A competitiveness model of production-teaching-research cooperation mode for enterprises and universities based on fuzzy ideal domain

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Abstract

This paper proposes an improved competitiveness model of production-teaching-research cooperation mode for enterprises and universities based on fuzzy ideal domain to enhance the overall quality as well as the competitiveness of high-tech talents in universities and enterprises. Through the analysis of the cooperation mode and after standardization of indicators, we are able to get the comprehensive fuzzy correlation between evaluation object and fuzzy ideal domain based on fuzzy correlation calculation model. As a result, we can get the competitiveness of production-teaching-research cooperation mode. Empirical study shows that the algorithm and the model are effective.

Keywords: Universities; production-teaching-research cooperation mode; fuzzy ideal domain; multiple attribute evaluation; competitiveness model

1 Introduction

With the development of modern technology, enterprises are yearning for high-tech talents. Traditional ways of training talents by universities cannot meet the demand of the society or enterprises. Universities production-teaching-research cooperation mode is a new way out. On one hand, it nurtures professional technicians for enterprises. On the other hand, it provides an employment opportunity for universities students and increases their competetiveness and overall quality [1-3].

However, many factors need to be taken into account such as enterprises, schools and society. Some factors are dynamic and fuzzy. It is significant to explore the optimal production-teaching-research cooperation mode in order to increase the competitiveness of universities and enterprises [4-7]. Many researches have done relevant studies and yielded fruitful results. But the analysis of fuzzy information is far from enough. Therefore, this paper proposes a competitiveness model of production-teaching-research cooperation mode for enterprises and universities based on fuzzy ideal domain based on fuzzy theory so as to improve hi-tech talents training.

2 A competitiveness index model of production-teaching-research cooperation mode

Evaluation indicators of this production-teaching-research cooperation mode are selected under certain principles. (1) Scientific principle: indicators selected should reflect the features of production, teaching and research in a scientific way. (2) Principle of completeness: the competitiveness should be measured with a panoramic view. (3) Representative principle: indicators should be representable. Redundancy should be avoided in case that some indicators fail to measure the production, teaching or research well. (4) Measurable principle: quantitative indicators should be capable of being quantified and qualitative indicators should have clear denotation and connotation of value of a quantity. According to these principles, this paper proposes a new type of competitiveness model of production-teaching-research cooperation mode, as is shown in Tab. 1.

TABLE 1 A competitiveness model of production-teaching-research cooperation mode for universities

Target layer	criteria layer	indicator layer
A competitiveness model of production-teaching-research cooperation mode for enterprises and universities U	cooperation input capacity U_1	hardware equipment input u_{11}
		number of key laboratories u_{12}
		number of university experts u_{13}
		univeristy scientific and technological achievements u_{14}
		Science and technology services u_{15}

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A competitiveness model of production-teaching-research cooperation mode for enterprises and universities U	talent training capacity U_2	number of scientific and technical talents trained u_{21}
		number of papers and patents u_{22}
		number of scientific and technical awards u_{23}
		number of cooperation projects u_{24}
		university-enterprise integration u_{25}
		technology innovation capacity u_{26}
	social output capacity U_3	conversion rate of scientific and technical achievements u_{31}
		profit growth rate u_{32}
		growth rate of cooperation production u_{33}
		social services capacity u_{34}
		resource utilization rate u_{35}

3 A competitiveness model of production-teaching-research cooperation mode for universities

3.1 STANDARDIZATION OF EVALUATION INDICATORS

Suppose there are m production-teaching-research cooperation modes between an enterprise and a university. In this mode, there are n criteria layers. And the U_i-th criteria layer has n_i evaluation indicators. There are $1 \le i \le n$ and $1 \le j \le n_i$. If the value of a quantity of k-th production-teaching-research cooperation mode about indicator u_{ij} is $V\left(u_{ij}^k\right)$, we can get the value of a quantity matrix $\boldsymbol{R}$ of indicators in the criteria layer U_i for m modes:

$$\boldsymbol{R} = \begin{bmatrix} V\left(u_{i1}^1\right) & \cdots & V\left(u_{ij}^1\right) & \cdots & V\left(u_{in_i}^1\right) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ V\left(u_{i1}^k\right) & \cdots & V\left(u_{ij}^k\right) & \cdots & V\left(u_{in_i}^k\right) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ V\left(u_{i1}^m\right) & \cdots & V\left(u_{ij}^m\right) & \cdots & V\left(u_{in_i}^m\right) \end{bmatrix} \quad (1)$$

In particular, if $V\left(u_{ij}^k\right) = \left[v_a\left(u_{ij}^k\right), v_b\left(u_{ij}^k\right)\right]$, then the value of a quantity matrix $\boldsymbol{R}$ can be expressed as:

$$\boldsymbol{R} = \begin{bmatrix} \left[v_a\left(u_{i1}^1\right), v_b\left(u_{i1}^1\right)\right] & \cdots & \left[v_a\left(u_{ij}^1\right), v_b\left(u_{ij}^1\right)\right] & \cdots & \left[v_a\left(u_{in_i}^1\right), v_b\left(u_{in_i}^1\right)\right] \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \left[v_a\left(u_{i1}^k\right), v_b\left(u_{i1}^k\right)\right] & \cdots & \left[v_a\left(u_{ij}^k\right), v_b\left(u_{ij}^k\right)\right] & \cdots & \left[v_a\left(u_{in_i}^k\right), v_b\left(u_{in_i}^k\right)\right] \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \left[v_a\left(u_{i1}^m\right), v_b\left(u_{i1}^m\right)\right] & \cdots & \left[v_a\left(u_{ij}^m\right), v_b\left(u_{ij}^m\right)\right] & \cdots & \left[v_a\left(u_{in_i}^m\right), v_b\left(u_{in_i}^m\right)\right] \end{bmatrix} \quad (2)$$

If indicator u_{ij} is a positive indicator, then the standardized $V\left(u_{ij}^k\right)$ is $C\left(u_{ij}^k\right)$:

$$C\left(u_{ij}^k\right) = \frac{V\left(u_{ij}^k\right) - \min\limits_{1 \le k \le m}\left(V\left(u_{ij}^k\right)\right)}{\max\limits_{1 \le k \le m}\left(V\left(u_{ij}^k\right)\right) - \min\limits_{1 \le k \le m}\left(V\left(u_{ij}^k\right)\right)} \quad (3)$$

f indicator u_{ij} is an adverse indicator, then the standardized $V\left(u_{ij}^k\right)$ is $C\left(u_{ij}^k\right)$:

$$C\left(u_{ij}^k\right) = \frac{\max\limits_{1 \le k \le m}\left(V\left(u_{ij}^k\right)\right) - V\left(u_{ij}^k\right)}{\max\limits_{1 \le k \le m}\left(V\left(u_{ij}^k\right)\right) - \min\limits_{1 \le k \le m}\left(V\left(u_{ij}^k\right)\right)} \quad (4)$$

The standardized value of a quantity matrix $\boldsymbol{T}$ of evaluation indicators is:

$$\boldsymbol{T}=\begin{bmatrix} C\left(u_{i1}^{1}\right) & \cdots & C\left(u_{ij}^{1}\right) & \cdots & C\left(u_{in_i}^{1}\right) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ C\left(u_{i1}^{k}\right) & \cdots & C\left(u_{ij}^{k}\right) & \cdots & C\left(u_{in_i}^{k}\right) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ C\left(u_{i1}^{m}\right) & \cdots & C\left(u_{ij}^{m}\right) & \cdots & C\left(u_{in_i}^{m}\right) \end{bmatrix} \quad (5)$$

In particular, if $V\left(u_{ij}^{k}\right)=\left[v_a\left(u_{ij}^{k}\right),v_b\left(u_{ij}^{k}\right)\right]$, when the indicator u_{ij} is a positive one, the standardized $V\left(u_{ij}^{k}\right)$ becomes $C\left(u_{ij}^{k}\right)$:

$$C\left(u_{ij}^{k}\right)=\left[c_a\left(u_{ij}^{k}\right),c_b\left(u_{ij}^{k}\right)\right]=\left[\frac{v_a\left(u_{ij}^{k}\right)-\min\limits_{1\le k\le m}\left(v_a\left(u_{ij}^{k}\right)\right)}{\max\limits_{1\le k\le m}\left(v_b\left(u_{ij}^{k}\right)\right)-\min\limits_{1\le k\le m}\left(v_a\left(u_{ij}^{k}\right)\right)},\frac{v_b\left(u_{ij}^{k}\right)-\min\limits_{1\le k\le m}\left(v_a\left(u_{ij}^{k}\right)\right)}{\max\limits_{1\le k\le m}\left(v_b\left(u_{ij}^{k}\right)\right)-\min\limits_{1\le k\le m}\left(v_a\left(u_{ij}^{k}\right)\right)}\right] \quad (6)$$

When u_{ij} is an adverse indicator, the standardized $V\left(u_{ij}^{k}\right)$ becomes $C\left(u_{ij}^{k}\right)$:

$$C\left(u_{ij}^{k}\right)=\left[c_a\left(u_{ij}^{k}\right),c_b\left(u_{ij}^{k}\right)\right]=\left[\frac{\max\limits_{1\le k\le m}\left(v_b\left(u_{ij}^{k}\right)\right)-v_a\left(u_{ij}^{k}\right)}{\max\limits_{1\le k\le m}\left(v_b\left(u_{ij}^{k}\right)\right)-\min\limits_{1\le k\le m}\left(v_a\left(u_{ij}^{k}\right)\right)},\frac{\max\limits_{1\le k\le m}\left(v_b\left(u_{ij}^{k}\right)\right)-v_b\left(u_{ij}^{k}\right)}{\max\limits_{1\le k\le m}\left(v_b\left(u_{ij}^{k}\right)\right)-\min\limits_{1\le k\le m}\left(v_a\left(u_{ij}^{k}\right)\right)}\right] \quad (7)$$

The standardized value of a quantity matrix $\boldsymbol{T}$ of evaluation indicators is expressed as:

$$\boldsymbol{T}=\begin{bmatrix} \left[c_a\left(u_{i1}^{1}\right),c_b\left(u_{i1}^{1}\right)\right] & \cdots & \left[c_a\left(u_{ij}^{1}\right),c_b\left(u_{ij}^{1}\right)\right] & \cdots & \left[c_a\left(u_{in_i}^{1}\right),c_b\left(u_{in_i}^{1}\right)\right] \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \left[c_a\left(u_{i1}^{k}\right),c_b\left(u_{i1}^{k}\right)\right] & \cdots & \left[c_a\left(u_{ij}^{k}\right),c_b\left(u_{ij}^{k}\right)\right] & \cdots & \left[c_a\left(u_{in_i}^{k}\right),c_b\left(u_{in_i}^{k}\right)\right] \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \left[c_a\left(u_{i1}^{m}\right),c_b\left(u_{i1}^{m}\right)\right] & \cdots & \left[c_a\left(u_{ij}^{m}\right),c_b\left(u_{ij}^{m}\right)\right] & \cdots & \left[c_a\left(u_{in_i}^{m}\right),c_b\left(u_{in_i}^{m}\right)\right] \end{bmatrix} \quad (8)$$

3.2 WEIGHT OF INDICATORS BASED ON ENTROPY

Different indicators have different weight, which can be determined by entropy following these steps:
First, acquire the entropy H_{ij} of indicator u_{ij} based on its value of a quantity:

$$H_{ij}=-\frac{1}{\ln(m)}\sum_{k=1}^{m}\left(\frac{C\left(u_{ij}^{k}\right)}{\sum\limits_{k=1}^{m}C\left(u_{ij}^{k}\right)}*\ln\left(\frac{C\left(u_{ij}^{k}\right)}{\sum\limits_{k=1}^{m}C\left(u_{ij}^{k}\right)}\right)\right) \quad (9)$$

Here prescribes that when $C\left(u_{ij}^{k}\right)=0$, there is $\ln\left(\frac{C\left(u_{ij}^{k}\right)}{\sum\limits_{k=1}^{m}C\left(u_{ij}^{k}\right)}\right)=0$.

In particular, if $C\left(u_{ij}^{k}\right)=\left[c_a\left(u_{ij}^{k}\right),c_b\left(u_{ij}^{k}\right)\right]$, the entropy H_{ij} of indicator u_{ij} is:

$$H_{ij}=-\frac{1}{\ln(m)}\sum_{k=1}^{m}\left(\frac{c_a\left(u_{ij}^{k}\right)+c_b\left(u_{ij}^{k}\right)}{\sum\limits_{k=1}^{m}\left(c_a\left(u_{ij}^{k}\right)+c_b\left(u_{ij}^{k}\right)\right)}*\ln\left(\frac{c_a\left(u_{ij}^{k}\right)+c_b\left(u_{ij}^{k}\right)}{\sum\limits_{k=1}^{m}\left(c_a\left(u_{ij}^{k}\right)+c_b\left(u_{ij}^{k}\right)\right)}\right)\right) \quad (10)$$

If the evaluation indicator system has multi-layers, then when we try to figure out the weight of indicator in the upper layer, the evaluation membership or correlation degree of its corresponding indicators in the sub layer can serve as the value of a quantity for those in the upper layer. Repeat expression (9) to (11) to get the weight.

3.3 CONSTRUCT THE FUZZY IDEAL DOMAIN OF INDICATORS

All indicators after standardization are positive indicators and are measured by 0-1 scale. If the value of a quantity of indicator u_{ij} after standardization is $C\left(u_{ij}^k\right)$, the fuzzy ideal domain of indicator u_{ij} in the criteria layer U_i is $C\left(u_{ij}^0\right)$:

$$C\left(u_{ij}^0\right)=\max_{1\le k\le m}\left(C\left(u_{ij}^k\right)\right) \tag{11}$$

Therefore, the fuzzy ideal domain of the criteria layer U_i is $C^0\left(u_{ij}^0\right)$:

$$C^0\left(u_{ij}^0\right)=\left(\max_{1\le k\le m}\left(C\left(u_{i1}^k\right)\right),\cdots,\max_{1\le k\le m}\left(C\left(u_{ij}^k\right)\right),\cdots,\max_{1\le k\le m}\left(C\left(u_{in_i}^k\right)\right)\right) \tag{12}$$

In particular, if $C\left(u_{ij}^k\right)=\left[c_a\left(u_{ij}^k\right),c_b\left(u_{ij}^k\right)\right]$, then the fuzzy ideal domain of the criteria layer U_i is $C^0\left(u_{ij}^0\right)$

$$C^0\left(u_{ij}^0\right)=\left(\left[\max_{1\le k\le m}c_a\left(u_{i1}^k\right),\max_{1\le k\le m}c_b\left(u_{i1}^k\right)\right],\cdots,\left[\max_{1\le k\le m}c_a\left(u_{ij}^k\right),\max_{1\le k\le m}c_b\left(u_{ij}^k\right)\right],\cdots,\left[\max_{1\le k\le m}c_a\left(u_{in_i}^k\right),\max_{1\le k\le m}c_b\left(u_{in_i}^k\right)\right]\right) \tag{13}$$

3.4 FUZZY CORRELATION MODEL

After the construction of the fuzzy ideal domain $C\left(u_{ij}^0\right)$ of indicators and the fuzzy ideal domain $C^0\left(u_{ij}^0\right)$ of relevant criteria layer, fuzzy decision-making analysis of m production-teaching-research cooperation modes can be operated. If the standardized value of a quantity of indicator u_{ij} in the k-th cooperation mode is $C\left(u_{ij}^k\right)$, then the fuzzy distance $D\left(u_{ij}\right)$ between it and its fuzzy ideal domain $C\left(u_{ij}^0\right)$ of indicator is:

$$D\left(u_{ij}\right)=\left|c\left(u_{ij}^k\right)-\max_{1\le k\le m}\left(C\left(u_{ij}^k\right)\right)\right| \tag{14}$$

If the standardized value of a quantity of indicator u_{ij} in the k-th cooperation mode is $C\left(u_{ij}^k\right)=\left[c_a\left(u_{ij}^k\right),c_b\left(u_{ij}^k\right)\right]$, then the fuzzy distance $D\left(u_{ij}\right)$ between it and its fuzzy ideal domain $C\left(u_{ij}^0\right)$ of indicator is:

$$D\left(u_{ij}\right)=\sqrt[P]{\left|\max_{1\le i\le m}\left(c_a\left(u_{ij}^k\right)\right)-c_a\left(u_{ij}^k\right)\right|^P+\left|\max_{1\le i\le m}\left(c_b\left(u_{ij}^k\right)\right)-c_b\left(u_{ij}^k\right)\right|^P}\,/\sqrt[P]{2} \tag{15}$$

In particular, when $P=1$, the fuzzy distance $D\left(u_{ij}\right)$ is Hamming distance:

$$D\left(u_{ij}\right)=\frac{\left|\max_{1\le i\le m}\left(c_a\left(u_{ij}^k\right)\right)-c_a\left(u_{ij}^k\right)\right|+\left|\max_{1\le i\le m}\left(c_b\left(u_{ij}^k\right)\right)-c_b\left(u_{ij}^k\right)\right|}{2} \tag{16}$$

When $P=2$, the fuzzy distance $D\left(u_{ij}\right)$ is Euclidean distance:

$$D\left(u_{ij}\right)=\sqrt{\frac{\left|\max_{1\le i\le m}\left(c_a\left(u_{ij}^k\right)\right)-c_a\left(u_{ij}^k\right)\right|^2+\left|\max_{1\le i\le m}\left(c_b\left(u_{ij}^k\right)\right)-c_b\left(u_{ij}^k\right)\right|^2}{2}} \tag{17}$$

If the weight of indicator u_{ij} in the criteria layer U_i is w_{ij}, the fuzzy correlation κ_i^k between the k-th cooperation mode about indicator u_{ij} and the fuzzy ideal domain $C\left(u_{ij}^0\right)$ of indicator is:

$$\kappa_i^k=\sum_{j=1}^{n_i}\left(w_{ij}*\left(1-D\left(u_{ij}\right)\right)\right) \tag{18}$$

If the weight of indicator u_{ij} is w_i, the fuzzy correlation φ_k between the k-th cooperation mode about all indicators and the fuzzy ideal domain $C\left(u_{ij}^0\right)$ of indicator is:

$$\varphi_k = \sum_{i=1}^{n}\left(w_i * \kappa_i^k\right) \quad (19)$$

According to optimization principle of fuzzy correlation, if there is:

$$\varphi_t = \max_{1\le k\le m}\left(\varphi_k\right), 1\le t\le m \quad (20)$$

It then indicates that the t-th production-teaching-research cooperation mode is in line with the demand of enterprises and has the biggest competitiveness. In other words, the t-th production-teaching-research cooperation mode is the best one. Based on that, follow-up plans for development can be made to bring more economic profits. Meanwhile, universities can strengthen cooperation with enterprises to provide a favourable environment for talents.

4 Case study and test

This paper takes cooperation modes between an enterprise and three universities at different stage as examples to prove that the model and the algorithm are effective. Through on-the-spot survey and after consultation with experts, data for evaluation indicators are available, as is shown in Table 2.

TABLE 2 Evaluation indicator of competitiveness in production-teaching-research cooperation mode

criteria layer	indicator layer	Value of a quantity of indicator		
		Institute of higher learning A	Institute of higher learning B	Institute of higher learning C
cooperation input capacity U_1	hardware equipment input u_{11}	85-90	85-90	90-95
	number of key laboratories u_{12}	4	3	3
	number of university experts u_{13}	6	8	8
	univeristy scientific and technological achievements u_{14}	75-80	80-85	70-75
	Science and technology services u_{15}	80-85	90-95	80-85
talent training capacity U_2	number of scientific and technical talents trained u_{21}	18	26	24
	number of papers and patents u_{22}	21	46	35
	number of scientific and technical awards u_{23}	1	3	2
	number of cooperation projects u_{24}	4	6	7
	university-enterprise integration u_{25}	75-80	80-85	90-95
	technology innovation capacity u_{26}	80-85	90-95	80-85
social output capacity U_3	conversion rate of scientific and technical achievements u_{31}	75-80	80-85	80-85
	profit growth rate u_{32}	0.065	0.152	0.137
	growth rate of cooperation production u_{33}	0.204	0.568	0.613
	social services capacity u_{34}	75-80	90-95	80-85
	resource utilization rate u_{35}	80-85	90-95	90-95

Standardize data in Table 2 and get Table 3.

TABLE 3 Standardized evaluation indicator of competitiveness in production-teaching-research cooperation mode

indicator layer	fuzzy ideal domain	Value of a quantity of standardized indicator		
		Institute of higher learning A	Institute of higher learning B	Institute of higher learning C
hardware equipment input u_{11}	0.5-1.0	0-0.5	0-0.5	0.5-1.0
number of key laboratories u_{12}	1.0	1.0	0	0
number of university experts u_{13}	1.0	0	1.0	1.0

univeristy scientific and technological achievements u_{14}	0.667-1.0	0.333-0.667	0.667-1.0	0-0.333
Science and technology services u_{15}	0.667-1.0	0-0.333	0.667-1.0	0-0.333
number of scientific and technical talents trained u_{21}	1.0	0	1.0	0.75
number of papers and patents u_{22}	1.0	0	1.0	0.667
number of scientific and technical awards u_{23}	1.0	0	1.0	0.5
number of cooperation projects u_{24}	1.0	0	0.667	1.0
university-enterprise integration u_{25}	0.75-1.0	0-0.25	0.25-0.50	0.75-1.0
technology innovation capacity u_{26}	0.667-1.0	0-0.333	0.667-1.0	0-0.333
conversion rate of scientific and technical achievements u_{31}	0.5-1.0	0-0.5	0.5-1.0	0.5-1.0
profit growth rate u_{32}	1.0	0	1.0	0. 828
growth rate of cooperation production u_{33}	1.0	0	0.890	1.0
social services capacity u_{34}	0.75-1.0	0-0.25	0.75-1.0	0.25-0.5
resource utilization rate u_{35}	0.667-1.0	0-0.333	0.667-1.0	0.667-1.0

We can get different fuzzy distance according to relevant expressions, as is shown in Table 4.

TABLE 4 Fuzzy distance of evaluation indicator of competitiveness in production-teaching-research cooperation mode

indicator layer	Fuzzy distance of evaluation indicator		
	Institute of higher learning A	Institute of higher learning B	Institute of higher learning C
hardware equipment input u_{11}	0.500	0.500	0
number of key laboratories u_{12}	0	1.000	1.000
number of university experts u_{13}	1.000	0	0
univeristy scientific and technological achievements u_{14}	0.333	0	0.667
Science and technology services u_{15}	0.667	0	0.667
number of scientific and technical talents trained u_{21}	1.000	0	0.250
number of papers and patents u_{22}	1.000	0	0.333
number of scientific and technical awards u_{23}	1.000	0	0.500
number of cooperation projects u_{24}	1.000	0.333	0
university-enterprise integration u_{25}	0.750	0.500	0
technology innovation capacity u_{26}	0.667	0	0.667
conversion rate of scientific and technical achievements u_{31}	0.500	0	0
profit growth rate u_{32}	1.000	0	0.172
growth rate of cooperation production u_{33}	1.000	0.110	0
social services capacity u_{34}	0.750	0	0.500
resource utilization rate u_{35}	0.667	0	0

According to calculation expression of fuzzy correlation, here gets the fuzzy sequence of competitiveness, namely, $\varphi = (0.261, 0.847, 0.703)$. There is $\varphi_{max} = \varphi_2$, which means university B is the most competitive. The enterprise can put more effort to enhance the cooperation with university B. It can help with talents nurturing of university B. Besides, C also has some competitiveness, though not as outstanding as B. But the enterprise is suggested to improve the key fields and continue the cooperation with C.

5 Conclusions

This paper studies the production-teaching-research cooperation between enterprises and universities and proposes an improved competitiveness model based on fuzzy ideal domain. By constructing the calculation model of fuzzy distance and fuzzy correlation, we are able to have a measurement on the quality of production-teaching-research cooperation modes. This paper's research result can provide guidance on talents nurturing. Empirical study has proved that the algorithm and the model are effective. It also provides an approach to evaluate the competitiveness of production-teaching-research cooperation mode through computers.

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