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Research Article

Algorithms for probabilistic uncertain linguistic multiple attribute group decision making based on the GRA and CRITIC method: application to location planning of electric vehicle charging stations

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method. Then, the optimal alternative is chosen by calculating largest relative relational degree from the probabilistic uncertain linguistic positive ideal solution (PULPIS) which considers both the largest grey relational coefficient from the PULPIS and the smallest grey relational coefficient from the probabilistic uncertain linguistic negative ideal solution (PULNIS). Finally, a numerical case for site selection of electric vehicle charging stations (EVCS) is designed to illustrate the proposed method. The result shows the approach is simple, effective and easy to calculate.

Keywords:

Multiple attribute group decision making (MAGDM) probabilistic uncertain linguistic term sets (PULTSs)

grey relational analysis (GRA) method CRITIC method site selection electric vehicle charging stations

JEL CODES:

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1. Introduction

In many … it has been
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have equal weight or importance. Thus, Pang, Wang, and Xu (2016) defined the probabilistic linguistic term sets (PLTSs) to overcome this defect. J.P. Lu et al. (2019) designed the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method for probabilistic linguistic MAGDM for supplier selection of new agricultural machinery products. Feng, Liu, and Wei (2019) proposed the probabilistic linguistic QUALItative FLEXible multiple criteria method (QUALIFLEX) method with possibility degree comparison. Chen, Wang, and Wang (2019) employed the probabilistic linguistic MULTIMOORA for cloud-based Enterprise Resource Planning (ERP) system selection. G.W. Wei, Wei, Wu, and Wang (2019) defined the supplier selection of medical consumption products with a probabilistic linguistic multi-attributive border approximation area comparison (MABAC) method. Lei, Wei, Lu, Wei, and Wu (2019) proposed the GRA method for probabilistic linguistic multiple attribute group decision making with incomplete weight information and its application to waste incineration plants location problem. Liao, Jiang, Lev, and Fujita (2019) studied the novel operations of PLTSs to solve the probabilistic linguistic ELimination Et Choix Traduisant la REalité (ELECTRE) III method. In some practical situations, a set of DMs may have their preferences to express their assessment information by using uncertain linguistic terms (Z.S. Xu, 2004) in the group decision making (GDM) processes because of lack of sufficient knowledge and the fuzziness of human’s thinking, However, these uncertain linguistic terms are different from each other and also the number of occurrences of each un
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total performances of the sample venture capital enterprises in order. Alptekin, Alptekin, and Sarac (2018) assessed the low carbon development of European Union countries and Turkey with GRA model. Tan, Chen, and Wu (2019) studied the green design alternatives and GRA integrated with Analytical Hierarchy Process (AHP). Sun, Guan, Yi, and Zhou (2018) and HFSs slope grey relational degree together to construct the HFSs synthetic grey relational degree which takes both the closeness and the linear fashion into consideration. Malek, Ebrahimnejad, and Tavakkoli-Moghaddam (2017) proposed an improved hybrid GRA method for green resilient supply. G. D. Tian et al. (2018) defined the grey-correlation based hybrid multi-criteria decision making (MCDM) method for green decoration materials selection under interior environment characteristics. G. Tian et al. (2019) designed the fuzzy grey Choquet integral for evaluation of multicriteria decision making problems with interactive and qualitative indices.

But there are no studies on the GRA method for MAGDM under PULTSs in the existing literature. Therefore, it is necessary to pay attention to this issue. The goal of this paper is to extend the GRA method to solve the probabilistic uncertain linguistic MAGDM with unknown weight information on the basis of the CRITIC method. The motivation of such paper can be outlined as follows: (1) the GRA method is extended by PULTSs with unknown weight information; (2) the scoring function of PULTs is employed to objectively derive the attribute weights based on the CRITIC method; (3) the
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Z. S. Xu (2005) designed the additive linguistic evaluation scale and Gou, Xu, and Liao (2017) proposed the corresponding transformation function between the linguistic terms and[0,1].

Definition 1.

(Gou et al., 2017; Z. S. Xu, 2005). Let $L=\{l\alpha|\alpha=-\theta,\ldots,-2,-1,0,1,2,\ldots\theta\}$ be an LTS (Z. S. Xu, 2005), the linguistic terms $l\alpha$ can depict the equivalent information to β is obtained by the transformation functiong (Gou et al., 2017):

$$g:[l-\theta,l\theta]\rightarrow[0,1],g(l\alpha)=\alpha+\theta2\theta=\beta \tag{1}$$

At the same time, β can be expressed the equivalent information to the linguistic terms $l\alpha$, which is derived by the transformation functiong−1:

$$g-1:[0,1]\rightarrow[l-\theta,l\theta],g-1(\beta)=l(2\beta-1)\theta=l\alpha \tag{2}$$

In order to strengthen the modeling capability of HFLTSs, Pang et al. (2016) designed the definition of PLTSs to link each linguistic term with a probability value.

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$$PULTS(p)=\{[L_\phi,U_\phi](p_\phi)|p_\phi\geq0,\phi=1,2,\ldots,\#PULTS(p),\sum_{\phi=1}^{\#PULTS(p)}p_\phi\leq1\}$$

(4) where $[L_\phi,U_\phi](p_\phi)$ depicts the uncertain linguistic term $[L_\phi,U_\phi]$ associated with the probability p_ϕ, L_ϕ,U_ϕ are linguistic term sets, $L_\phi\leq U_\phi$, and $\#PULT(p)$ is the cardinality of $PULTS(p)$.

In order to convenient computation, Lin et al. (2018) normalized the PULTS $PULTS(p)$ as $NPULTS(p)=\{[L_\phi,U_\phi](\tilde{p}_\phi)|\tilde{p}_\phi\geq0,\phi=1,2,\ldots,\#NPULTS(\tilde{p}),\sum_{\phi=1}^{\#NPULTS(\tilde{p})}\tilde{p}_\phi=1\}$, where $\tilde{p}(\phi)=p(\phi)/\sum_{\phi=1}^{\#L(p)}p(\phi)$ for all$\phi=1,2,\ldots,\#NPULTS(\tilde{p})$.

Definition 4.

(Lin et al., 2018). Let$PULTS_1(p)=\{[L_{1\phi},U_{1\phi}](p_{1\phi})|\phi=1,2,\ldots,\#PULTS_1(p)\}$ and $PULTS_2(p)=\{[L_{2\phi},U_{2\phi}](p_{2\phi})|\phi=1,2,\ldots,\#PULTS_2(p)\}$ be two PULTSs, where $\#PULTS_1(p)$ and $\#PULTS_2(p)$ are the numbers of PULTSs $PULTS_1(p)$ and $PULTS_2(p)$, respectively. If $\#PULTS_1(p)>\#PULTS_2(p)$, then add $\#PULTS_1(p)-\#PULTS_2(p)$ linguistic terms to $PULTS_2(p)$. Moreover, the added uncertain linguistic terms should be the smallest linguistic term in $PULTS_2(p)$ and the probabilities of added linguistic terms should be zero.

Definition 5.

(Lin et al., 2018). For the$PULTS(p)=\{[L_\phi,U_\phi](p_\phi)|\phi=1,2,\ldots,\#PULTS(p)\}$, the expected value $E(PULTS(p))$ and deviation degree $DD(PULTS(p))$ of $PULTS(p)$ is defined:

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then Hamming distance HD(PULTS1(p), PULTS2(p)) between PULTS1(p) and PULTS2(p) is defined as follows:

$$HD(PULTS1(p),PULTS2(p))=\sum \phi=1\#PULTS(p)\ (|g(L1\phi)p\phi-g(L2\phi)p\phi|+|g(U1\phi)p\phi-g(U2\phi)p\phi|)2\#PULTS(p) \quad (7)$$

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3. GRA method for PUL-MAGDM with CRITIC weight

In such section, we propose the probabilistic uncertain linguistic GRA (PUL-GRA) method for MAGDM problems with unknown weight information. The following mathematical notations are used to denote the probabilistic linguistic MAGDM problems. Let A={A1,A2,…,Am} be a discrete set of chosen alternatives, and G={G1,G2,…,Gn} with weight vectorw=(w1,w2,…,wn), where wj∈[0,1], j=1,2,…,n,∑j=1nwj=1, and a set of experts E={E1,E2,…,Eq}. Suppose that there are n qualitative attribute and their values are evaluated by qualified experts and denoted as uncertain linguistic expressions information [Lijk,Uijk](i=1,2,…,m,j=1,2,…,n,k=1,2,…,q) .

Then, PUL-GRA method is designed to solve the MAGDM problems with PULTs and CRITIC weight. The detailed calculating steps are listed as follows:

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Step 4

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In such section, an essential method called CRiteria Importance Through Intercriteria Correlation (CRITIC) was initially presented by (Diakoulaki., Mavrotas., & Papayannakis., 1995), will be introduced to decide the objective weights of attributes. Subsequently, the detailed computing procedures of this combined weight method are given as follows.

1. Build the probabilistic uncertain linguistic correlation coefficient matrix PULCCM=(PULCCjt)n×n by computing the correlation coefficient between attributes.

PULCCjt=∑i=1m((∑ϕ=1#NPULDMij(p)(g(Lijϕ)pijϕ−g(Ljϕ)pjϕ)+(g(Uijϕ)pijϕ−g(Ujϕ)pjϕ)2)·(∑ϕ=1#NPULDMij(p)(g(Litϕ)pitϕ−g(Ltϕ)ptϕ)+(g(Uitϕ)pitϕ−g(Utϕ)ptϕ)2))∑i=1m(∑ϕ=1#NPULDMij(p)(g(Lijϕ)pijϕ−g(Ljϕ)pjϕ)+(g(Uijϕ)pijϕ−g(Ujϕ)pjϕ)2)2·∑i=1m((∑ϕ=1#NPULDMij(p)(g(Litϕ)pitϕ−g(Ltϕ)ptϕ)+(g(Uitϕ)pitϕ−g(Utϕ)ptϕ)2))2,

j,t=1,2,…,n

(7) where [Ljϕ,Ujϕ](pjϕ)=[∑i=1mLijϕm,∑i=1mUijϕm](∑i=1mpijϕm) and [Ltϕ,Utϕ](ptϕ)=[∑i=1mLitϕm,∑i=1mUitϕm](∑i=1mpitϕm).

2. Derive the probabilistic uncertain linguistic standard deviation (PULSD) of attri

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$$PULPIS=(PULPIS_1,PULPIS_2,\ldots,PULPIS_n)$$
(10)

$$PULNIS=(PULNIS_1,PULNIS_2,\ldots,PULNIS_n)$$
(11) where

$$PULPIS_j=\{pl_j^{\phi}(p_j^{\phi})|\phi=1,2,\ldots,\#NPULDM_{ij}(p)\},EV(PULPIS_j)=\{\max_i EV(NPULDM_{ij}(p))\}$$
(12)

$$PULNIS_j=\{nl_j^{\phi}(p_j^{\phi})|\phi=1,2,\ldots,\#NPULDM_{ij}(p)\},EV(PULNIS_j)=\{\min_i EV(NPULDM_{ij}(p))\}$$
(13)

Step 6. Calculate the grey relational coefficient of each alternative from PULPIS and PULNIS, respectively:

The grey relational coefficient of each alternative from PULPIS is given as

$$PULPIS(\xi_{ij})=\frac{\min_{1\le i\le m}\min_{1\le j\le n}HD(PULA_{ij},PULPIS_j)+\rho\max_{1\le i\le m}\max_{1\le j\le n}HD(PULA_{ij},PULPIS_j)}{HD(PULA_{ij},PULPIS_j)+\rho\max_{1\le i\le m}\max_{1\le j\le n}HD(PULA_{ij},PULPIS_j)},$$

$$i=1,2,\ldots,m,j\in1,2,\ldots,n.$$
(14)

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$$PULPIS(\xi_i)=\sum_{j=1}^{n} w_j PULPIS(\xi_{ij}), i=1,2,\ldots,m, \quad (18)$$

$$PULNIS(\xi_i)=\sum_{j=1}^{n} w_j PULNIS(\xi_{ij}), i=1,2,\ldots,m, \quad (19)$$

The fundamental principle of the GRA method is that the chosen alternative should have the ‘largest degree of grey relational coefficient’ from the PULPIS and the ‘smallest degree of grey relational coefficient’ from the PULNIS. Obviously, the larger $PULPIS(\xi_i)$ and the smaller $PULNIS(\xi_i)$, the better alternativeA_i is.

Step 8. Calculate the probabilistic uncertain linguistic relative relational degree (PULRRD) of each alternative from PULPIS.

$$PULRRD(\xi_i)=\frac{PULPIS(\xi_i)}{PULPIS(\xi_i)+PULNIS(\xi_i)}, i=1,2,\ldots,m, \quad (20)$$

Step 9. According to $PULRRD(\xi_i)$, the ranking order of all alternatives can be determined. Thus, if any alternative has the largest $PULRRD(\xi_i)$ value, then, it is the optimal alternative.

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facilities are an important guarantee to promote the large-scale use of electric logistics vehicles, and it is particularly important to reasonably determine the location distribution of charging facilities. At the same time, compared with the distribution of traditional fuel vehicles, the distribution of electric logistics vehicles is faced with difficulties such as limited battery capacity, few charging facilities and long charging time, so the traditional vehicle route distribution method cannot be directly applied to the distribution system of electric logistics vehicles. The location of charging station and the path planning of electric logistics vehicle depend on each other, so it is necessary to combine the site selection and vehicle path planning. The site selection of EVCS is deemed as a kind of MAGDM issue(Li et al., 2019; J. Wang, Lu, Wei, Lin, & Wei, 2019; J. Wang, Wei, et al., 2019; G. W. Wei, Wang, Wei, Wei, & Zhang, 2019; S. Q. Zhang, Wei, Gao, Wei, & Wei, 2019). Thus, in this section we present a numerical example for site selection of EVCS to illustrate the method designed in this paper. There are five possible EVCS sites Ai(i=1,2,3,4,5) to select. The experts selects four attribute to evaluate the five possible EVCS sites: ①G_1 is the waste discharge; ②G_2 is the construction cost; ③G_3 is the traffic convenience; ④G_4 is the service capability. The construction cost is not beneficial attribute, others are beneficial attribute. The five possible EVCS sites Ai(i=1,2,3,4,5) are to be evaluated by using the linguistic term set

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Table 3. Uncertain linguistic assessing matrix by the DM$_3$.

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Table 4. Uncertain linguistic assessing matrix by the DM$_4$.

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Table 5. Uncertain linguistic assessing matrix by the DM$_5$.

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Table 6. Uncertain linguistic assessing matrix by the DM$_1$.

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Table 10. Uncertain linguistic assessing matrix by the DM_5.

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Table 11. Probabilistic uncertain linguistic assessing matrix.

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Table 12. Normalized probabilistic uncertain linguistic assessing matrix.

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Table 13. PULPIS and PULNIS.

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Table 15. PULRRD of each alternative from PULPIS.

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Table 16. The sensitively analysis for PUL-GRA method.

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Table 17. The calculating results and sorting results by using PUL-TOPSIS method.

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Step 1 value is [sc s−β,s−α] (Se

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Step 4. Define the probabilistic linguistic positive ideal solution (PLPIS) and probabilistic linguistic negative ideal solution (PLNIS) (Table 13).

Step 5. Computing the corresponding GRC of each alternative from PULPIS and PULNIS (Tables 14 and 15), let ρ=0.5:

Step 6. the weight vector of attributes can be got: w=(0.2966,0.1930,0.2534,0.2570)T.

Step 7. Calculating the degree of GRC of all possible alternatives from PULPIS and PULNIS, respectively (Table 14):

Step 8. Calculating the PULRRD(ξi) of each alternative from PULPIS by Eq.(14) (Table 15).

Step 9. According to the PULRRD(ξi)(i=1,2,3,4,5), all the waste incineration plants sites can be ranked. Evidently, the order is A3>A4>A5>A1>A2 and the most desirable EVCS site among five alternatives isA3.

At the same time, we conduct the sensitively analysis to show the robustness of the proposed method. The parameter valueρ varies from 0.1 to 1. We could get the calculating result which is listed in Table 16. The ranking result is same and the order is: A3>A4>A5>A1>A2 when The parameter valueρ varies from 0.1 to 1. The optimal alternati the

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Firstly, w stic weighte attributes is derived ll attribute value of A operator.

$$Z2(w)=\{[l_{-0.6497},l_{-0.4331}],[l_{-0.5042},l_{-0.2521}],[l_{-1.0382},l_{-0.5069}]\}$$

$$Z3(w)=\{[l_{0.0000},l_{0.0514}],[l_{0.2121},l_{0.4242}],[l_{1.4730},l_{2.2095}]\}$$

$$Z4(w)=\{[l_{0.0000},l_{0.1158}],[l_{-0.0452},l_{0.2655}],[l_{0.6131},l_{1.1866}]\}$$

$$Z5(w)=\{[l_{-0.1414},l_{0.2707}],[l_{0.1693},l_{0.5572}],[l_{0.3100},l_{0.5100}]\}$$

Then, the score values of these five overall attribute values of each alternative Zi(w) (i=1,2,3,4,5) are obtained by Definition 9 (Lin et al., 2018) as follows:

$$E(Z1(w))=l_{-0.2043},E(Z2(w))=l_{-0.3760},E(Z3(w))=l_{0.4856}E(Z4(w))=l_{0.2373},E(Z5(w))=l_{0.1862}$$

Furthermore, we can derive the ranking result: A3>A4>A5>A1>A2. Thus, we have the same optimal EVCS siteA3.

4.2.2. Compared with PUL-TOPSIS method

Then, we compare our proposed method with probabilistic uncertain linguistic TOPSIS method (PUL-TOPSIS method) (Lin et al., 2018), then we can acquire the calculating results a … S siteA2.

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Z1(w … ,l2.6851]

Then, the score values of these five alternatives Zi(w)(i=1,2,3,4,5) are obtained by Definition 9 (Lin et al., 2018) as follows:

$$E(Z1(w))=l-0.9194,E(Z2(w))=l-1.6921,E(Z3(w))=l2.1851$$

$$E(Z4(w))=l1.0679,E(Z5(w))=l0.8379$$

Furthermore, we can derive the ranking result: A3>A4>A5>A1>A2. Thus, we have the same optimal EVCS siteA3.

5. Conclusion

In this paper, we extend the classical GRA method to the probabilistic uncertain linguistic MAGDM with unknown weight information. Firstly, the basic concept, comparative formula and Hamming distance of PULTs are briefly introduced. Then, the definition of the expected value is employed to objectively compute the attribute weights based on the CRITIC method. Then, the optimal alternative(s) is determined by calculating the 'largest degree of grey relational coefficient' from the PULPIS and the 'smallest degree of grey relational coefficient' from the PULNIS. Finally, a practical case study for site selection of EVCS is provided to validate the proposed algorithm and

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Additional information

Funding

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