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APPLICATION OF FUZZY LOGIC IN AGRICULTURAL NETWORK ANALYSIS FOR OPTIMIZING CROP PRODUCTION

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Abstract

This study investigates the application of fuzzy logic and fuzzy set theory in agricultural networking to identify the optimal paths for different crop production activities. Traditionally networking methods often face challenges with incomplete and uncertain data, which are prevalent in agriculture. Fuzzy logic using decagonal fuzzy number offers a more versatile method of handing imprecise data. In this study decagonal fuzzy numbers are defuzzified by rolling averages with a window of three to determine the optimal path. The solution of the formulated mathematical programming model is obtained using R software which enabling accurate computation of the best routes in agricultural networks and three different examples were taken and the network diagram is also shown. This paper further shows the scope of agriculture especially network path analysis in agriculture which can enhance decision making, which in turn can rise crop yields and improve agriculture productivity.

Keywords: Fuzzy sets, Fuzzy logics, Network path analysis, Optimization

1. Introduction

Fuzzy logic and fuzzy set theory have gained significant attention in fields of scientific investigations, particularly in agriculture. It is due to their ability to manage uncertainty and deal with incomplete data sets. These techniques have been explored to various aspects of agriculture like decision making processes, precision farming, wireless sensor networks for precision agriculture and project management. The goal is to increase crop yields and overall agricultural productivity, fizzy expert system has been used in various agriculture tasks which includes seed selection, scheduling, transportation, pesticide management and soil preparations. This shows the adaptability of fuzzy logic and potential in solving agriculture problems which are challenging in nature. Lin [3] introduces a technique to solve shortest path problems in fuzzy environment using triangular fuzzy numbers and signed distance ranking. Nagoorgani and Begam [6] propose an alternative approach to determine the optimal shortest path using graded mean integration representation and triangular fuzzy numbers. An algorithm for fuzzy critical path analysis in project networks is developed by Liana and Han [4] using trapezoidal fuzzy numbers to enhance decision-making in project management. Kung et al. [2] proposed a method for discrete fuzzy networks.

A dynamic programming approach for obtaining shortest paths in fuzzy networks presented in Mahdavi et al. [5]. De and Bhincher [1] used triangular and trapezoidal fuzzy numbers to compare linear programming approach and dynamic programming for fuzzy shortest path problems. Pal et.al [7] apply an Ai based approach to solve intuitionistic fuzzy assignment problems in agriculture through dynamic programming approach. Bose & Tarafdar [8] used fuzzy logic to optimize supply chain management in agriculture with crop transportation models. Singh & Joshi [9] emphasizes fuzzy models to predict crop yield influenced by different factors for improving calibration. Chen, Zhang, & Wang [10] optimizes irrigation schedules based on weather data and to contingent crop planning with weather parameters. Zadeh [11] outlines fuzzy logic principles widely applicable in agriculture decision making particularly network path analysis under uncertainty.

Sivakumar [12] enhance agriculture metrical application in essential for calibrating crop production with whether data. used for basic system providing insights into how to system can manage in preside agriculture. Mendel [13] provides insights how fuzzy system can manage imprecise agriculture data for optimizing crop production. Sharma & Dhillon [14] demonstrates the use of fuzzy logic for predicting crop diseases based on weather patterns. Qin & Liu [15] used fuzzy decision -making methods applied for crop planning for agriculture optimization problems. Pandey [16] use of fuzzy logic for improving agriculture yield by analyzing network paths. Rahman & Sarker, [17] Used fuzzy decision systems to optimize water usage in irrigation, under uncertain weather conditions. Solimun *et al*. [18] demonstrates that certain combinations to provide more accurate path models, for interpreting relationships between categorical variables. Sanjana and Ramesh [19] presents an innovative approach to handle complex assignment problems with imprecise data using the Hungarian method. Behera *et al*. [20] focused on new computational methods to discourse linear programming problems under triangular fuzzy uncertainty.

2. Basic Preliminary

Fuzzy set: Let A be a classical set, $\mu_{\bar{A}}(x)$ be a function from A to $[0,1]$. A fuzzy set $\bar{A}$ with the membership function $\mu_{\bar{A}}(x)$ is defined by $\bar{A} = \{(x, \mu_{\bar{A}}(x)); x \in A, \mu_{\bar{A}}(x) \in [0,1]\}$.

Membership Function $\mu_{\bar{A}}(x)$: Describes the degree of belonging of x to the fuzzy set $\bar{A}$.
Non- Membership Function $v_{\bar{A}}(x)$: Describes the degree to which x does not belonging to the fuzzy set $\bar{A}$. That is $v_{\bar{A}}(x) = 1 - \mu_{\bar{A}}(x)$.

Fuzzy Number: is a specific type of fuzzy set defined on real numbers having membership function that assigns a value between 0 and 1 for each real number. This value indicates the degree of membership of that number which belongs to the fuzzy set. Fuzzy numbers help to represent uncertain or imprecise values, typically having a peak when membership function having value 1 and gradually decreases to 0 on either side.

Triangular Fuzzy Number: A triangular fuzzy number having triangular shaped membership function with three parameters (a_1, a_2, a_3) where $a_1 \le a_2 \le a_3$. The function rises linearly from a_1 and a_2, and reaches its peak at a_2 and then falls linearly to a_3. The membership function denoted by $\mu_{\bar{A}}(x)$ is given :

$$\mu_{\bar{A}}(x)=\begin{cases}0, & x<a_1\\ \frac{(x-a_1)}{a_2-a_1}, & a_1\le x\le a_2\\ \frac{(a_3-x)}{a_3-a_2}, & a_2\le x\le a_3\end{cases} \tag{1}$$

Here a_1 and a_3 are the points where membership function starts and ends at 0, while a_2 is the peak where membership value is 1.

Trapezoidal Fuzzy Number: A trapezoidal fuzzy number having trapezoid shaped membership function with four parameters (a_1, a_2, a_3, a_4) where $a_1 \le a_2 \le a_3 \le a_4$. The function rises linearly from a_1 and a_2, and reaches its peak at a_2 and then falls linearly to a_3. The membership function denoted by $\mu_{\bar{A}}(x)$ is given :

$$\mu_{\bar{A}}(x)=\begin{cases}0, & x<a_1 \ or \ \ x>a_4\\ \frac{(x-a_1)}{a_2-a_1}, & a_1\le x\le a_2\\ 1, & a_2\le x\le a_3\\ \frac{(a_4-x)}{a_4-a_3}, & a_3\le x\le a_4\end{cases} \tag{2}$$

Here a_1 and a_4 are the points where membership function starts and ends at 0, while a_2 and a_3 is the flat top of the trapezoid where membership value is 1.

Pentagonal Fuzzy Number: A pentagonal fuzzy number having five parameters $(a_1, a_2, a_3, a_4, a_5)$ where $a_1 \le a_2 \le a_3 \le a_4 \le a_5$. The membership function denoted by $\mu_{\bar{A}}(x)$ is given :

$$\mu_{\bar{A}}(x)=\begin{cases}0, & x<a_1 \ or \ \ x>a_5\\ \frac{(x-a_1)}{a_2-a_1}, & a_1\le x\le a_2\\ \frac{(x-a_2)}{a_3-a_2}, & a_2\le x\le a_3\\ \frac{(a_4-x)}{a_4-a_3}, & a_3\le x\le a_4\\ \frac{(a_5-x)}{a_5-a_4}, & a_4\le x\le a_5\end{cases} \tag{3}$$

Hexagonal Fuzzy Number: A Hexagonal fuzzy number having six parameters $(a_1, a_2, a_3, a_4, a_5, a_6)$ where $a_1 \le a_2 \le a_3 \le a_4 \le a_5 \le a_6$. The membership function denoted by $\mu_{\bar{A}}(x)$ is given :

$$\mu_{\bar{A}}(x)=\begin{cases}0, & x<a_1 \; or \; x>a_6 \\ \frac{(x-a_1)}{a_2-a_1}, & a_1\le x\le a_2 \\ \frac{(x-a_2)}{a_3-a_2}, & a_2\le x\le a_3 \\ 1, & a_3\le x\le a_4 \\ \frac{(a_5-x)}{a_5-a_4}, & a_4\le x\le a_5 \\ \frac{(a_6-x)}{a_6-a_5}, & a_5\le x\le a_6 \end{cases} \tag{4}$$

Heptagonal Fuzzy Number: A heptagonal fuzzy number having seven parameters $(a_1, a_2, a_3, a_4, a_5, a_6, a_7)$ where $a_1 \le a_2 \le a_3 \le a_4 \le a_5 \le a_6 \le a_7$. The membership function denoted by $\mu_{\bar{A}}(x)$ is given :

$$\mu_{\bar{A}}(x)=\begin{cases}0, & x<a_1 \; or \; x>a_7 \\ \frac{(x-a_1)}{a_2-a_1}, & a_1\le x\le a_2 \\ \frac{(x-a_2)}{a_3-a_2}, & a_2\le x\le a_3 \\ \frac{(x-a_2)}{a_4-a_3}, & a_3\le x\le a_4 \\ 1, & a_4\le x\le a_5 \\ \frac{(a_6-x)}{a_6-a_5}, & a_5\le x\le a_6 \\ \frac{(a_7-x)}{a_7-a_6}, & a_6\le x\le a_7 \end{cases} \tag{5}$$

Octagonal Fuzzy Number: A Octagonal fuzzy number having seven parameters $(a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8)$ where $a_1 \le a_2 \le a_3 \le a_4 \le a_5 \le a_6 \le a_7 \le a_8$. The membership function denoted by $\mu_{\bar{A}}(x)$ is given :

$$\mu_{\bar{A}}(x)=\begin{cases}0, & x<a_1 \ or \ x>a_8\\ \frac{(x-a_1)}{a_2-a_1}, & a_1\le x\le a_2\\ \frac{(x-a_2)}{a_3-a_2}, & a_2\le x\le a_3\\ \frac{(x-a_2)}{a_4-a_3}, & a_3\le x\le a_4\\ 1, & a_4\le x\le a_5\\ \frac{(a_6-x)}{a_6-a_5}, & a_5\le x\le a_6\\ \frac{(a_7-x)}{a_7-a_6}, & a_6\le x\le a_7\\ \frac{(a_7-x)}{a_8-a_7}, & a_7\le x\le a_8\end{cases} \quad (6)$$

Nonagonal Fuzzy Number: A Nonagonal fuzzy number having seven parameters $(a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9)$ where $a_1 \le a_2 \le a_3 \le a_4 \le a_5 \le a_6 \le a_7 \le a_8 \le a_9$. The membership function denoted by $\mu_{\bar{A}}(x)$ is given :

$$\mu_{\bar{A}}(x)=\begin{cases}0, & x\le a_1\\ \frac{(x-a_1)}{a_2-a_1}, & a_1< x\le a_2\\ \frac{(x-a_2)}{a_3-a_2} & a_2< x\le a_3\\ \frac{(x-a_2)}{a_4-a_3}, & a_3< x\le a_4\\ \frac{(x-a_4)}{a_5-a_4}, & a_4< x\le a_5\\ \frac{(x-a_5)}{a_6-a_5}, & a_5< x\le a_6\\ \frac{(x-a_6)}{a_7-a_6}, & a_6< x\le a_7\\ \frac{(x-a_7)}{a_8-a_7}, & a_7< x\le a_8\\ \frac{(x-a_8)}{a_9-a_8}, & a_8< x\le a_9\\ 0, & x\le a_9\end{cases} \quad (7)$$

Decagonal Fuzzy Number: A Decagonal fuzzy number having seven parameters $(a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10})$ where $a_1 \le a_2 \le a_3 \le a_4 \le a_5 \le a_6 \le a_7 \le a_8 \le a_9 \le a_{10}$. The membership function denoted by

$\mu_{\bar{A}}(x)$ is given :

$$\mu_{\bar{A}}(x) = \begin{cases} 0, & x < a_1 \; or \; x > a_{10} \\ \frac{(x-a_1)}{a_2 - a_1}, & a_1 \le x \le a_2 \\ \frac{(x-a_2)}{a_3 - a_2} & a_2 \le x \le a_3 \\ \frac{(x-a_3)}{a_4 - a_3}, & a_3 \le x \le a_4 \\ \frac{(x-a_4)}{a_5 - a_4}, & a_4 \le x \le a_5 \\ 1, & a_5 \le x \le a_6 \\ \frac{(a_7 - x)}{a_7 - a_6}, & a_6 \le x \le a_7 \\ \frac{(a_8 - x)}{a_8 - a_7}, & a_7 \le x \le a_8 \\ \frac{(a_9 - x)}{a_9 - a_8}, & a_8 \le x \le a_9 \\ \frac{(a_{10} - x)}{a_{10} - a_9}, & a_9 \le x \le a_{10} \end{cases} \tag{8}$$

Defuzzified Decagonal Fuzzy Number: The rolling average is used to Defuzzifying Decagonal fuzzy number $(a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10})$ with three as window width taken.

$$\begin{aligned} RAvg(a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10}) = & \left[Average\left(\frac{a_1 + a_2 + a_3}{3} \right) = A_1 \right] + \left[Average\left(\frac{a_2 + a_3 + a_4}{3} \right) = A_2 \right] \\ & + \left[Average\left(\frac{a_3 + a_4 + a_5}{3} \right) = A_3 \right] + \left[Average\left(\frac{a_4 + a_5 + a_6}{3} \right) = A_4 \right] \\ & + \left[Average\left(\frac{a_5 + a_6 + a_7}{3} \right) = A_5 \right] + \left[Average\left(\frac{a_6 + a_7 + a_8}{3} \right) = A_6 \right] \\ & + \left[Average\left(\frac{a_7 + a_8 + a_9}{3} \right) = A_7 \right] + \left[Average\left(\frac{a_8 + a_9 + a_{10}}{3} \right) = A_8 \right] \end{aligned}$$

$$RAvg(a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10}) = \frac{A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + A_8 + A_9}{9}$$

3. Formulation of Network Path Problem

1. Formulate the Problem: To minimize the transportation duration from agriculture.
2. Set up the Network: Develop network diagram with nodes representing farms and markets and transportation path by edges.
3. Define Constraints: setting of constraints like transportation vehicles (maximum Capacity), Market demand and farm production capacity.
4. Develop an Optimization Model: Formulate a Mathematical Model.

5. Implement the Model in Software: R software is used to solve the optimization model.

4. Numerical illustration

Example1: Let us consider an agriculture data set, where each path represents time/duration required for various agriculture processes between different stages of crop production like soil preparation, planting, irrigation etc. used as fuzzy durations.

Table 1: *Duration required for various agriculture processes*

Nodes (i-j)	Fuzzy Duration(hrs)	Defuzzified Duration(hrs)
S1-S2	0.77, 0.79,0.81,0.82,0.84,0.86,0.88,0.9,0.92,0.94	0.85
S1-S3	0.19, 0.2,0.2,0.2,0.21,0.21,0.21,0.22,0.22,0.23	0.21
S2-S4	2.92, 2.95,2.98,3.01,3.04,3.06,3.07,3.12,3.15,3.18	3.05
S2-S5	0.79, 0.8,0.81,0.82,0.83,0.84,0.85,0.86,0.87,0.88	0.84
S3-S5	0.59, 0.6,0.6,0.61,0.61,0.62,0.63,0.63,0.64,0.65	0.62
S3-S6	0.96, 0.98,0.99,1,1.02,1.03,1.04,1.06,1.07,1.08	1.02
S4-S7	0.17,0.17,0.17,0.17,0.17,0.17,0.17,0.18,0.18,0.18	0.17
S5-S7	1.04,1.06,1.09,1.11,1.14,1.16,1.18,1.21,1.23,1.25	1.15
S5-S8	3.22,3.25,3.28,3.31,3.34,3.37,3.39,3.42,3.45,3.48	3.35
S6-S8	2.24, 2.32,2.4,2.48,2.56,2.64,2.72,2.8,2.88,2.96	2.60

Where S1: Initial Soil Preparation, S2: Fertilization, S3: Seed Planting, S4: First Irrigation, S5: Weed Control, S6: Pest Management, S7: Final Irrigation, S8: Harvesting
The network Diagram is shown below

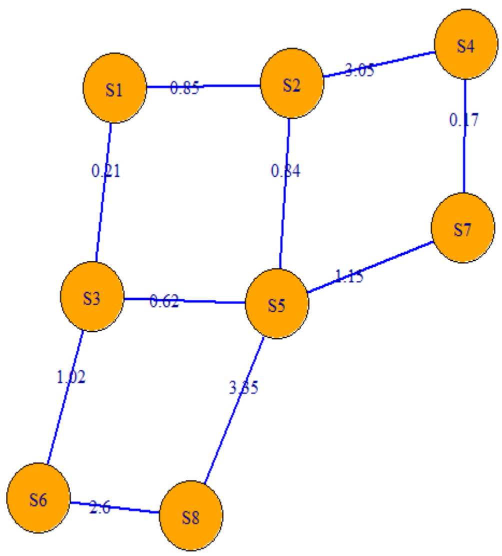

Figure 1: Network diagram

Example2: Here is another example for an agriculture network path problem which represents different agriculture processes between various stages of crop production through fuzzy duration.

Table 2: *Duration required for various agriculture processes*

Nodes (i-j)	Fuzzy Duration(hrs)	Defuzzified Duration(hrs)
P1-P2	0.902,0.922,0.975,0.985,1.005,1.025,1.045,1.065,1.085,1.105	1.03
P1-P3	0.289,0.332,0.365,0.365,0.375,0.375,0.375,0.385,0.385,0.395	0.37
P2-P4	3.019,3.082,3.145,3.175,3.205,3.225,3.235,3.285,3.315,3.345	3.23
P2-P5	0.889,0.932,0.975,0.985,0.995,1.005,1.015,1.025,1.035,1.045	1.00
P3-P5	0.689,0.732,0.765,0.775,0.775,0.785,0.795,0.795,0.805,0.815	0.78
P3-P6	1.059,1.112,1.155,1.165,1.185,1.195,1.205,1.225,1.235,1.245	1.19
P4-P7	0.269,0.302,0.335,0.335,0.335,0.335,0.335,0.345,0.345,0.345	0.33
P5-P7	1.139,1.192,1.255,1.275,1.305,1.325,1.345,1.375,1.395,1.415	1.33
P5-P8	3.319,3.382,3.445,3.475,3.505,3.535,3.555,3.585,3.615,3.645	3.54
P6-P8	2.339,2.452,2.565,2.645,2.725,2.805,2.885,2.965,3.045,3.125	2.83

Interpretation of Nodes: P1: Land Clearing, P2: Soil Testing and Preparation, P3: Seed Selection, P4: Planting and Seeding, P5: Nutrient Management, P6: Pest and Disease Contro, P7: Water Management P8: Harvest and Post-Harvest Processing.

The network Diagram is shown below:

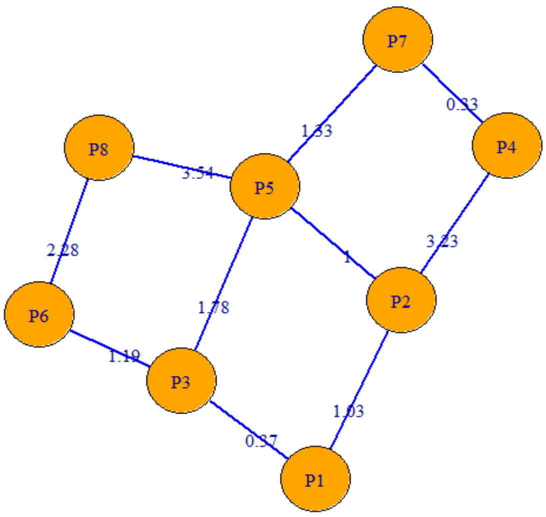

Figure 2: Network diagram

Example 3: Let's consider another network path problem in agriculture. In this data set the aim to is determining the optimal path of transportation for supplying items from agriculture farms to the specified markets.

Table 3: *Duration required transportation for supplying items from agriculture farms to the specified markets.*

Nodes (i-j)	Fuzzy Duration (hrs)	Defuzzified Duration (hrs)
F1-M(A)	(1.5, 1.6, 1.7, 1.8, 1.9, 2, 2.1, 2.4, 2.6, 2.7)	2.01
F1-M(B)	(2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3, 3.2, 3.5)	2.77
F1-M(C)	(3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4, 4.1)	3.65
F2-M(A)	(1.7, 1.8, 1.9, 2, 2.1, 2.2, 2.3, 2.5, 2.7 ,3)	2.20
F2-M(B)	(1.4, 1.5, 1.6, 1.7,1.8,1.9,2,2.3,2.5, 2.8)	1.92
F2- M(C)	(2.7, 2.8, 2.9, 3, 3.1, 3.2, 3.3, 3.3, 3.4, 3.7)	3.13
F 3- M(A)	(2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3, 3.2)	2.65
F3- M(B)	(2, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 3)	2.45

F3- M(C)	(1.3, 1.4, 1.5,1.6,1.7,1.8, 2, 2.3, 2.4, 2.7)	1.85

Here Farms denoted as F1, F2 and F3 and Markets as M(A), M(B), M(C).
The network Diagram is shown below:

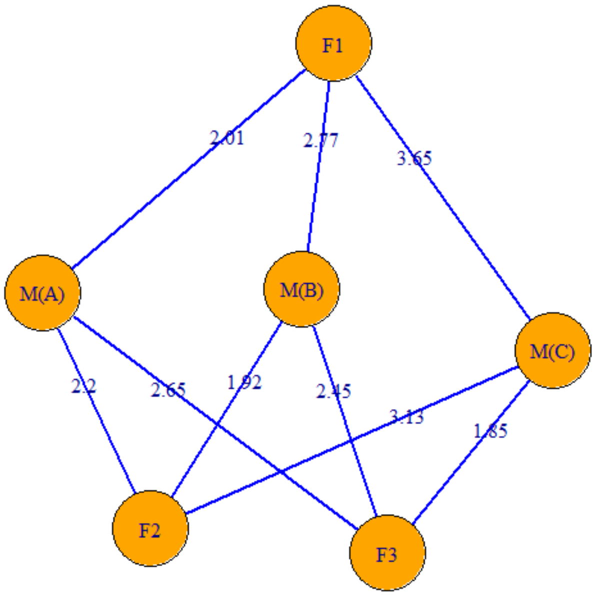

Figure 3: Network diagram

5. Conclusion

This study shows applications of different agriculture process through fuzzy set theory and fuzzy logic. In this study a reliable technique for agricultural logistics optimization of decagonal fuzzy number transforms into crisp values by defuzzifying through rolling regression. In this study if we change the width of the window based rolling average can also slightly change. This is a useful tool for decision-making in a variety of industries and it can be expanded to other domains where uncertainties in path durations must be taken into consideration.

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