Combined Framework for Type-2 Neutrosophic Number Multiple-Attribute Decision-Making and Applications to Quality Evaluation of Digital Agriculture Park Information System

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***Abstract*—A digital agriculture park refers to an agricultural production and organizational unit of a certain scale where digital technology is used to optimize the agricultural supply chain. It enhances park management and service levels, achieving a new development model characterized by safe, low-carbon, high-quality, high-yield, precise, and efficient production, management, service, and operation. The quality evaluation of digital agriculture park information system is a multiple-attribute decision-making (MADM). Currently, the Exponential TODIM (ExpTODIM) and TOPSIS was put forward MADM. The Type-2 neutrosophic numbers (T2NNs) are employed to portray fuzzy information during the quality evaluation of digital agriculture park information system. In this works, the Type-2 neutrosophic number Exponential TODIM-TOPSIS (T2NN-ExpTODIM-TOPSIS) approach is put forward MAGDM under T2NNs. Finally, numerical study for quality evaluation of digital agriculture park information system is determined to demonstrate the T2NN-ExpTODIM-TOPSIS approach. The major research motivation is cultivated: (1) ExpTODIM and TOPSIS approach was enhanced under IFSs; (2) Entropy is put forward weight numbers in light with score values along with T2NNs; (3) T2NN-ExpTODIM-TOPSIS is put forward the MADM along with T2NNs; (4) numerical example for quality evaluation of digital agriculture park information system and different comparative analysis is put forward the validity of T2NN-ExpTODIM-TOPSIS.**

Keywords*—Multiple-Attribute Decision-Making (MADM); Type-2 Neutrosophic Numbers (T2NNs); ExpTODIM approach; TOPSIS approach; quality evaluation

I. INTRODUCTION

Building digital agriculture parks is a significant trend in modern agriculture, with countries worldwide gradually adopting this model. By integrating digital technologies like Internet of things, big data, and Artificial Intelligence, these parks enhance production, management, and services [1-3]. Currently, many countries are actively exploring and developing digital agriculture parks [4, 5]. Sensor networks and drone technology are widely used for land monitoring and crop management, enabling real-time data collection and precise management. This improves crop yield and quality while reducing the use of fertilizers and pesticides, thus lowering environmental pollution [6-8]. Digital parks also optimize production decisions through big data analysis. Farmers can adjust plans based on real-time data, enhancing resource efficiency and reducing costs. The introduction of intelligent management systems allows comprehensive monitoring and automation of production processes, increasing operational efficiency. Moreover, digital agriculture parks play a crucial role in food safety. Blockchain technology ensures traceability from production to sales, enhancing product safety and traceability [9-11]. This not only boosts consumer trust but also strengthens market competitiveness. The significance of building digital agriculture parks is substantial. Firstly, they increase agricultural productivity and efficiency. The application of digital technologies makes production processes more intelligent and precise, significantly improving resource utilization. Secondly, digital parks promote sustainable development. The use of precision agriculture technology reduces environmental pollution, achieving low-carbon and green agriculture. The development of digital agriculture parks also boosts rural economic growth. As park construction progresses, related industries develop, creating more jobs and improving rural economies[12-15]. Additionally, digital parks serve as testing grounds for technological innovation. The application and promotion of new technologies not only advance agricultural science but also provide references for innovation in other fields. However, there are challenges in building digital agriculture parks. High technical costs, data security issues, and farmers' acceptance of technology need to be addressed. Therefore, countries need to enhance policy support, drive technological innovation, and provide training to improve farmers' digital literacy. In the global context, the development of digital agriculture parks offers new opportunities for international cooperation. Countries can share technologies and experiences to address food security and environmental challenges together [16, 17]. Through global collaboration and technology sharing, digital agriculture parks will provide strong support for sustainable agricultural development worldwide. In summary, building digital agriculture parks not only enhances agricultural efficiency and safety but also promotes sustainable development and rural economic growth. It is a crucial path for modern agricultural transformation. With continuous technological advancement, digital agriculture parks will play an increasingly important role, becoming a core model for future agricultural development [18, 19].

With the development of decision science and practical needs, research on MADM has become popular again. In the 1980s, some foreign scholars conducted research on group AHP and proposed some methods and some famous scholars in China also conducted relevant discussions [20-24]. Hwang and Yoon [25] systematically reviewed and summarized a large number of previous research results on MADM and edited and published the first monograph on multi-attribute decision-making, "Multiple Attribute Decision Making Method and Application.". After the 1980s, many scholars studied various types of interactive algorithms for solving the MADM problems. At that time, there were already some mature methods for studying MADM problems [26-31], such as the optimal selection method, connection method, and separation method used to screen options when there were too many options, the least squares method and eigenvector method used to determine attribute weights, the most commonly used simple additive weighting method and hierarchical additive weighting method for option ranking, the dictionary ordering method for selecting options based on attribute weight size, TOPSIS method [32] and LINMAP [33-37] method based on the concept of ideal solutions, as well as the queuing method based on estimating relative positions, linear allocation method, ELECTRE [38-41] method, and so on. The quality evaluation of digital agriculture park information system is MADM. Currently, the ExpTODIM [42, 43] and TOPSIS technique[32, 44, 45] is put forward the MADM. The Type-2 neutrosophic numbers (T2NNs) [46] are put forward for portraying fuzzy information during quality evaluation of digital agriculture park information system. Until now, no or few approaches were investigated on ExpTODIM and TOPSIS technique in light with entropy model along with T2NNs. Therefore, T2NN-ExpTODIM-TOPSIS model is put forward MADM along with T2NNs. Numerical example for quality evaluation of digital agriculture park information system and comparative analysis is put forward the validity of T2NN-ExpTODIM-TOPSIS approach. The major research motivation is cultivated: (1) ExpTODIM and TOPSIS approach was enhanced under T2NNs; (2) Entropy is put forward weight numbers in light with score values along with T2NNs; (3) T2NN-ExpTODIM-TOPSIS is put forward the MADM along with T2NNs; (4) numerical example for quality evaluation of digital agriculture park information system and comparative analysis is put forward the validity of T2NN-ExpTODIM-TOPSIS.

The structure of such study is cultivated. Preliminaries is given in Section II. In Section III, T2NN-ExpTODIM-TOPSIS model is put forward MADM along with T2NNs. Section IV numerical study for quality evaluation of digital agriculture park information system through different comparative analysis. Final conclusion is cultivated in Section V.

II. Preliminaries

Wang et al. [47] built the SVNSs

Definition 1 [47]. The SVNSs is cultivated:

$$VA=\left\{\left(\theta,VT_{VA}\left(\theta\right),VI_{VA}\left(\theta\right),VF_{VA}\left(\theta\right)\right)\middle|\theta\in\Theta\right\} \quad (1)$$

where $VT_{VA}\left(\theta\right),VI_{VA}\left(\theta\right),VF_{VA}\left(\theta\right)$ is truth-membership (TM), indeterminacy-membership (IM) and falsity-membership (FM), $VT_{VA}\left(\theta\right),VI_{VA}\left(\theta\right),VF_{VA}\left(\theta\right)\in\left[0,1\right]$, $0\le VT_{VA}\left(\theta\right)+VI_{VA}\left(\theta\right)+VF_{VA}\left(\theta\right)\le 3$. The SVNN is implemented as $VA=\left(VT_A,VI_A,VF_A\right)$, where $VT_A,VI_A,VF_A\in\left[0,1\right]$, and $0\le VT_A+VI_A+VF_A\le 3$.

Abdel-Basset et al. [46] cultivated the T2NNs.

Definition 1[46]. The T2NN is cultivated:

$$VV=\left\{\left(\theta,VT\left(\theta\right),VI\left(\theta\right),VF\left(\theta\right)\right)\middle|\theta\in\Theta\right\} \quad (2)$$

where $VT\left(\theta\right),VI\left(\theta\right),VF\left(\theta\right)\in\left[0,1\right]$ be TM, IM and FM based on triangular fuzzy numbers.

$$VT\left(\theta\right)=\left(VT^L\left(\theta\right),VT^M\left(\theta\right),VT^U\left(\theta\right)\right),0\le VT^L\left(\theta\right)\le VT^M\left(\theta\right)\le VT^U\left(\theta\right)\le 1 \quad (3)$$

$$VI\left(\theta\right)=\left(VI^L\left(\theta\right),VI^M\left(\theta\right),VI^U\left(\theta\right)\right),0\le VI^L\left(\theta\right)\le VI^M\left(\theta\right)\le VI^U\left(\theta\right)\le 1 \quad (4)$$

$$VF\left(\theta\right)=\left(VF^L\left(\theta\right),VF^M\left(\theta\right),VF^U\left(\theta\right)\right),0\le VF^L\left(\theta\right)\le VF^M\left(\theta\right)\le VF^U\left(\theta\right)\le 1 \quad (5)$$

We let $VV=\left\{\begin{matrix}\left(VT^L,VT^M,VT^U\right),\\ \left(VI^L,VI^M,VI^U\right),\left(VF^L,VF^M,VF^U\right)\end{matrix}\right\}$ be a T2NN, $0\le VT^U+VI^U+VF^U\le 3$.

Definition 2[46]. Let $VV_1=\left\{\begin{matrix}\left(VT_1^L,VT_1^M,VT_1^U\right),\\ \left(VI_1^L,VI_1^M,VI_1^U\right),\left(VF_1^L,VF_1^M,VF_1^U\right)\end{matrix}\right\}$, $VV_2=\left\{\begin{matrix}\left(VT_2^L,VT_2^M,VT_2^U\right),\\ \left(VI_2^L,VI_2^M,VI_2^U\right),\left(VF_2^L,VF_2^M,VF_2^U\right)\end{matrix}\right\}$ and

$VV=\left\{\begin{matrix}\left(VT^{L},VT^{M},VT^{U}\right),\\ \left(VI^{L},VI^{M},VI^{U}\right),\left(VF^{L},VF^{M},VF^{U}\right)\end{matrix}\right\}$ be TFNNs, the operation laws are cultivated:

$$(1)\ VV_1\oplus VV_2=\left\{\begin{matrix}\left(VT_1^L+VT_2^L\text{-}VT_1^LVT_2^L,VT_1^M+VT_2^M\text{-}VT_1^MVT_2^M,VT_1^U+VT_2^U\text{-}VT_1^UVT_2^U\right),\\ \left(VI_1^LVI_2^L,VI_1^MVI_2^M,VI_1^UVI_2^U\right),\left(VF_1^LVF_2^L,VF_1^MVF_2^M,VF_1^UVF_2^U\right)\end{matrix}\right\};$$

$$(2)VV_1\otimes VV_2=\left\{\begin{matrix}\left(VT_1^LVT_2^L,VT_1^MVT_2^M,VT_1^UVT_2^U\right),\\ \left(VI_1^L+VI_2^L\text{-}VI_1^LVI_2^L,VI_1^M+VI_2^M\text{-}VI_1^MVI_2^M,VI_1^U+VI_2^U\text{-}VI_1^UVI_2^U\right),\\ \left(VF_1^L+VF_2^L\text{-}VF_1^LVF_2^L,VF_1^M+VF_2^M\text{-}VF_1^MVF_2^M,VF_1^U+VF_2^U\text{-}VF_1^UVF_2^U\right)\end{matrix}\right\};$$

$$(3)\ \lambda VV=\left\{\begin{matrix}\left(1-\left(1-VT^L\right)^\lambda,1-\left(1-VT^M\right)^\lambda,1-\left(1-VT^U\right)^\lambda\right),\\ \left(\left(VI^L\right)^\lambda,\left(VI^M\right)^\lambda,\left(VI^U\right)^\lambda\right),\\ \left(\left(VF^L\right)^\lambda,\left(VF^M\right)^\lambda,\left(VF^U\right)^\lambda\right)\end{matrix}\right\},\lambda>0;$$

$$(4)VV^\lambda=\left\{\begin{matrix}\left(\left(VT^L\right)^\lambda,\left(VT^M\right)^\lambda,\left(VT^U\right)^\lambda\right),\\ \left(1-\left(1-VI^L\right)^\lambda,1-\left(1-VI^M\right)^\lambda,1-\left(1-VI^U\right)^\lambda\right),\\ \left(1-\left(1-VF^L\right)^\lambda,1-\left(1-VF^M\right)^\lambda,1-\left(1-VF^U\right)^\lambda\right)\end{matrix}\right\},\lambda>0.$$

The operation laws have several properties.

$$(1)\ VV_1\oplus VV_2=VV_2\oplus VV_1,VV_1\otimes VV_2=VV_2\otimes VV_1,\left(\left(VV_1\right)^{\lambda_1}\right)^{\lambda_2}=\left(VV_1\right)^{\lambda_1\lambda_2}; \quad (6)$$

$$(2)\ \lambda\left(VV_1\oplus VV_2\right)=\lambda VV_1\oplus\lambda VV_2,\left(VV_1\otimes VV_2\right)^\lambda=\left(VV_1\right)^\lambda\otimes\left(VV_2\right)^\lambda; \quad (7)$$

$$(3)\ \lambda_1VV_1\oplus\lambda_2VV_1=\left(\lambda_1+\lambda_2\right)VV_1,\left(VV_1\right)^{\lambda_1}\otimes\left(VV_1\right)^{\lambda_2}=\left(VV_1\right)^{\left(\lambda_1+\lambda_2\right)}. \quad (8)$$

Definition 3 [46]**.** Let $VV=\left\{\begin{matrix}\left(VT^{L},VT^{M},VT^{U}\right),\\ \left(VI^{L},VI^{M},VI^{U}\right),\left(VF^{L},VF^{M},VF^{U}\right)\end{matrix}\right\}$ be TFNN, the SF (score function) and AF (accuracy function) are cultivated:

$$SF\left(VV\right)=\frac{1}{12}\begin{bmatrix}8+\left(VT^L+2VT^M+VT^U\right)\\ -\left(VI^L+2VI^M+VI^U\right)\\ -\left(VF^L+2VF^M+VF^U\right)\end{bmatrix},SF\left(VV\right)\in\left[0,1\right] \quad (9)$$

$$AF\left(VV\right)=\frac{1}{12}\begin{bmatrix}\left(VT^L+2VT^M+VT^U\right)\\ +\left(VI^L+2VI^M+VI^U\right)\\ +\left(VF^L+2VF^M+VF^U\right)\end{bmatrix},AF\left(VV\right)\in\left[0,1\right] \quad (10)$$

For two TFNNs, based on Definition 3, the following results are cultivated:

$$
\begin{aligned}
&(1)\ if\ \ SF(VV_1) \prec SF(VV_2), then\ VV_1 \prec VV_2; \\
&(2)\ if\ \ SF(VV_1) = SF(VV_2), AF(VV_1) \prec AF(VV_2), then\ VV_1 \prec VV_2; \\
&(3)\ if\ \ SF(VV_1) = SF(VV_2), AF(VV_1) = AF(VV_2), then\ VV_1 = VV_2.
\end{aligned}
$$

Definition 4[46]. Let $VV_1 = \left\{ \begin{array}{l} (VT_1^L, VT_1^M, VT_1^U), \\ (VI_1^L, VI_1^M, VI_1^U), (VF_1^L, VF_1^M, VF_1^U) \end{array} \right\}$, $VV_2 = \left\{ \begin{array}{l} (VT_2^L, VT_2^M, VT_2^U), \\ (VI_2^L, VI_2^M, VI_2^U), (VF_2^L, VF_2^M, VF_2^U) \end{array} \right\}$ be T2NNs, the T2NNs Hamming distance (T2NNHD) is cultivated:

$$
T2NNHD(VV_1, VV_2) = \frac{1}{9} \left(\begin{array}{l} |VT_1^L - VT_2^L| + |VT_1^M - VT_2^M| + |VT_1^U - VT_2^U| \\ + |VI_1^L - VI_2^L| + |VI_1^M - VI_2^M| + |VI_1^U - VI_2^U| \\ + |VF_1^L - VF_2^L| + |VF_1^M - VF_2^M| + |VF_1^U - VF_2^U| \end{array} \right) \quad (11)
$$

III. T2NN-ExpTODIM-TOPSIS Approach for MADM with Entropy

The T2NN-ExpTODIM-TOPSIS is cultivated for MAGDM. Let $VA = \{VA_1, VA_2, \cdots, VA_m\}$ be alternative and $VG = \{VG_1, VG_2, \cdots, VG_n\}$ be attributes with weight vw, $vw_j \in [0,1], \sum_{j=1}^{n} vw_j = 1$. Then, T2NN-ExpTODIM-TOPSIS is cultivated for MADM (see Fig. 1).

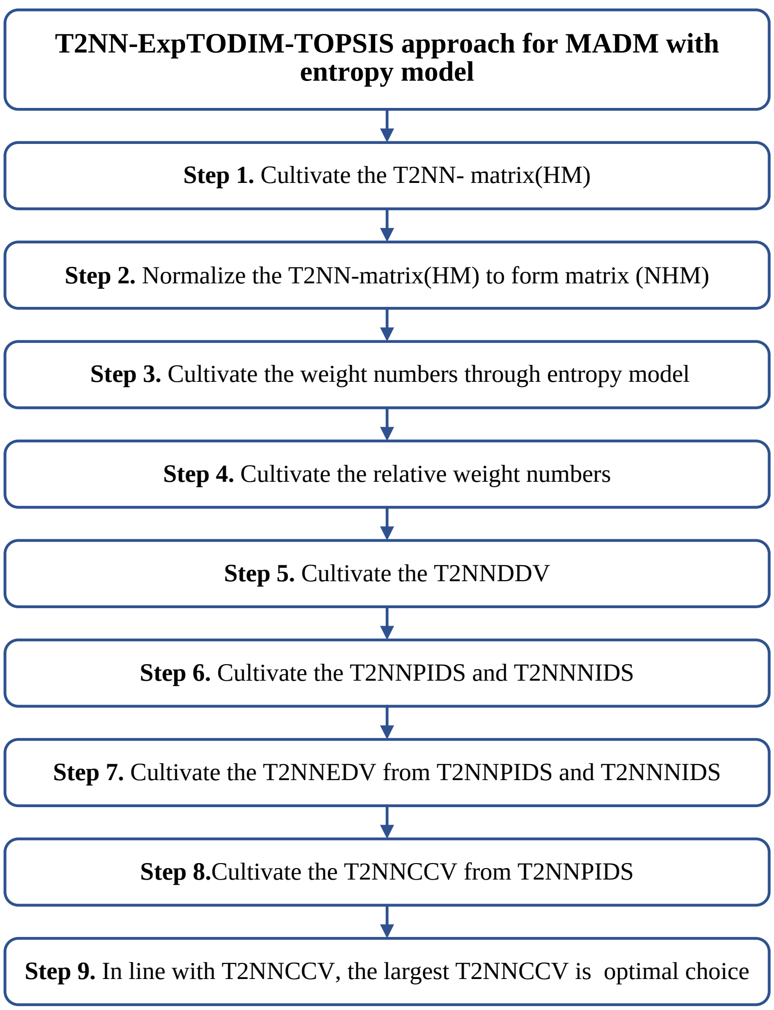

Fig. 1. T2NN-ExpTODIM-TOPSIS approach for MADM with entropy.

A. T2NN-MADM Problem

Step 1. Cultivate the T2NN-matrix $VM = \left[VM_{ij}\right]_{m\times n}$:

$$VM = \left[VM_{ij}\right]_{m\times n} = \begin{array}{c} \\ VA_1 \\ VA_2 \\ \vdots \\ VA_m \end{array} \begin{array}{c} \begin{array}{cccc} VG_1 & VG_2 & \dots & VG_n \end{array} \\ \begin{bmatrix} VM_{11} & VM_{12} & \dots & VM_{1n} \\ VM_{21} & VM_{22} & \dots & VM_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ VM_{m1} & VM_{m2} & \dots & VM_{mn} \end{bmatrix} \end{array} \tag{12}$$

$$VM_{ij} = \begin{Bmatrix} \left(\left(VI_{ij}^{L}\right),\left(VI_{ij}^{M}\right),\left(VI_{ij}^{U}\right)\right), \\ \left(\left(VI_{ij}^{L}\right),\left(VI_{ij}^{M}\right),\left(VI_{ij}^{U}\right)\right), \\ \left(\left(VF_{ij}^{L}\right),\left(VF_{ij}^{M}\right),\left(VF_{ij}^{U}\right)\right) \end{Bmatrix} \tag{13}$$

Step 2. Normalize $VM = \left[VM_{ij}\right]_{m\times n}$ into $NVM = \left[NVM_{ij}\right]_{m\times n}$.

Aiming at benefit attributes:

$$NVM_{ij} = \begin{Bmatrix} \left(\left(NVT_{ij}^{L}\right),\left(NVT_{ij}^{M}\right),\left(NVT_{ij}^{U}\right)\right), \\ \left(\left(NVI_{ij}^{L}\right),\left(NVI_{ij}^{M}\right),\left(NVI_{ij}^{U}\right)\right), \\ \left(\left(NVF_{ij}^{L}\right),\left(NVF_{ij}^{M}\right),\left(NVF_{ij}^{U}\right)\right) \end{Bmatrix} = \begin{Bmatrix} \left(\left(VT_{ij}^{L}\right),\left(VT_{ij}^{M}\right),\left(VT_{ij}^{U}\right)\right), \\ \left(\left(VI_{ij}^{L}\right),\left(VI_{ij}^{M}\right),\left(VI_{ij}^{U}\right)\right), \\ \left(\left(VF_{ij}^{L}\right),\left(VF_{ij}^{M}\right),\left(VF_{ij}^{U}\right)\right) \end{Bmatrix} \tag{14}$$

Aiming at cost attributes:

$$NVM_{ij} = \begin{Bmatrix} \left(\left(NVT_{ij}^{L}\right),\left(NVT_{ij}^{M}\right),\left(NVT_{ij}^{U}\right)\right), \\ \left(\left(NVI_{ij}^{L}\right),\left(NVI_{ij}^{M}\right),\left(NVI_{ij}^{U}\right)\right), \\ \left(\left(NVF_{ij}^{L}\right),\left(NVF_{ij}^{M}\right),\left(NVF_{ij}^{U}\right)\right) \end{Bmatrix} = \begin{Bmatrix} \left(\left(VF_{ij}^{L}\right),\left(VF_{ij}^{M}\right),\left(VF_{ij}^{U}\right)\right), \\ \left(\left(VI_{ij}^{L}\right),\left(VI_{ij}^{M}\right),\left(VI_{ij}^{U}\right)\right), \\ \left(\left(VT_{ij}^{L}\right),\left(VT_{ij}^{M}\right),\left(VT_{ij}^{U}\right)\right) \end{Bmatrix} \tag{15}$$

B. Cultivate the Weight Numbers Through Entropy

Step 3. Cultivate the weight numbers through entropy.

The weight is fundamental for MAGDM [48-52]. Entropy [53] is cultivated for weight numbers. The normalized fuzzy decision matrix (NFDM) is cultivated:

$$NFDM_{ij} = \frac{\left(\dfrac{AF\begin{Bmatrix} \left(\left(NHA_{ij}^{L}\right),\left(NHA_{ij}^{M}\right),\left(NHA_{ij}^{U}\right)\right), \\ \left(\left(NHB_{ij}^{L}\right),\left(NHB_{ij}^{M}\right),\left(NHB_{ij}^{U}\right)\right), \\ \left(\left(NHC_{ij}^{L}\right),\left(NHC_{ij}^{M}\right),\left(NHC_{ij}^{U}\right)\right) \end{Bmatrix}+1}{SF\begin{Bmatrix} \left(\left(NHA_{ij}^{L}\right),\left(NHA_{ij}^{M}\right),\left(NHA_{ij}^{U}\right)\right), \\ \left(\left(NHB_{ij}^{L}\right),\left(NHB_{ij}^{M}\right),\left(NHB_{ij}^{U}\right)\right), \\ \left(\left(NHC_{ij}^{L}\right),\left(NHC_{ij}^{M}\right),\left(NHC_{ij}^{U}\right)\right) \end{Bmatrix}+1} \right)}{\sum_{i=1}^{m}\left(\dfrac{AF\begin{Bmatrix} \left(\left(NHA_{ij}^{L}\right),\left(NHA_{ij}^{M}\right),\left(NHA_{ij}^{U}\right)\right), \\ \left(\left(NHB_{ij}^{L}\right),\left(NHB_{ij}^{M}\right),\left(NHB_{ij}^{U}\right)\right), \\ \left(\left(NHC_{ij}^{L}\right),\left(NHC_{ij}^{M}\right),\left(NHC_{ij}^{U}\right)\right) \end{Bmatrix}+1}{SF\begin{Bmatrix} \left(\left(NHA_{ij}^{L}\right),\left(NHA_{ij}^{M}\right),\left(NHA_{ij}^{U}\right)\right), \\ \left(\left(NHB_{ij}^{L}\right),\left(NHB_{ij}^{M}\right),\left(NHB_{ij}^{U}\right)\right), \\ \left(\left(NHC_{ij}^{L}\right),\left(NHC_{ij}^{M}\right),\left(NHC_{ij}^{U}\right)\right) \end{Bmatrix}+1} \right)}, \tag{16}$$

The fuzzy Shannon decision entropy (FSDE) is cultivated:

$$FSDE_j = -\frac{1}{\ln m}\sum_{i=1}^{m} NFDM_{ij} \ln NFDM_{ij} \tag{17}$$

and $NFDM_{ij} \ln NFDM_{ij} = 0$ if $NFDM_{ij} = 0$.

Then, the weight numbers $vw = \left(vw_1, vw_2, \cdots, vw_n\right)$ is cultivated:

$$vw_j = \frac{1 - FSDE_j}{\sum_{j=1}^{n}\left(1 - FSDE_j\right)} \tag{18}$$

C. T2NN-ExpTODIM-TOPSIS Approach for MADM

The T2NN-ExpTODIM-TOPSIS approach is cultivated for MADM.

Step 4. Cultivate relative weight numbers:

$$rvw_j = vw_j \Big/ \max_j vw_j, \tag{19}$$

Step 5. Cultivate the The T2NN dominance degree values (T2NNDDV).

1) The T2NNDDV of VA_i over VA_t for VG_j is cultivated:

$$T2NNDDV_j\left(VA_i,VA_t\right)=\begin{cases}\dfrac{rvw_j\times\left(1-10^{-\rho T2NNHD\left(NVM_{ij},NVM_{tj}\right)}\right)}{\sum_{j=1}^{n}rvw_j} & if\ SF\left(NVM_{ij}\right)>SF\left(NVM_{tj}\right)\\ 0 & if\ SF\left(NVM_{ij}\right)=SF\left(NVM_{tj}\right)\\ -\dfrac{1}{v\theta}\dfrac{\sum_{j=1}^{n}rvw_j\times\left(1-10^{-\rho T2NNHD\left(NVM_{ij},NVM_{tj}\right)}\right)}{rvw_j} & if\ SF\left(NVM_{ij}\right)<SF\left(NVM_{tj}\right)\end{cases} \quad (20)$$

where, $v\theta$ is presented from Tversky and Kahneman [54] and $\rho\in[1,5]$[55].

2) The $T2NNDDV_j\left(VA_i\right)\left(j=1,2,3,\cdots,n\right)$ with respect to VG_j is cultivated:

$$T2NNDDV_j\left(VA_i\right)=\left[T2NNDDV_j\left(VA_i,VA_t\right)\right]_{m\times m}$$

$$=\begin{matrix} & VA_1 & VA_2 & \cdots & VA_m\\ VA_1 & 0 & T2NNDDV_j\left(VA_1,VA_2\right) & \cdots & T2NNDDV_j\left(VA_1,VA_m\right)\\ VA_2 & T2NNDDV_j\left(VA_2,VA_1\right) & 0 & \cdots & T2NNDDV_j\left(VA_2,VA_m\right)\\ \vdots & \vdots & \vdots & \cdots & \vdots\\ VA_m & T2NNDDV_j\left(VA_m,VA_1\right) & T2NNDDV_j\left(VA_m,VA_2\right) & \cdots & 0\end{matrix}$$

3) Cultivate the overall T2NNDDV of VA_i over others for VG_j:

$$T2NNDDV_j\left(VA_i\right)=\sum_{t=1}^{m}T2NNDDV_j\left(VA_i,VA_t\right) \quad (21)$$

4) The overall T2NNDDD matrix is cultivated:

$$T2NNDDV=\left(T2NNDDV_{ij}\right)_{m\times n}$$

$$=\begin{bmatrix} & VG_1 & VG_2 & \cdots & VG_n\\ VA_1 & \sum_{t=1}^{m}T2NNDDV_1\left(VA_1,VA_t\right) & \sum_{t=1}^{m}T2NNDDV_2\left(VA_1,VA_t\right) & \dots & \sum_{t=1}^{m}T2NNDDV_n\left(VA_1,VA_t\right)\\ VA_2 & \sum_{t=1}^{m}T2NNDDV_1\left(VA_2,VA_t\right) & \sum_{t=1}^{m}T2NNDDV_2\left(VA_2,VA_t\right) & \dots & \sum_{t=1}^{m}T2NNDDV_n\left(VA_2,VA_t\right)\\ \vdots & \vdots & \vdots & \vdots & \vdots\\ VA_m & \sum_{t=1}^{m}T2NNDDV_1\left(VA_m,VA_t\right) & \sum_{t=1}^{m}T2NNDDV_2\left(VA_m,VA_t\right) & \dots & \sum_{t=1}^{m}T2NNDDV_n\left(VA_m,VA_t\right)\end{bmatrix}$$

Step 6. Cultivate the T2NN positive ideal decision solution (T2NNPIDS) and T2NN negative ideal decision solution (T2NNNIDS):

$$T2NNPIDS=\left(T2NNPIDS_1,T2NNPIDS_1,\cdots,T2NNPIDS_n\right) \quad (22)$$

$$T2NNNIDS=\left(T2NNNIDS_1,T2NNNIDS_1,\cdots,T2NNNIDS_n\right) \quad (23)$$

$$T2NNPIDS_j=\max_{j=1}^{n}T2NNDDV_{ij}, \quad (24)$$

$$T2NNNIDS_j=\min_{j=1}^{n}T2NNDDV_{ij} \quad (25)$$

Step 7. Cultivate the T2NN Euclidean distance values (T2NNEDV) for T2NNPIDS and T2NNNIDS.

$$T2NNEDV\left(HA_i,T2NNPIDS\right)=\sqrt{\sum_{j=1}^{n}\left(T2NNDDV_{ij}-T2NNPIDS_j\right)^2} \quad (26)$$

$$T2NNEDV\left(VA_i, T2NNNIDS\right) = \sqrt{\sum_{j=1}^{n}\left(T2NNDDV_{ij} - T2NNNIDS_j\right)^2} \quad (27)$$

Step 8. Cultivate the T2NN closeness coefficient values (T2NNCCV) for T2NNPIDS.

$$T2NNCCV\left(VA_i, T2NNPIDS\right) = \frac{T2NNEDV\left(VA_i, T2NNNIDS\right)}{\left(\begin{array}{l} T2NNEDV\left(VA_i, T2NNPIDS\right) \\ + T2NNEDV\left(VA_i, T2NNPIDS\right) \end{array}\right)} \quad (28)$$

$$= \frac{\sqrt{\sum_{j=1}^{n}\left(T2NNDDD_{ij} - T2NNNIDS_j\right)^2}}{\left(\begin{array}{l} \sqrt{\sum_{j=1}^{n}\left(T2NNDDD_{ij} - T2NNNIDS_j\right)^2} \\ + \sqrt{\sum_{j=1}^{n}\left(T2NNDDD_{ij} - T2NNPIDS_j\right)^2} \end{array}\right)} \quad (29)$$

Step 9. Rank and choose the optimal scheme in line with maximum T2NNCCV.

IV. Numerical Example and Comparative Analysis

A. *Numerical Example for Quality Evaluation of Digital Agriculture Park Information System*

Since the 1990s, under the joint promotion of the Ministry of Agriculture, the Ministry of Science and Technology, and other ministries, China has initiated the construction of modern agricultural demonstration zones and agricultural science and technology parks at various levels. The aim is to cluster high-quality agricultural production elements such as science, policy, and funding in these parks to lead the transformation and development of agriculture. Some parks comprehensively utilize the Internet of Things, cloud computing, and automatic control technologies to enhance their production and management levels. As modern agricultural parks deepen their exploration of information systems, the precise and intelligent advantages of digital technology have been leveraged, enhancing the value of park development. However, this has also exposed some deficiencies, mainly manifested in the following aspects: the disconnection between information systems and the main business of the parks; information system operations becoming a "negative asset" as they fail to fully enhance management performance and continuously overdraw management costs; "cold wars" and redundant construction between information systems due to a lack of overall planning and coordination, leading to a lack of unified standards and coordination between old and new systems; the lack of distinct agricultural characteristics in the parks, with agricultural-specific sensors currently lacking and intelligent control based on operation types and models still in the theoretical research stage; the breadth of the potential of information technology to stimulate agricultural economy is insufficient, and the economic potential of the combination of information technology and agriculture has not been fully tapped. Digital agricultural parks are not limited to production functions; they can combine the multi-dimensional advantages of the parks to play multifunctional effects such as technology promotion, scientific and educational training, capital aggregation, and scientific research transformation, thereby enhancing the added value of the development of digital agricultural parks. The construction of digital agricultural parks is a systematic and all-inclusive project that requires the support of various management tools like performance, system, and organization to improve the priority level of digital agriculture, achieve top-down, unified resource organization effects, and effectively mobilize organizational enthusiasm to realize construction goals. It is necessary to focus on the financial sustainability during the construction and operational phases as an important indicator for the construction of digital agriculture, incorporating it into feasibility or planning studies. The construction of digital agricultural parks cannot be separated from the deep involvement of a professional team, which should at least include roles such as IT consultants, project managers, product managers, developers, and operations engineers, and maintain the team's continuity and stability in the development of the park to ensure the continuous advancement of the digitalization strategy. The quality evaluation of digital agriculture park information system is MADM. Therefore, the quality evaluation of digital agriculture park information system is presented to demonstrate T2NN-ExpTODIM-TOPSIS. Five potential digital agriculture park information systems $VA_i\left(i=1,2,3,4,5\right)$ to assessed in line with different attributes: ①VG_1 is software function for digital agriculture park information systems; ②VG_2 is software performance for digital agriculture park information systems; ③VG_3 is management cost for digital agriculture park information systems; ④VG_4 is software supplier for digital agriculture park information systems. The VG_3 is cost attribute. The T2NN-ExpTODIM-TOPSIS is put forward the quality evaluation of digital agriculture park information system.

Step 1. Cultivate the T2NN-matrix $VM = \left[VM_{ij}\right]_{5\times 4}$ (see Table I).

TABLE I. T2NN INFORMATION

	VG_1	VG_2
VA_1	$\{(0.53,0.62,0.87),(0.48,0.64,0.75),(0.45,0.51,0.59)\}$	$\{(0.42,0.53,0.62),(0.27,0.46,0.58),(0.48,0.53,0.57)\}$
VA_2	$\{(0.32,0.43,0.64),(0.28,0.39,0.67),(0.25,0.36,0.48)\}$	$\{(0.49,0.57,0.69),(0.58,0.65,0.74),(0.45,0.53,0.61)\}$
VA_3	$\{(0.51,0.58,0.76),(0.54,0.56,0.67),(0.35,0.39,0.54)\}$	$\{(0.39,0.57,0.65),(0.51,0.64,0.79),(0.54,0.58,0.73)\}$
VA_4	$\{(0.49,0.67,0.71),(0.32,0.45,0.67),(0.26,0.38,0.56)\}$	$\{(0.62,0.74,0.83),(0.37,0.46,0.58),(0.32,0.36,0.49)\}$
VA_5	$\{(0.48,0.52,0.59),(0.27,0.36,0.46),(0.42,0.45,0.48)\}$	$\{(0.65,0.76,0.84),(0.52,0.54,0.63),(0.56,0.62,0.72)\}$
	VG_3	VG_4
VA_1	$\{(0.57,0.63,0.67),(0.29,0.52,0.63),(0.26,0.39,0.45)\}$	$\{(0.23,0.34,0.45),(0.43,0.51,0.57),(0.49,0.53,0.62)\}$
VA_2	$\{(0.39,0.47,0.53),(0.51,0.56,0.62),(0.34,0.57,0.69)\}$	$\{(0.43,0.47,0.52),(0.26,0.35,0.38),(0.46,0.49,0.52)\}$
VA_3	$\{(0.64,0.66,0.72),(0.73,0.81,0.85),(0.69,0.76,0.79)\}$	$\{(0.63,0.67,0.76),(0.37,0.45,0.52),(0.21,0.23,0.26)\}$
VA_4	$\{(0.25,0.34,0.62),(0.59,0.63,0.72),(0.46,0.53,0.62)\}$	$\{(0.38,0.42,0.47),(0.43,0.46,0.48),(0.32,0.43,0.53)\}$
VA_5	$\{(0.43,0.45,0.52),(0.43,0.52,0.65),(0.36,0.45,0.53)\}$	$\{(0.51,0.53,0.62),(0.43,0.54,0.65),(0.53,0.62,0.73)\}$

Step 2. Normalize the $VM = \left[VM_{ij}\right]_{5\times4}$ into $NVM = \left[NVM_{ij}\right]_{5\times4}$ (see Table II).

TABLE II. THE NORMALIZED T2NN

	VG1	VG2
VA1	$\{(0.53,0.62,0.87),(0.48,0.64,0.75),(0.45,0.51,0.59)\}$	$\{(0.42,0.53,0.62),(0.27,0.46,0.58),(0.48,0.53,0.57)\}$
VA2	$\{(0.32,0.43,0.64),(0.28,0.39,0.67),(0.25,0.36,0.48)\}$	$\{(0.49,0.57,0.69),(0.58,0.65,0.74),(0.45,0.53,0.61)\}$
VA3	$\{(0.51,0.58,0.76),(0.54,0.56,0.67),(0.35,0.39,0.54)\}$	$\{(0.39,0.57,0.65),(0.51,0.64,0.79),(0.54,0.58,0.73)\}$
VA4	$\{(0.49,0.67,0.71),(0.32,0.45,0.67),(0.26,0.38,0.56)\}$	$\{(0.62,0.74,0.83),(0.37,0.46,0.58),(0.32,0.36,0.49)\}$
VA5	$\{(0.48,0.52,0.59),(0.27,0.36,0.46),(0.42,0.45,0.48)\}$	$\{(0.65,0.76,0.84),(0.52,0.54,0.63),(0.56,0.62,0.72)\}$
	VG3	VG4
VA1	$\{(0.26,0.39,0.45),(0.29,0.52,0.63),(0.57,0.63,0.67)\}$	$\{(0.23,0.34,0.45),(0.43,0.51,0.57),(0.49,0.53,0.62)\}$
VA2	$\{(0.34,0.57,0.69),(0.51,0.56,0.62),(0.39,0.47,0.53)\}$	$\{(0.43,0.47,0.52),(0.26,0.35,0.38),(0.46,0.49,0.52)\}$
VA3	$\{(0.69,0.76,0.79),(0.73,0.81,0.85),(0.64,0.66,0.72)\}$	$\{(0.63,0.67,0.76),(0.37,0.45,0.52),(0.21,0.23,0.26)\}$
VA4	$\{(0.46,0.53,0.62),(0.59,0.63,0.72),(0.25,0.34,0.62)\}$	$\{(0.38,0.42,0.47),(0.43,0.46,0.48),(0.32,0.43,0.53)\}$
VA5	$\{(0.36,0.45,0.53),(0.43,0.52,0.65),(0.43,0.45,0.52)\}$	$\{(0.51,0.53,0.62),(0.43,0.54,0.65),(0.53,0.62,0.73)\}$

Step 3. Cultivate the weight numbers:

$$vw_1 = 0.3250, vw_2 = 0.3071$$
$$vw_3 = 0.1461, vw_4 = 0.2218.$$

Step 4. Cultivate the relative weight numbers:

$$rvw = (1.0000, 0.9449, 0.4495, 0.6825)$$

Step 5. Cultivate the $T2NNDDD = \left(T2NNDDD_{ij}\right)_{5\times4}$ (see Table III):

TABLE III. THE $T2NNDDD = \left(T2NNDDD_{ij}\right)_{5\times4}$

	VG_1	VG_2	VG_3	VG_4
VA_1	-0.6281	-1.8156	0.5728	0.4033
VA_2	0.4370	1.4745	1.2118	1.1449
VA_3	-0.0216	-0.9719	-1.4074	-1.5380
VA_4	-0.7467	-0.2071	-0.6192	-0.4214
VA_5	-2.4991	0.3732	1.2087	-0.7838

Step 6. Cultivate the T2NNPIDS and T2NNNIDS (see Table IV).

TABLE IV. THE T2NNPIDS AND T2NNNIDS

	VG_1	VG_2	VG_3	VG_4
T2NNPIDS	0.4370	1.4745	1.2118	1.1449
T2NNNIDS	-2.4991	-1.8156	-1.4074	-1.5380

Step 7. Cultivate the $T2NNEDV\left(VA_i, T2NNPIDS\right)$ and $T2NNEDV\left(VA_i, T2NNNIDS\right)$ (see Table V).

TABLE V. THE $T2NNEDV\left(VA_i, T2NNPIDS\right)$ AND $T2NNEDV\left(VA_i, T2NNNIDS\right)$

Alternative	$T2NNEDV\left(VA_i, T2NNPIDS\right)$	$T2NNEDV\left(VA_i, T2NNNIDS\right)$
VA_1	3.5941	3.3452
VA_2	0.0000	5.7882
VA_3	4.5004	2.6172
VA_4	3.1678	2.7434
VA_5	3.6815	3.4933

Step 8. Cultivate the $T2NNCCV\left(VA_i, T2NNPIDS\right)$ (see Table VI).

TABLE VI. THE $T2NNCCV\left(VA_i, T2NNPIDS\right)$

Alternative	$T2NNCCV\left(VA_i, T2NNPIDS\right)$	Order
VA_1	0.4821	3
VA_2	1.0000	1
VA_3	0.3677	5
VA_4	0.4641	4
VA_5	0.4869	2

Step 9. In light with $T2NNCCV(VA_i, T2NNPIDS)$, the order is: $VA_2 > VA_5 > VA_1 > VA_4 > VA_3$ and the optimal digital agriculture park information system is VA_2.

B. Comparative Analysis

Then, the T2NN-ExpTODIM-TOPSIS approach is compared with T2NNWA approach [46], T2NNWG approach [46], T2NN-TOPSIS approach [46], T2NN-EDAS approach [56], T2NN-MABAC approach [57], T2NN-TODIM approach [58] and T2NN-TODIM-VIKOR approach [59]. The comparative results are cultivated in Table VII and Fig. 2.

From the above concrete analysis, it could be implemented that the order of these different approaches is slightly different, however, these different approaches have same optimal digital agriculture park information system and worst digital agriculture park information system. This verifies the T2NN-ExpTODIM-TOPSIS approach is effective for quality evaluation of digital agriculture park information system. Thus, the major advantages of T2NN-ExpTODIM-TOPSIS approach are administrated: (1) T2NN-ExpTODIM-TOPSIS approach not only administrated the uncertainty, but also administrated the psychological behavior during quality evaluation of digital agriculture park information system. (2) T2NN-ExpTODIM-TOPSIS administrated the different behavior of ExpTODIM and TOPSIS when these two techniques are hybrid with each other.

TABLE VII. ORDER FOR DIFFERENT APPROACHES

Approaches	order
T2NNWA approach [46]	$VA_2 > VA_5 > VA_1 > VA_4 > VA_3$
T2NNWG approach[46]	$VA_2 > VA_5 > VA_4 > VA_1 > VA_3$
T2NN-TOPSIS approach [46]	$VA_2 > VA_5 > VA_1 > VA_4 > VA_3$
T2NN-EDAS approach [56]	$VA_2 > VA_5 > VA_4 > VA_1 > VA_3$
T2NN-MABAC approach[57]	$VA_2 > VA_5 > VA_1 > VA_4 > VA_3$
T2NN-TODIM approach[58]	$VA_2 > VA_5 > VA_1 > VA_4 > VA_3$
T2NN-TODIM-VIKOR approach[59]	$VA_2 > VA_5 > VA_1 > VA_4 > VA_3$
The T2NN-ExpTODIM-TOPSIS approach	$VA_2 > VA_5 > VA_1 > VA_4 > VA_3$

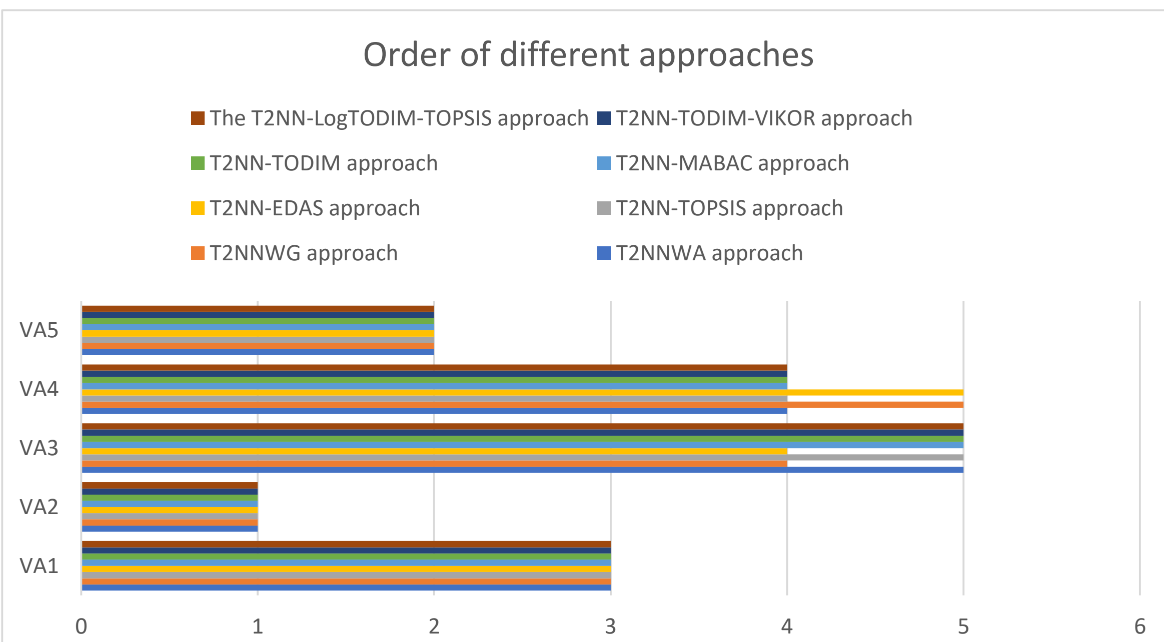

Fig. 2. Order of different approaches.

V. CONCLUSION

Modern agricultural parks gather elements such as land, capital, technology, talent, and information. They serve multiple functions including agricultural science and technology innovation and transformation, clustering and incubation of agri-tech enterprises, cultivation and functional expansion of new agricultural industries, and modern agricultural technology training and information services. These parks are crucial in effectively promoting the transition from traditional to modern agriculture, facilitating regional agricultural industrial structure adjustments and industrial optimization and upgrading, and achieving agricultural modernization. Digital agriculture treats data information as a key element of agricultural production. It integrates modern information technologies such as the Internet of Things, cloud computing, and big data to intelligently control agricultural resources and environments, agricultural production processes, and agricultural products, representing a new form of agriculture. Digital agriculture can effectively change traditional production relationships, compel small-scale economies towards scalable development, reduce transaction costs, establish the fastest circulation paths, and accelerate the development of rural economies. Digital agriculture is a crucial "direction marker" for the modernization of agriculture, and the implementation of digital technologies in modern agricultural parks is the "opening move" in the strategic game of digital agriculture. The quality evaluation of digital agriculture park information system is MADM. The TODIM and TOPSIS was put up with MADM. The T2NNs are put up with characterizing fuzzy information during the quality evaluation of digital agriculture park information system. In this work, T2NN-ExpTODIM-TOPSIS model is put forward MADM along with T2NNs. Numerical example for quality evaluation of digital agriculture park information system and comparative analysis is put forward the validity of T2NN-ExpTODIM-TOPSIS approach. The major research motivation is cultivated: (1) ExpTODIM and TOPSIS approach was enhanced under T2NNs; (2) Entropy is put forward weight numbers in light with score values along with T2NNs; (3) T2NN-ExpTODIM-TOPSIS is put forward the MADM along with T2NNs; (4) numerical example for quality evaluation of digital agriculture park information system and comparative analysis is put forward the validity of T2NN-ExpTODIM-TOPSIS.

There may be some possible study limitations, which could be further executed the quality evaluation of digital agriculture park information system: (1) It is a worthwhile research contents to execute consensus issue [60-62] to quality evaluation of digital agriculture park information system under T2NNs; (2) It is also worthwhile research contents to execute regret theory model to quality evaluation of digital agriculture park information system under T2NNs [63-65]; (3) In future research contents, full integration of ExpTODIM approach with other approaches could be executed for quality evaluation of digital agriculture park information system [66, 67].

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