extra cost of 0.5. Additionally, the lower bound turns into $18.6+0.5=19.1$
2. If $X_{C_4,C_2}=1$, we can take $C_4 \rightarrow C_2$. So we are not able to take $C_2 \rightarrow C_4$, thus configure it to N.

Row C_3 and column C_1 are now removed, so the resulting matrix is

Table 11. Reduced cost matrix.

City	C_1	C_2	C_3
C_1	N	0	0.066
C_2	0.167	0	N
C_3	0	N	1.233

Determine the lowest possible element for each column and deduct it from that column.

Table 12. Reduced cost matrix.

City	C_1	C_2	C_3
C_1	N	0	0
C_2	0.167	0	N
C_3	0	N	1.167
	(-0)	(-0)	(-0.066)

So, the column minimum will be 0.066. ($0+0+0.07=0.066$). We get the lower bound = $18.6+0+0.066=18.666$. Compute the penalty of all 0's (penalty = lowest element in that row + lowest element in that column).

Table 13. Reduced cost matrix.

City	C_1	C_2	C_3
C_1	N	0(0)	0(1.167)
C_2	0.167	0(0.167)	N
C_3	0(1.334)	N	1.167

Here, the greatest penalty in this case is 1.334; it takes place at X_{C_3,C_1} , so we choose X_{C_3,C_1} To start the branch. It has two branches.

1. If $X_{C_3,C_1}=0$, then we have an additional cost of 1.334, and the lower bound becomes $18.666+1.334=20$
2. If $X_{C_3,C_1}=1$, we can take $C_3 \rightarrow C_1$. So, we are not able to take $C_1 \rightarrow C_3$, thus configure it to N. Row C_2 and column Depo are now moved, consequently reduced matrix becomes.

Table 14. Reduced cost matrix.

City	C_2	C_3
Depo	N	0
C_1	0	N

In this case, 0 appears in each row and column. Thus, the lower bound doesn't change. i.e., $18.666+0=18.666$. Compute the penalty of all 0's (penalty = lowest element in that row + lowest element in that column).

Table 15. Final reduced cost matrix.

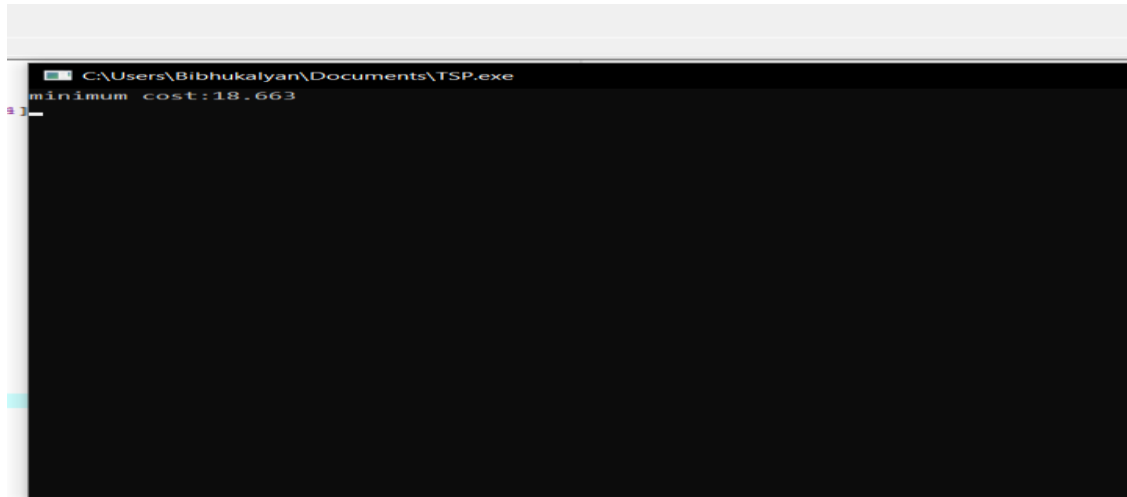
City	C_2	C_3
Depo	N	0(0)
C_1	0(0)	N

We can take $C_1 \rightarrow C_4$ and $C_2 \rightarrow C_3$. So our final path is $C_4 \rightarrow C_2 \rightarrow C_3 \rightarrow C_1 \rightarrow C_4$. And the total distance is $4+3.833+4+6.833=18.666$.

7 | Solution of TSP by Hungarian Algorithm using C++

The minimum cost obtained using our approach matches the minimum cost implemented using C++ programming.

This statement conveys that the results from our approach and the C++ implementation are consistent, which is a good validation of our method (see Figure 3).

**Figure 3.** Optimal value by implementation of the Hungarian algorithm.

Minimum cost =18.66

8 | Comparable Results

Our novel approach for solving the Traveling Salesman Problem yields comparable results to the traditional existing algorithm, suggesting that both methods are effective in finding optimal or near-optimal solutions. The similarity in results highlights the need for more research to understand the strengths and limitations of each approach and to identify the most suitable algorithm for specific TSP instances.

Figure 4 illustrates the convergence of the two algorithms, demonstrating that the novel approach can achieve similar solution quality to the traditional algorithm.

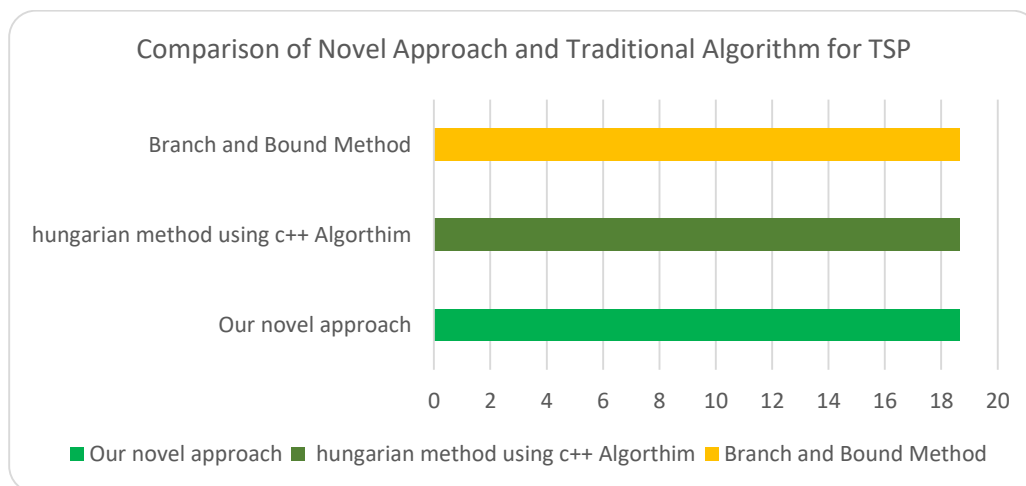


Figure 4. Convergence of the two algorithms.

9 | Conclusion

For solving fuzzy traveling salesman problems with pentagonal fuzzy numbers as the decision criteria, we have put forth a fuzzy alternative technique. A fuzzy optimal solution that is sharper than the fuzzy optimal solution was created by applying a novel pentagonal fuzzy number arithmetic operation to the parametric formulation of the fuzzy numbers (decision parameters). This research paper demonstrates the accuracy and effectiveness of our proposed method, as evidenced by the identical results obtained from our approach and the expected outcome. The consistency between the two solutions validates the reliability and robustness of our method, highlighting its potential for practical applications. Future research can build upon this foundation to explore further refinements and extensions of our approach.

Author Contribution

All authors contributed equally to this work.

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Data Availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data, but are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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