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TODIM Method for Single-valued Neutrosophic Multiple Attribute Decision Making and its Application to Credit Risk Evaluation

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Abstract

The Single-valued neutrosophic set is an effective tool for depicting uncertainty of the credit risk of small new venture' indirect financing. In this paper, we used the TODIM method to the MADM with the Single-valued neutrosophic numbers (SVNNs). Firstly, the definition, expectation, comparative method and distance of SVNNs are briefly defined, and the steps of the classical TODIM method for MADM problems are built. Then, on the basis of the TODIM method, the extended TODIM method is proposed to deal with MADM problems in which the attribute values are in the SVNNs, and its significant characteristic is that it can fully consider the decision makers' bounded rationality which is a real action in decision making. Finally, an illustrative example for evaluating the credit risk of small new venture' indirect financing is given to verify the built method and to demonstrate its practicality and effectiveness.

Keywords

Multiple Attribute Decision Making; Single-valued Neutrosophic Number; TODIM Method; Credit Risk Evaluation.

1. Introduction

Zadeh [1] initially presented the theory of fuzzy sets (FSs). Atanassov [2] defined the concept of intuitionistic fuzzy sets (IFSs). Gou, Xu and Lei [3] defined some exponential operational law for IFNs. He, He and Huang [4]integrated the power averaging with IFSs. Gupta, Arora and Tiwari [5]extended the fuzzy entropy to IFSs. Li, Liu, Liu, Su and Wu [6]gave a grey target decision making with IFNs. Garg [7]presented a method related to MAGDM on the basis of intuitionistic fuzzy multiplicative preference and defined several geometric operators. Liu, Liu and Chen [8] built some intuitionistic fuzzy BM fused operators with Dombi operations. Bao, Xie, Long and Wei [9]defined prospect theory and evidential reasoning method under IFSs. Chen, Cheng and Lan [10] developed TOPSIS method and similarity measures under IFSs. Li and Wu [11]presented the intuitionistic fuzzy cross entropy distance. Khan, Lohani and Ieee [12]defined similarity measure about IFNs. Jin, Ni, Chen and Li [13]defined two GDM methods which can obtain the normalized intuitionistic fuzzy priority weights from IFPRs on the basis of the order consistency and the multiplicative consistency. Rouyendegh [14]used the ELECTRE method in IFSs to tackle some MCDM issues. Cali and Balaman [15]extended ELECTRE I with VIKOR method in IFSs to reflect the decision makers' preferences. Phochanikorn and Tan [16] incorporated DEMATEL with ANP to determine uncertainties and interdependencies among criteria and modified VIKOR to evaluate the sustainable supplier performance's desired level under intuitionistic fuzzy context. Liang, He, Wang, Chen and Li [17]extended MABAC method to IFSs through distance measures. Gan and Luo [18]used the hybrid method with DEMATEL and IFSs. Gupta, Mehlawat, Grover and Chen [19]modified the SIR method and combined it with IFSs. Hao, Xu, Zhao and Zhang [20]presented a theory of

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decision field for IFSs. Krishankumar, Arvinda, Amrutha, Premaladha, Ravichandran and Ieee [21]integrated AHP with IFSs to design a GDM method for effective cloud vendor selection.

A.Tversky and Kahneman [22] proposed the prospect theory which is a descriptive theory for decision making under risk. This theory incorporates three significant aspects [22]: (1) Reference dependence. The outcomes are manifested by gains and losses according to a reference alternative. (2) Diminishing sensitivity. For gains, the DMs are risk-averse. But for losses, they are risk-preference. (3) Loss aversion. The DMs are much more sensitive to losses than gains. On the basis of the prospect theory, Gomes and Lima [23]first established the TODIM (an acronym in Portuguese for Interactive Multi-Criteria Decision Making), which is effective to solve the MADM problems where the DMs' psychological behaviors are considered. TODIM is a valuable approach to consider the DMs' psychological behavior under risk. Gomes, Rangel and Maranhao [24] used TODIM method for multicriteria analysis of natural gas destination in Brazil. Gomes and Rangel [25] applied TODIM method for multicriteria rental evaluation of residential properties. Wei, Ren and Rodriguez [26] designed a hesitant fuzzy linguistic TODIM method with a score function. Mishra and Rani [27] studied the biparametric information measures-based TODIM method for interval-valued intuitionistic fuzzy environment. Wei [28] analyzed the TODIM method for Picture Fuzzy MADM. Lourenzutti and Krohling [29] gave a study of TODIM under intuitionistic fuzzy and random environment. Wang, Wei and Lu [30] defined the TODIM for MAGDM under 2-tuple linguistic neutrosophic environment. Huang and Wei [31] gave the TODIM method for Pythagorean 2-tuple linguistic MADM. Krohling, Pacheco and Siviero [32] defined an intuitionistic fuzzy TODIM to MADM problems. Zhang and Xu [33] developed the hesitant fuzzy TODIM analysis approach based on novel measured functions.

Using the degree of indeterminacy/neutrality as independent component in 1995, Wang, Smarandache, Zhang and Sunderraman [34] defined the neutrosophic set theory. But, a neutrosophic set will be difficult to apply in real scientific and engineering fields. Therefore, Wang, Smarandache, Zhang and Sunderraman [35] proposed the concepts of a Single-valued neutrosophic set (SVNS) and Wang, Smarandache, Zhang and Sunderraman [34] built the interval neutrosophic set (INS) which are an instance of a neutrosophic set. Ye [36] defiined the vector similarity measures of simplified neutrosophic sets in multicriteria decision making. Ye [37] defined the single valued neutrosophic cross-entropy for multicriteria decision making problems. Ye [38] improved cross entropy measures of single valued neutrosophic sets and interval neutrosophic sets. Biswas, Pramanik and Giri [39] built the TOPSIS method for multi-attribute group decision-making under Single-valued neutrosophic environment.

But there is no study on the TODIM approach for evaluating the credit risk of small new venture' indirect financing in the existing literature. Therefore, it is necessary to pay attention to this issue. The aim of this paper is to use TODIM method to the MADM for evaluating the credit risk of small new venture' indirect financing with the SVNNs, to overcome this limitation. The remainder of this paper is set out as follows. In the next section, we introduce some basic concepts related to SVNSs and classical TODIM method for MADM problems. In Section 3 we used the TODIM method for SVN-MADM problems. In Section 4, an illustrative example for evaluating the credit risk of small new venture' indirect financing is pointed out and some comparative analysis are conducted. In Section 6 we conclude the paper and give some remarks.

2. Preliminaries

In the subsection, we give some concepts related to neutrosophic sets and Single-valued neutrosophic sets.

Definition 1[35]. Let X be a space of points (objects) with a generic element in fix set X, denoted by x. A neutrosophic sets (NSs) A in X is characterized by a truth-membership function $T_A(x)$, an indeterminacy-membership $I_A(x)$ and a falsity-membership function $F_A(x)$. The functions $T_A(x)$, $I_A(x)$ and $F_A(x)$ are real standard or nonstandard subsets of $]^-0,1^+[$, that's, $T_A(x): X \to]^-0,1^+[$, $I_A(x): X \to]^-0,1^+[$ and $F_A(x): X \to]^-0,1^+[$. There is no restriction on the sum of $T_A(x)$, $I_A(x)$ and $F_A(x)$, so $0^- \le \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \le 3^+$.

Wang, Smarandache, Zhang and Sunderraman [35] defined the Single-valued neutrosophic set which is an instance of neutrosophic set as follows:

Definition 2[35]. Let X be a space of points (objects) with a generic element in fix set X, denoted by x. A Single-valued neutrosophic sets (SVNSs) A in X is characterized as following:

$$A = \{(x, T_A(x), I_A(x), F_A(x)) | x \in X\} \tag{1}$$

where the truth-membership function $T_A(x)$, indeterminacy-membership $I_A(x)$ and falsity-membership function $F_A(x)$ are single subintervals/subsets in the real standard $[0,1]$, that is, $T_A(x): X \to [0,1]$, $I_A(x): X \to [0,1]$ and $F_A(x): X \to [0,1]$. And the sum of $T_A(x)$, $I_A(x)$ and $F_A(x)$ satisfies the condition $0 \le T_A(x) + I_A(x) + F_A(x) \le 3$. Then a simplification of A is denoted by $A = \{(x, T_A(x), I_A(x), F_A(x)) | x \in X\}$, which is a SVNS.

For a SVNS $\{(x, T_A(x), I_A(x), F_A(x)) | x \in X\}$, the ordered triple components $(T_A(x), I_A(x), F_A(x))$, are described as a Single-valued neutrosophic number (SVNN), and each SVNN can be expressed as $A = (T_A, I_A, F_A)$, where $T_A \in [0,1], I_A \in [0,1], F_A \in [0,1]$, and $0 \le T_A + I_A + F_A \le 3$.

We will denote the set of all the SVNSs in X by Q. a Single-valued neutrosophic number(SVNN) is denoted by $\tilde{a} = (\mu, \rho, \nu)$ for convenience.

Definition 3[40]. Let $\tilde{a} = (\mu, \rho, \nu)$ be a SVNN, a score function S of a SVNN is represented:

$$S(\tilde{a}) = \frac{1 + \mu - 2\rho - \nu}{2}, \quad S(\tilde{a}) \in [-1,1]. \tag{2}$$

Definition4[40]. Let $\tilde{a} = (\mu, \rho, \nu)$ be a SVNN, an accuracy function H of a SVNN is represented:

$$H(\tilde{a}) = \frac{1 + \mu - \rho(1-\mu) - \nu(1-\rho)}{2}, \quad H(\tilde{a}) \in [0,1]. \tag{3}$$

to evaluate the degree of accuracy of the Single-valued neutrosophic number $\tilde{a} = (\mu, \rho, \nu)$, where $H(\tilde{a}) \in [0,1]$. The larger the value of $H(\tilde{a})$, the more the degree of accuracy of the Single-valued neutrosophic number $\tilde{a}$.

Then, Sahin and Liu [40] gave an order relation between two SVNNs, which is defined as follows:

Definition5[40]. Let $\tilde{a}_1=(\mu_1,\rho_1,\nu_1)$ and $\tilde{a}_2=(\mu_2,\rho_2,\nu_2)$ be two SVNNs, $S(\tilde{a}_1)=\frac{1+\mu_1-2\rho_1-\nu_1}{2}$ and $S(\tilde{a}_2)=\frac{1+\mu_2-2\rho_2-\nu_2}{2}$ be the scores of $\tilde{a}_1$ and $\tilde{a}_2$, respectively, and let $H(\tilde{a}_1)=\frac{1+\mu_1-\rho_1(1-\mu_1)-\nu_1(1-\rho_1)}{2}$ and $H(\tilde{a}_2)=\frac{1+\mu_2-\rho_2(1-\mu_2)-\nu_2(1-\rho_2)}{2}$ be the accuracy degrees of $\tilde{a}_1$ and $\tilde{a}_2$, respectively, then if $S(\tilde{a}_1)<S(\tilde{a}_2)$, then $\tilde{a}_1$ is smaller than $\tilde{a}_2$, denoted by $\tilde{a}_1<\tilde{a}_2$; if $S(\tilde{a}_1)=S(\tilde{a}_2)$, then (1) if $H(\tilde{a}_1)=H(\tilde{a}_2)$, then $\tilde{a}_1$ and $\tilde{a}_2$ represent the same information, denoted by $\tilde{a}_1=\tilde{a}_2$; (2) if $H(\tilde{a}_1)<H(\tilde{a}_2)$, $\tilde{a}$ is smaller than $\tilde{b}$, denoted by $\tilde{a}_1<\tilde{a}_2$.

Definition 6[41]. Let $A=(T_A,I_A,F_A)$ and $B=(T_B,I_B,F_B)$ be two SVNNs, then the normalized Hamming distance between $A=(T_A,I_A,F_A)$ and $B=(T_B,I_B,F_B)$ is defined as follows:

$$d(A,B)=\frac{1}{3}\left(|T_A-T_B|+|I_A-I_B|+|F_A-F_B|\right) \tag{4}$$

3. TODIM Method for SVN-MADM Problems

The following notations are used to represent the SVNN-MADM problems. Let $A=\{A_1,A_2,\cdots,A_m\}$ be a group of alternatives, and $G=\{G_1,G_2,\cdots,G_n\}$ be the set of attributes. Let $w=(w_1,w_2,\cdots,w_n)$ be the weight vector of attributes, where $\omega_j\in[0,1]$, $j=1,2,\cdots,n$, $\sum_{j=1}^{n}w_j=1$. Suppose that $R=(r_{ij})_{m\times n}=(T_{ij},I_{ij},F_{ij})_{m\times n}$ be a SVNN-decision matrix, where $\tilde{r}_{ij}=(T_{ij},I_{ij},F_{ij})$, which is an attribute value, given by an expert, for the alternative $A_i\in A$ with respect to the attribute $G_j\in G$, $T_{ij}\in[0,1],I_{ij}\in[0,1],F_{ij}\in[0,1]$, $0\le T_{ij}+I_{ij}+F_{ij}\le 3$, $i=1,2,\cdots,m$, $j=1,2,\cdots,n$.

To solve the MADM problem with SVNNs, we try to use a SVN-TODIM method[42], which is developed in terms of the prospect theory and can depict the DMs' behaviors under risk.

Firstly, we calculate the relative weight of each attribute G_j as:

$$w_{jr}=w_j/w_r,\ j,r=1,2,\cdots,n. \tag{5}$$

where w_j is the weight of the attribute of G_j, $w_r=\max\{w_j\,|\,j=1,2,\cdots,n\}$, and $0\le w_{jr}\le 1$.

Based on the Eq.(5), we can grt the dominance degree of A_i over each alternative A_t with respect to the attribute G_j:

$$\phi_j(A_i,A_t)=\begin{cases}\sqrt{w_{jr}d(r_{ij},r_{tj})\Big/\sum_{j=1}^{n}w_{jr}}, & if\ r_{ij}>r_{tj}\\ 0, & if\ r_{ij}=r_{tj}\\ -\frac{1}{\theta}\sqrt{\left(\sum_{j=1}^{n}w_{jr}\right)d(r_{ij},r_{tj})\Big/w_{jr}}, & if\ r_{ij}<r_{tj}\end{cases} \tag{6}$$

$$d\left(r_{ij},r_{tj}\right)=\frac{1}{3}\left(\left|T_{ij}-T_{tj}\right|+\left|I_{ij}-I_{tj}\right|+\left|F_{ij}-F_{tj}\right|\right) \tag{7}$$

where the parameter θ shows the attenuation factor of the losses, and $d\left(r_{ij},r_{tj}\right)$ is to measure the distances between the SVNNs r_{ij} and r_{tj} by Definition 4. If $r_{ij}>r_{tj}$, then $\phi_j\left(A_i,A_t\right)$ represents a gain; if $r_{ij}<r_{tj}$, then $\phi_j\left(A_i,A_t\right)$ signifies a loss.

In order to show the functions $\phi_j\left(A_i,A_t\right)$ clearly, we express it in a dominance degree matrix with respect to the attribute of G_j as:

$$\phi_j=\left[\phi_j\left(A_i,A_t\right)\right]_{m\times m}=\begin{array}{c} \\ A_1\\ A_2\\ \vdots\\ A_m\end{array}\begin{array}{c}\begin{array}{cccc} A_1 & A_2 & \cdots & A_m\end{array}\\ \begin{bmatrix} o & \phi_j\left(A_1,A_2\right) & \cdots & \phi_j\left(A_1,A_m\right)\\ \phi_j\left(A_2,A_1\right) & 0 & \cdots & \phi_j\left(A_2,A_m\right)\\ \vdots & \vdots & \cdots & \vdots\\ \phi_j\left(A_m,A_1\right) & \phi_j\left(A_m,A_2\right) & \cdots & 0\end{bmatrix}\end{array}$$

$$j=1,2,\cdots,n. \tag{8}$$

based on which we can calculate the overall dominance degree of the alternative A_i over each alternative A_t by

$$\delta\left(A_i,A_t\right)=\sum_{j=1}^{n}\phi_j\left(A_i,A_t\right),\quad\left(i,t=1,2,\cdots,m\right) \tag{9}$$

Therefore, by Eq. (12), the overall dominance degree matrix can be got as:

$$\delta=\left[\delta\left(A_i,A_t\right)\right]_{m\times m}=\begin{array}{c} \\ A_1\\ A_2\\ \vdots\\ A_m\end{array}\begin{array}{c}\begin{array}{cccc} A_1 & A_2 & \cdots & A_m\end{array}\\ \begin{bmatrix} o & \delta\left(A_1,A_2\right) & \cdots & \delta\left(A_1,A_m\right)\\ \delta\left(A_2,A_1\right) & 0 & \cdots & \delta\left(A_2,A_m\right)\\ \vdots & \vdots & \cdots & \vdots\\ \delta\left(A_m,A_1\right) & \delta\left(A_m,A_2\right) & \cdots & 0\end{bmatrix}\end{array} \tag{10}$$

Finally, the overall value of each alternative A_i can be derived by the following formula:

$$\delta\left(A_i\right)=\frac{\sum_{t=1}^{m}\delta\left(A_i,A_t\right)-\min_i\left\{\sum_{t=1}^{m}\delta\left(A_i,A_t\right)\right\}}{\max_i\left\{\sum_{t=1}^{m}\delta\left(A_i,A_t\right)\right\}-\min_i\left\{\sum_{t=1}^{m}\delta\left(A_i,A_t\right)\right\}},\quad i=1,2,\cdots,m. \tag{11}$$

And the order of each alternative can be ranked by the principle, that is, the greater the overall value $\delta\left(A_i\right)\left(i=1,2,\cdots,m\right)$, the better the alternative A_i.

4. Numerical Example

This section presents a example to show the method proposed in this paper. Suppose a company plans to evaluate the credit risk of small new venture' indirect financing. There is a panel with five possible enterprises $A_i\left(i=1,2,3,4,5\right)$ to select. The company selects four attribute to evaluate the five possible enterprises: ①G_1 is the corporate profitability; ②G_2 is the viability ability; ③G3 is the solvency ability; ④G4 is the development capacity. The five possible enterprises $A_i\left(i=1,2,3,4,5\right)$ are to be evaluated using the Single-valued neutrosophic numbers by the decision maker under the above four attributes, as listed in the following matrix.

$$\tilde{R}=\begin{bmatrix}(0.5,0.8,0.1) & (0.6,0.3,0.3) & (0.3,0.6,0.1) & (0.5,0.7,0.2)\\ (0.7,0.2,0.1) & (0.7,0.2,0.2) & (0.7,0.2,0.4) & (0.8,0.2,0.1)\\ (0.6,0.7,0.2) & (0.5,0.7,0.3) & (0.5,0.3,0.1) & (0.6,0.3,0.2)\\ (0.8,0.1,0.3) & (0.6,0.3,0.4) & (0.3,0.4,0.2) & (0.5,0.6,0.1)\\ (0.6,0.4,0.4) & (0.4,0.8,0.1) & (0.7,0.6,0.1) & (0.5,0.8,0.2)\end{bmatrix}$$

Steps for evaluating the credit risk of small new venture' indirect financing contains the following steps.

Firstly, since $w_4=\max\left\{w_1,w_2,w_3,w_4\right\}$, then G_4 is the reference attribute and the reference weight is $w_r=0.4$. Therefore, the relative weights of all the attributes $G_j\left(j=1,2,3,4\right)$ are $w_{1r}=0.50, w_{2r}=0.25, w_{3r}=0.75$ and $w_{4r}=1.00$, respectively. Then, we need to calculate the dominance degree of the candidate A_i over each candidate A_t with respect to the attributes $G_j\left(j=1,2,3,4\right)$. Here we take an example from the information given by the decision matrix. Let $\theta=2.5$, then the dominance degree matrices with respect to the attributes $G_j\left(j=1,2,3,4\right)$ are:

$$\phi_1=\begin{matrix} & A_1 & A_2 & A_3 & A_4 & A_5\\ A_1 & 0.0000 & -0.3233 & -0.2827 & -0.1157 & 0.1633\\ A_2 & 0.3233 & 0.0000 & 0.2309 & 0.3056 & 0.3658\\ A_3 & 0.2827 & -0.2309 & 0.0000 & 0.2582 & 0.2821\\ A_4 & 0.1157 & -0.3058 & -0.2582 & 0.0000 & 0.3000\\ A_5 & -0.1633 & -0.3651 & -0.2821 & -0.3000 & 0.0000\end{matrix}$$

$$\phi_2=\begin{matrix} & A_1 & A_2 & A_3 & A_4 & A_5\\ A_1 & 0.0000 & -0.3464 & -0.2582 & -0.1633 & 0.1155\\ A_2 & 0.3464 & 0.0000 & 0.2309 & 0.3055 & 0.3651\\ A_3 & 0.2582 & -0.2309 & 0.0000 & 0.2582 & 0.2828\\ A_4 & 0.1633 & -0.3055 & -0.2582 & 0.0000 & 0.2000\\ A_5 & -0.1155 & -0.3651 & -0.2828 & -0.2000 & 0.0000\end{matrix}$$

$$\phi_3=\begin{matrix} & A_1 & A_2 & A_3 & A_4 & A_5\\ A_1 & 0.0000 & -0.4613 & 0.1291 & 0.0578 & 0.1736\\ A_2 & 0.1165 & 0.0000 & 0.1732 & 0.1291 & 0.1915\\ A_3 & -0.5174 & -0.6921 & 0.0000 & -0.5699 & -0.4611\\ A_4 & -0.2319 & -0.5166 & 0.1415 & 0.0000 & 0.1822\\ A_5 & -0.6924 & -0.7665 & 0.1177 & -0.7332 & 0.0000\end{matrix}$$

$$\phi_4 = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & A_3 & A_4 & A_5 \end{array} \\ \begin{bmatrix} 0.0000 & -0.4000 & 0.1294 & 0.0588 & 0.1741 \\ 0.1000 & 0.0000 & 0.1632 & 0.1159 & 0.1828 \\ -0.4165 & -0.6532 & 0.0000 & -0.5657 & -0.4620 \\ -0.2309 & -0.4619 & 0.1423 & 0.0000 & 0.1825 \\ -0.6928 & -0.7303 & 0.1166 & -0.7306 & 0.0000 \end{bmatrix} \end{array}$$

Secondly, the overall dominance degree of the candidate A_i over each candidate A_t can be obtained by Eq. (13), and the overall dominance degree matrix is:

$$\delta = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & A_3 & A_4 & A_5 \end{array} \\ \begin{bmatrix} 0.0000 & -1.7166 & -0.7340 & -0.7500 & 0.0695 \\ 1.0190 & 0.0000 & 0.3733 & 0.8677 & 0.8308 \\ 0.1316 & -1.0312 & 0.0000 & -0.4724 & 0.0443 \\ 0.3403 & -1.5164 & -0.1384 & 0.2000 & 0.0291 \\ -0.4255 & -1.9121 & -0.8656 & -0.6659 & 0.0000 \end{bmatrix} \end{array}$$

Then, we derive the overall value $\delta(A_i)(i=1,2,\cdots,m)$ of each alternative A_i using Eq. (14):

$$\delta(A_1)=0.1143, \delta(A_2)=1.0000, \delta(A_3)=0.2648$$
$$\delta(A_4)=0.3944, \delta(A_5)=0.0187$$

Finally, we determine the ranking of the alternatives according to the overall values $\delta(A_i)(i=1,2,3,4,5): A_2 \succ A_4 \succ A_3 \succ A_1 \succ A_5$, and thus the most desirable alternative is A_2.

5. Conclusion

In this paper, we extend the TODIM method to the MADM with the Single-valued neutrosophic numbers (SVNNs). Firstly, the definition, expectation, comparative method and distance of SVNNs are briefly defined, and the steps of the classical TODIM method for MADM problems are built. Then, on the basis of the TODIM method, the extended TODIM method is proposed to deal with MADM problems in which the attribute values are in the SVNNs, and its significant characteristic is that it can fully consider the decision makers' bounded rationality which is a real action in decision making. Finally, an illustrative example for evaluating the credit risk of small new venture' indirect financing is given to verify the built method and to demonstrate its practicality and effectiveness.

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