Journal of Soft Computing Exploration

Three stages algorithm for finding optimal solution of balanced triangular fuzzy transportation problems

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Article Info

Article history:

Received Jan 25, 2021
Revised Feb 28, 2021
Accepted March 18, 2021

Keywords:

Fuzzy transportation problem
Segregated method
Balanced triangular fuzzy number
Total difference method
Modified distribution method
Fuzzy optimal solution

ABSTRACT

In the literature, the fuzzy optimal solution of balanced triangular fuzzy transportation problem is negative fuzzy number. This is contrary to the constraints that must be non-negative. Therefore, the three stages algorithm is proposed to overcome this problem. The proposed algorithm consists of segregated method with segregating triangular fuzzy parameters into three crisp parameters. This method avoids the ranking technique. Next, total difference method is used to get the initial basic feasible solution (IBFS) value based on segregating triangular fuzzy parameters. While modified distribution algorithm is used to determine optimal solution based on IBFS value. In order to illustrate the proposed algorithm is given the numerical example and based on the result comparison, the proposed algorithm equality to the two existing algorithms and better than the one existing algorithm. The proposed algorithm can solve the fuzzy decision-making problems and can also be extended to an unbalanced fuzzy transportation problem.

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1. INTRODUCTION

In real life, parameters of transportation problems (supply, demand, and transportation cost) sometimes are uncertain in values. The transportation cost, depends on fuel prices, congested routes and weather, while supply is caused by reduced quantities of raw materials, machine breakdowns and production failures. In addition, volatile market situations create uncertainty in demand. However, Zadeh [1] introduced transportation problem with the numbers of supply, demand, and transportation cost are represented by fuzzy number that is called Fuzzy Transportation Problem (FTP). The solving of FTP, many researchers changed the fuzzy parameters to crisp sets and solved by crisp transportation algorithm [2]–[12].

[13] used Yanger's ranking function to change L-R flat fuzzy parameters to crisp numbers and fuzzy classical transportation algorithm i.e. VAM (Vogel's Approximation Method), LCM (Least Cost Method) and NWC (North West Corner) to obtain L-R flat fuzzy optimal solution. [14] proposed the new ranking function-based integral value to rank triangular fuzzy parameters and generalized fuzzy classical algorithm i.e. GVAM, GLCM and GNWC to determine a generalized triangular fuzzy optimal solution. [6] simplified the new ranking function that was proposed by [3] to rank trapezoidal fuzzy parameters and GLCM to obtain generalized trapezoidal fuzzy optimal solution. Chandran and Kandaswamy presented the score ranking method to change

the triangular and trapezoidal fuzzy parameters and the modification of fuzzy LCM to find fuzzy optimal solution. [7] discussed the ranking method based mean of triangular fuzzy numbers and minimum demand-supply method to obtain crisp optimal solution. [9] proposed the classical ranking method and VAM-based harmonic mean method to obtain penalty value of each column and row. [15] introduced a score and accuracy function based on the Pythagorean fuzzy number and applied it on the fuzzy VAM to obtain fuzzy optimal solution. [16] presented the classical ranking function and the generalized minimum supply-demand to obtain triangular fuzzy optimal solution. [11] presented a segregated advancement scheme based minimum demand-supply method and stepping stone to obtain triangular fuzzy optimal solution.

Furthermore, the direct approach of solving FTP such as the Zero point method to obtain fuzzy optimal solution [17]. Robust ranking to rank fuzzy number and Zero suffix method to obtain the fuzzy optimal solution Fuzzy dual matrix to obtain a fuzzy optimal solution [18], [19], Improved and revised Zero point [20]–[22]. The modification of Zero-point [23]. Particle Swarm Optimization algorithm (PSO) with fuzzy constraint and conjugate constraint [24]–[27].

The use of the ranking function in the solving of FTP has a very significant impact on the resulting fuzzy optimal solution. As the results of [13] which produce a negative fuzzy optimal solution, this is contrary to the constraints that must be non-negative in the FTP model. In addition, the ranking process takes a long time to compute so that it will affect the computational performance that is not good. Therefore, in this article, we use the segregated advancement scheme approach based on the total difference method and modified distribution method to produce a fuzzy optimal solution without ranking function.

2. THE MODELING OF BALANCED TRIANGULAR FUZZY TRANSPORTATION PROBLEM

Based on the triangular fuzzy transportation problem with a delivers and b receivers. Given $\tilde{s}_i = s_i^l, s_i^m, s_i^u$ be the triangular fuzzy supply at the i^{th} deliverer, $\tilde{d}_j = d_j^l, d_j^m, d_j^u$ be the triangular fuzzy demand at the j^{th} receiver where $i = 1,2,\dots,a; j = i = 1,2,\dots,b$. Let $\tilde{c}_{ij} = (c_{ij}^l, c_{ij}^m, c_{ij}^u)$ be the per unit triangular fuzzy transportation cost from the i^{th} deliverer to the j^{th} receiver and $\tilde{x}_{ij} = (x_{ij}^l, x_{ij}^m, x_{ij}^u)$ be the number of triangular fuzzy approximation unit to assign from the i^{th} deliverer to the j^{th} receiver. The modeling of balanced triangular FTP can be formulated as follows,

$$\min Z = \sum_{i=1}^{a} \sum_{j=1}^{b} \tilde{c}_{ij}\tilde{x}_{ij} \quad (1)$$

subject to

$$\begin{aligned} &\sum_{j=1}^{b} \tilde{x}_{ij} = \tilde{s}_i && i = 1,2,\dots,a, \\ &\sum_{i=1}^{a} \tilde{x}_{ij} = \tilde{d}_j && j = i = 1,2,\dots,b \\ &\tilde{x}_{ij} \geq 0 && \forall i,j \end{aligned} \quad (2)$$

3. THREE STAGES ALGORITHM FOR FINDING TRIANGULAR FUZZY OPTIMAL SOLUTION

In this section, the three stages algorithm is proposed to find fuzzy optimal solution of a balanced triangular fuzzy transportation problem. The proposed algorithm consists of a segregated scheme to partition triangular fuzzy numbers, Total Difference Method (TDM)1 [12] to find Initial Basic Feasible Solution (IBFS) and Modified Distribution method (MODI) to obtain optimal solution based IBFS.

4. A SEGREGATED SCHEME

The segregated method is based on the possibility of optimized output concept of balanced triangular fuzzy transportation problem when the triangular fuzzy parameters with the corresponding demand and supply be partitioned one by one. This scheme consists of pointwise segregation of each triangular fuzzy parameters such that the first element of each triangular fuzzy parameters will be defined first segregated transportation problem is denoted STP^1. Similarly, the second and third elements of each triangular fuzzy parameters are denoted STP^3 and STP^3 respectively.

Using the segregated method, Eq. (1) and (2) can be transformed into the followings three STPs as follows,

1) STP^1

$$\min Z_1^l = \sum_{i=1}^{a} \sum_{j=1}^{b} c_{ij}^l x_{ij}^l \tag{3}$$

$$\begin{aligned} &\sum_{j=1}^{b} x_{ij}^l = s_i^l && i = 1,2,\dots,a, \\ &\sum_{i=1}^{a} x_{ij}^l = d_j^l && j = i = 1,2,\dots,b \\ &x_{ij}^l \geq 0 && \forall i,j \end{aligned} \tag{4}$$

2) STP^2

$$\min Z_2^m = \sum_{i=1}^{a} \sum_{j=1}^{b} c_{ij}^m x_{ij}^m \tag{5}$$

$$\begin{aligned} &\sum_{j=1}^{b} x_{ij}^m = s_i^m && i = 1,2,\dots,a, \\ &\sum_{i=1}^{a} x_{ij}^m = d_j^m && j = i = 1,2,\dots,b \\ &x_{ij}^m \geq 0 && \forall i,j \end{aligned} \tag{6}$$

3) STP^3

$$\min Z_3^u = \sum_{i=1}^{a} \sum_{j=1}^{b} c_{ij}^u x_{ij}^u \tag{7}$$

$$\begin{aligned} &\sum_{j=1}^{b} x_{ij}^u = s_i^u && i = 1,2,\dots,a, \\ &\sum_{i=1}^{a} x_{ij}^u = d_j^u && j = i = 1,2,\dots,b \\ &x_{ij}^u \geq 0 && \forall i,j \end{aligned} \tag{8}$$

4.1 Total Difference Method 1

For a crisp balanced transportation problem with transportation cost matrix of order (a, b) having supply $s_i^q, i = 1,2,\dots,a$; demand $d_j^q, i = j = 1,2,\dots,b$ and the corresponding transportation cost $c_{ij}^q, q = l,m,u$. In detail, TDM 1 algorithm shown in Algorithm 1 shown in Figure 1.

4.2 Modified Distribution Method

MODI to obtain the optimal solution of balanced triangular fuzzy transportation problem Algorithm 2 shown in Figure 2.

4.3 Three Stages Algorithm

Three stages algorithm to obtain the optimal solution of balanced triangular fuzzy transportation problem shown Algorithm 3 shown in Figure 3.

Algorithm 1: TDM Algorithm

Data: Initialization: Number of rows is a, Number of column is b, s_i^q is i^{th} supply, d_j^q is j^{th} demand, c_{ij}^q is distribution cost from i^{th} supply to j^{th} demand, x_{ij}^q is the number of approximation unit to assign from i^{th} supply to j^{th} demand, $i = 1, 2, \ldots, a; j = 1, 2, \ldots, b; q = l, m, u.$

Result: $\min z_q$

repeat

  {Produce a minimal total distribution cost} ;

  for *i=1 to m+n-1* **do**

    Find the penalty (F_i^q) for each i^{th} row by F_i = $\sum_{j=1}^{n}(c_{i,j}^q - \min(c_{i,j}^q))$;

    Select highest of F_i^q (HF) by HF = $\max(F_i^q)$;

    Select the least $c_{i,j}^q$ of HF;

    Allocate the x_{ij}^q to it;

    There may arise the following three cases;

    if $\min(s_i^q, d_j^q) = s_i^q$ **then**

      $x_{ij}^q = s_i^q$, $d_j^q = d_j^q - s_i^q$, $s_i^q = 0$, cross out of s_i^q

    end

    if $\min(s_i^q, d_j^q) = d_j^q$ **then**

      $x_{ij}^q = d_j^q$, $s_i^q = s_i^q - d_j^q$, $d_j^q = 0$, cross out of d_j^q

    end

    if $s_i^q = d_j^q$ **then**

      $s_i^q = 0$, $d_j^q = 0$, cross out of s_i^q and d_j^q

    end

  end

  Recalculate the penalty without considering the cross out rows and columns

until $\{\sum_{i=1}^{a} s_i^q = \sum_{j=1}^{b} d_j^q\}$;

Figure 1. TDM 1 algorithm

Algorithm 2: Modified-Distribution Method

Step 1: The IBFS obtained of FTP by using Algorithm 1

Step 2: Introduce m_i^q and n_j^q as variable convenient for every i^th and j^th, respectively. In front of i^th write m_i^q in row and at n_j^q the under ofj^th in column. Let $m_i^q = 0$ is maximum number of allocations row;

Step 3: Determine $\lambda_{i,j}^q$ and n_j^q by using $c_{ij}^q = m_i^q + n_j^q$ for base of cell, then determine $\lambda_{i,j}^q = \tilde{c}_{ij}^q - (u_i^q + v_j^q)$ of non-base of cells. Next, two possibilities as follow;

(a) If $\lambda_{i,j}^q \geq 0, \forall i, j$, then the resulted of IBFS is done. In other words, fuzzy optimal solution has been satisfied;

(b) Otherwise, $\exists\lambda_{i,j}^q$, then the resulted of IBFS do not finished yet. In other words, fuzzy optimal solution is not optimal. Therefore, fuzzy optimal solution is chosen a cell of $(i, j)^th$ in which $\lambda_{i,j}^q$ is smallest negative. Next, make a horizontal and vertical closed path that starts from unchosen base of cell of $(i, j)^{th}$. The path can only replace to angle on base of cell $(i, j)^th$ and the path is chosen must pass through base and non-base cell of $(i, j)^{th}$;

Step 4: Give sign $(+)$ and $(-)$ for closed loop started with $(+)$ for chosen non-base cells. After that, determine fuzzy quantity on cells with signs $(+)$ and $(-)$. Consequently, new TP table is obtained.

Step 5: Repeat of steps 2, 3 and 4 for TP table until $\lambda_{i,j}^q \geq 0, \forall i, j$

Step 6: Obtain a new improved solution by allocating units to the unfilled cell according step 5 and calculate the new TP.

Step 7:Determine the value of fuzzy optimal solution or objective function $\min z_q$

Figure 2. MODI algorithm

Algorithm 3: Three stages algorithm

Step 1 Imply the segregated scheme discussed in Section 3.1. to determine the corresponding three $STP_q, q = l, m, n$.

Step 2 Imply the TDM 1 in Algorithm 1 to each STP_q to find IBFS.

Step 3 Imply the MODI method in Algorithm 2 to each of the three STP_q to obtain the optimal solutions.

Step 4 Determine a fuzzy optimal solution of balanced triangular fuzzy transportation problem as a combination of the optimal solutions obtained in Step 3.

Figure 3. Three stages algorithm

5. NUMERICAL ILLUSTRATION

In this section , we illustrate the proposed method by using numerical example is adapted from Ebrahimnejad [28] in which a trading company wants to optimize the transportation cost of products.

Example 1 A leading trading factory wants to obtain the fuzzy number of the commodity that should be distributed from each warehouse to each object such that the total fuzzy transportation cost is at a minimum. The factory has two production houses and three distribution centers. The parameters of transportation are fuzzy numbers that are represented by triangular fuzzy numbers because of disinformation real-life conditions. The summary of fuzzy parameters i.e. supply, demand and transportation cost (dollar) are shown in Table 1 with l as the least amount value, m as the most possible value and u as the greatest amount value.

Table 1. Data of example 1 (in U.S. dollar)

Parameters		Triangular fuzzy numbers		
		Least amount value (l)	Most possible value (m)	Greatest amount value (n)
Transportation cost ($)	c_{11}	15	25	35
	c_{12}	55	65	85
	c_{13}	85	95	105
	c_{21}	65	75	85
	c_{22}	80	90	110
	c_{23}	30	40	50
Supply in unit	s_1	75	95	125
	s_2	45	65	95
Demand in unit	d_1	35	45	65
	d_2	25	35	45
	d_3	60	80	110

Solution: After implementing the segregated scheme discussed in Section 5.1, three crisp transportation problems i.e. STP^1, STP^2, STP^3 are resulted as follows:

1) for STP^1 by using Eq. (3) and (4)

$$\min Z_1^l = 15x_{11}^l + 55x_{12}^l + 85x_{13}^l + 65x_{21}^l + 80x_{22}^l + 30x_{23}^l \quad (9)$$

subject to

$$\begin{aligned} x_{11}^l + x_{12}^l + x_{13}^l &= 75 \\ x_{21}^l + x_{22}^l + x_{23}^l &= 45 \\ x_{11}^l + x_{21}^l &= 35 \\ x_{12}^l + x_{22}^l &= 25 \\ x_{13}^l + x_{23}^l &= 25 \end{aligned} \quad (10)$$

2) for STP^2 by using Eq. (5) and (6)

$$\min Z_2^m = 25x_{11}^m + 65x_{12}^m + 95x_{13}^m + 75x_{21}^m + 90x_{22}^m + 40x_{23}^m \quad (11)$$

subject to

$$\begin{aligned} x_{11}^m + x_{12}^m + x_{13}^m &= 95 \\ x_{21}^m + x_{22}^m + x_{23}^m &= 65 \\ x_{11}^m + x_{21}^m &= 45 \\ x_{12}^m + x_{22}^m &= 35 \\ x_{13}^m + x_{23}^m &= 805 \end{aligned} \tag{12}$$

3) for STP^3 by using Eq. (7) and (8)

$$\min Z_3^u = 35x_{11}^u + 85x_{12}^u + 105x_{13}^u + 85x_{21}^u + 110x_{22}^u + 50x_{23}^u \tag{13}$$

subject to

$$\begin{aligned} x_{11}^u + x_{12}^u + x_{13}^u &= 125 \\ x_{21}^u + x_{22}^u + x_{23}^u &= 95 \\ x_{11}^u + x_{21}^u &= 65 \\ x_{12}^u + x_{22}^u &= 45 \\ x_{13}^u + x_{23}^u &= 110 \end{aligned} \tag{14}$$

After implementing the TDM 1 in Algorithm 5.2, the penalty value resulted

(a) for STP^1 is $F_1 = 110$ and $F_2 = 85$ such that the IBFS obtained $\begin{matrix} x_{11}^l = 35 & x_{12}^l = 25 & x_{13}^l = 15 \\ x_{21}^l = 0 & x_{22}^l = 0 & x_{23}^l = 45 \end{matrix}$

(b) for STP^2 is $F_1 = 110$ and $F_2 = 85$ such that the IBFS obtained $\begin{matrix} x_{11}^m = 45 & x_{12}^m = 35 & x_{13}^m = 15 \\ x_{21}^m = 0 & x_{22}^m = 0 & x_{23}^m = 65 \end{matrix}$

(c) for STP^3 is $F_1 = 120$ and $F_2 = 95$ such that the IBFS obtained $\begin{matrix} x_{11}^u = 65 & x_{12}^u = 45 & x_{13}^u = 15 \\ x_{21}^u = 0 & x_{22}^u = 0 & x_{23}^u = 95 \end{matrix}$

After implementing the MODI method shown in Algorithm 2(`)@ is used to obtain optimal solution based on the IBFS value of all three $STP_q, q = l, m, n$ and resulted in minimal transportation cost for $STP_l = 4535, STP_m = 7425$ and $STP_u = 12425$.

After combining the minimal transportation cost of all three STP_q, so that the fuzzy optimal solution of balanced triangular fuzzy optimal solution is (4525, 7425, 1245) where represents that the minimal transportation cost most likely will be $7,425 but certainly not less than $4,525. Meanwhile, if things are not in favor of decision-maker, it could be as high as $12,425.

6. CONCLUSION

In this article, the three stages algorithm consist of a segregated method, total difference method 1 and modified distribution method is proposed to optimize of balanced triangular fuzzy transportation problem. A segregated method scheme and TDM 1 are used to get IBFS value, meanwhile, the MODI method to obtain optimal solution based IBFS value. The numerical example is given to illustrate the justification of proposed algorithm. The Comparative study of results with the literature journal shows that the fuzzy optimal solution that is resulted by proposed algorithm equivalent to those by [13] and [11] and better than those by [2]. All the acquired allocations by proposed algorithm there are non-negative triangular fuzzy numbers whereas one allocation by [2] is negative and violates the basic rule of trading.

REFERENCES

[1] L. A. Zadeh, "Fuzzy sets," *Inf. Control*, vol. 8, no. 3, pp. 338–353, 1965, doi: 10.1016/S0019-9958(65)90241-X.

[2] A. Kumar, J. Kaur, and P. Singh, "A new method for solving fully fuzzy linear programming problems," *Appl. Math. Model.*, vol. 35, no. 2, pp. 817–823, 2011, doi: 10.1016/j.apm.2010.07.037.

[3] S. Chandran and G. Kandaswamy, "A fuzzy approach to transport optimization problem," *Optim. Eng.*, vol. 17, no. 4, pp. 965–980, 2016, doi: 10.1007/s11081-012-9202-6.

[4] G. De França Aguiar, B. De Cássia Xavier Cassins Aguiar, and V. E. Wilhelm, "New methodology to find initial solution for transportation problems: A case study with fuzzy parameters," *Appl. Math. Sci.*,

vol. 9, no. 17–20, pp. 915–927, 2015, doi: 10.12988/ams.2015.4121018.

[5] A. Kumar and P. Singh, “A new method for solving fully fuzzy linear programming problems,” *Ann. Fuzzy Math. Inf.*, vol. 3, pp. 103–118, 2012.

[6] A. Ebrahimnejad, “A simplified new approach for solving fuzzy transportation problems with generalized trapezoidal fuzzy numbers,” *Appl. Soft Comput. J.*, vol. 19, pp. 171–176, 2014, doi: 10.1016/j.asoc.2014.01.041.

[7] N. Mathur, P. K. Srivastava, and A. Paul, “Trapezoidal fuzzy model to optimize transportation problem,” *Int. J. Model. Simulation, Sci. Comput.*, vol. 7, no. 3, 2016, doi: 10.1142/S1793962316500288.

[8] D. Hunwisai and P. Kumam, “A method for solving a fuzzy transportation problem via Robust ranking technique and ATM,” *Cogent Math.*, vol. 4, no. 1, 2017, doi: 10.1080/23311835.2017.1283730.

[9] K. Balasubramanian and S. Subramanian, “Optimal solution of fuzzy transportation problems using ranking function,” *Int. J. Mech. Prod. Eng. Res. Dev.*, vol. 8, no. 4, pp. 551–558, 2018, doi: 10.24247/ijmperdaug201856.

[10] D. Chakraborty, D. K. Jana, and T. K. Roy, “A new approach to solve fully fuzzy transportation problem using triangular fuzzy number,” *Int. J. Oper. Res.*, vol. 26, no. 2, pp. 153–179, 2016, doi: 10.1504/IJOR.2016.076299.

[11] R. K. Saini, A. Sangal, and O. Prakash, “Fuzzy transportation problem with generalized triangular-trapezoidal fuzzy number,” in *Advances in Intelligent Systems and Computing*, 2018, vol. 583, pp. 723–734, doi: 10.1007/978-981-10-5687-1_64.

[12] D. Rani and T. R. Gulati, “A new approach to solve unbalanced transportation problems in imprecise environment,” *J. Transp. Secur.*, vol. 7, no. 3, pp. 277–287, 2014, doi: 10.1007/s12198-014-0143-5.

[13] A. Kumar and A. Kaur, “Application of Classical Transportation Methods to Find the Fuzzy Optimal Solution of Fuzzy Transportation Problems,” *Fuzzy Inf. Eng.*, vol. 3, no. 1, pp. 81–99, 2011, doi: 10.1007/s12543-011-0068-7.

[14] A. Kaur and A. Kumar, “A new approach for solving fuzzy transportation problems using generalized trapezoidal fuzzy numbers,” *Appl. Soft Comput. J.*, vol. 12, no. 3, pp. 1201–1213, 2012, doi: 10.1016/j.asoc.2011.10.014.

[15] R. Kumar, S. A. Edalatpanah, S. Jha, and R. Singh, “A Pythagorean fuzzy approach to the transportation problem,” *Complex Intell. Syst.*, vol. 5, no. 2, pp. 255–263, 2019, doi: 10.1007/s40747-019-0108-1.

[16] P. K. Srivastava and D. C. S. Bisht, “A Segregated Advancement in the Solution of Triangular Fuzzy Transportation Problems,” *Am. J. Math. Manag. Sci.*, pp. 1–11, 2020, doi: 10.1080/01966324.2020.1854137.

[17] P. Pandian and G. Natarajan, “A new algorithm for finding a fuzzy optimal solution for fuzzy transportation problems,” *Appl. Math. Sci.*, vol. 4, no. 1–4, pp. 79–90, 2010, doi: 10.1504/IJMMNO.2021.111715.

[18] A. Edward Samuel and M. Venkatachalapathy, “IZPM for unbalanced fuzzy transportation problems,” *Int. J. Pure Appl. Math.*, 2013, doi: 10.12732/ijpam.v86i4.8.

[19] K. Selvakumari and S. Sathya Geetha, “A new approach for solving intuitionistic fuzzy transportation problem,” *J. Adv. Res. Dyn. Control Syst.*, vol. 12, no. 5 Special Issue, pp. 956–963, 2020, doi: 10.5373/JARDCS/V12SP5/20201841.

[20] A. Edward Samuel and M. Venkatachalapathy, “Improved zero point method for solving fuzzy transportation problems using ranking function,” *Far East J. Math. Sci.*, vol. 75, no. 1, pp. 85–100, 2013.

[21] A. Edward Samuel, “Improved zero point method (IZPM) for the transportation problems,” *Appl. Math. Sci.*, vol. 6, no. 109–112, pp. 5421–5426, 2012.

[22] T. Karthy and K. Ganesan, “Improved zero point method for the fuzzy optimal solution to fuzzy transportation problems,” *Glob. J. Pure Appl. Math.*, vol. 12, no. 1, pp. 255–260, 2016.

[23] A. Akilbasha, G. Natarajan, and P. Pandian, “A new approach for solving transportation problems in fuzzy nature,” *Int. J. Appl. Eng. Res.*, vol. 11, no. 1, pp. 498–502, 2016.

[24] A. Baykasoğlu and K. Subulan, “A direct solution approach based on constrained fuzzy arithmetic and metaheuristic for fuzzy transportation problems,” *Soft Comput.*, vol. 23, no. 5, pp. 1667–1698, 2019, doi: 10.1007/s00500-017-2890-2.

[25] M. A. Imron and B. Prasetyo, “Improving algorithm accuracy K-Nearest Neighbor using Z-Score Normalization and Particle Swarm Optimization to predict customer churn,” *J. Soft Comput. Explor.*, vol. 1, no.1, pp. 56–62, 2020.

[26] R. H. Saputra and B. Prasetyo, “Improve the accuracy of c4.5 algorithm using particle swarm optimization (pso) feature selection and bagging technique in breast cancer diagnosis,” *J. Soft Comput. Explor.*, vol. 1, no.1, pp. 47–55, 2020.

[27] D. Aprilianto, “SVM optimization with correlation feature selection based binary particle swarm optimization for diagnosis of chronic kidney disease,” *J. Soft Comput. Explor.*, vol. 1, no.1, pp. 24–31, 2020.
[28] A. Ebrahimnejad, “An improved approach for solving fuzzy transportation problem with triangular fuzzy numbers,” *J. Intell. Fuzzy Syst.*, vol. 29, no. 2, pp. 963–974, 2015, doi: 10.3233/IFS-151625.