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Bi-TODIM METHOD AND ITS APPLICATION IN URBAN LAND USE EFFICIENCY EVALUATION

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ABSTRACT

Considering that some multiple indicator evaluation problems have three characteristics: indicators interact with each other, the value of the indicator is in a bipolar interval, and the psychological behavior of evaluator will have an impact on evaluation results. On the basis of the TODIM method and bi-capacity theory, the Bi-TODIM method was constructed. The bi-capacity of the indicator (set) is taken as the weight, and then the dominance degree and comprehensive dominance degree of each alternative are calculated. Moreover, the properties of comprehensive dominance degree are discussed. Finally, based on the Bi-TODIM method, the land use efficiency of 13 cities in Jiangsu Province was evaluated, and the effectiveness of the method was proved.

KEYWORDS: Bi-Capacity, Bi-TODIM Method, Interactions Between Indicators, Psychological Behavior & Evaluation of Urban Land Use Efficiency

INTRODUCTION

In recent years, the problem of haze governance evaluation has caused widespread concern. This problem has the following three characteristics: (1) The evaluation indicators of haze governance are interrelated(Liang et al., 2017). (2) The indicators are often measured on a bipolar scale (Grabisch & Labreuche, 2008). For example, the governance effect may or may not meet expectations; (3) the evaluator's psychological behavior will also have an impact on the evaluation results (Liang et al., 2017). In fact, many other multiple-evaluation problems(Liang et al., 2015; Yang et al., 2015) have similar characteristics to the haze governance evaluation. They need to consider the interactions of indicators, the bipolar value of the indicators and the evaluator's psychological behavior.

For the treatment of interrelated indicators, the existing literature commonly uses fuzzy measures (capacity) to model the interactions between indicators (Zhang et al., 2016; Xu et al., 2018; Zhang et al., 2015). The capacity theory can only deal with the indicator in the unipolar interval [0,1]. When using the capacity theory to measure the indicators whose evaluation values are in the bipolar interval, the "Grabisch paradox" may be generated (Grabisch & Labreuche, 2008). In order to deal with the indicators in bipolar interval, Grabisch extended the capacity theory to the bipolar interval and proposed the bi-capacity theory (Grabisch and Labreuche, 2005a; 2005b). At present, the theory of bi-capacity and its application have attracted the attention of scholars (Zhang et al., 2017; Greco & Rindone, 2012; Kojadinovic & Labreuche, 2009).

Due to the uncertainty of real problems, more and more scholars believe that evaluators are not completely rational, and their psychological behavior will have a certain impact on the evaluation results (Tsetlin & Winkler, 2006; Kahneman & Tversky, 1979). Specifically, evaluators often have psychological expectations on the evaluation indicators (reference dependencies)and are more sensitive to losses rather than return (loss avoidance)(Abdellaoui, Han, & Paraschiv; 2007). Therefore, it is very meaningful to consider the evaluator's psychological behavior when studying the multiple indicator evaluation problems. The prospect theory (Zhang & Fan, 2012)can be used to analyze the influence of the evaluator's psychological behavior on the evaluation results, but it needs to determine the reference point in advance. Another method for dealing with the evaluator's psychological behavior, TODIM (Tomada de Decisao Interativa Multicriterio), does not require a prior determination of the reference point. The method uses the indicator values of other alternatives as a reference point to explore the influence of the evaluator's psychological behavior (reference dependence and loss avoidance behavior) on the evaluation results. Specifically, TODIM obtains the comprehensive dominance degree of the alternative by calculating the dominance degree for each alternative over the other one and ranks the alternatives (Gomes& Lima; 1991). The TODIM method has been widely used in evaluation fields such as evaluation questions (Liang et al., 2017; Liu &Teng, 2017). Some scholars have extended the TODIM method for different types of problems, such as the linguisticTODIM method (Kong & Tan; 2017), the fuzzy TODIM method (Wu & Wen, 2017), and the TODIM method based on interval gray number (Wang & Dang; 2016). It should be emphasized that in order to extend the TODIM method to the multiple indicator evaluation fields with interrelated indicators, Liang et al. (2015) combined the Choquet integral with the TODIM method and proposed the C-TODIM method. However, the existing TODIM method and its extension have not yet involved the bipolar value of the indicator. Therefore, they are not able to solve the multiple indicator evaluations problems such as haze governance evaluation.

Based on the above analysis, this paper combines the bi-capacity with the TODIM method, proposes the Bi-TODIM method, and uses this method to evaluate the urban land use efficiency of Jiangsu province.

PRELIMINARIES

Bi-Capacities

Let us consider a finite set of alternatives a_i (i = 1, 2, …,m) and a finite set of indicators c_j (j = 1, 2, …, n). Each alternative $a_i \in A$ is associated with a vector of performance ratings $x_{ij} \in IR^n$, which represents the contribution degree of a_i with respect to (w.r.t.) the criterion c_j.

Definition 1: (Grabisch and Labreuche, 2005a; 2005b) $P(C)$ is the power set of C, a bi-capacity is defined in $P(C)$ on the set of function $\mu : P(C) \to [-1,\ 1]$, which satisfies the following properties:

- $\mu(\phi,\phi) = 0$,
- $M \subseteq N \subseteq A_{ij}$, there exists $\mu(M,.) \le \mu(N,.)$ and $\mu(.,M) \ge \mu(.,N)$,

In addition, $\mu(A_{ij},\phi) = 1 = -\mu(\phi, A_{ij})$, when the indicator values are all positive (or negative). The concept of λ bi-capacity is often used to model the weights of indicators and their interactions. To determine bi-capacities, we suppose the interactions among indicators can be measured with the coefficient λ. The λ bi-capacity paradigm meets the following properties:

$$\mu(S \cup c_j,\phi)=\mu(S,\phi) + \mu(c_j,\phi) + \lambda \cdot \mu(S,\phi) \cdot \mu(c_j,\phi) \tag{1}$$

$$\mu(\phi,Q \cup c_j)=\mu(\phi,Q) + \mu(\phi,c_j) - \lambda \cdot \mu(\phi,Q) \cdot \mu(\phi,c_j) \tag{2}$$

$$\mu(S,Q)=\mu(S,\phi)+\mu(\phi,Q)+\lambda\cdot\mu(S,\phi)\cdot\mu(\phi,Q) \quad (3)$$

The TODIM Method

The TODIM method was proposed by Gomes and Lima. The method uses the indicator values of other alternatives as a reference point to explore the influence of the evaluator's psychological behavior (reference dependence and loss avoidance behavior) on the evaluation results. Specifically, TODIM obtains the comprehensive dominance degree of the alternatives by calculating the dominance degree of one alternative relative to other alternatives.

Definition 2: (Gomes& Lima; 1991) The dominance degree of alternative a_i relative to alternative a_k under indicator c_j is defined as follows:

$$\varphi_j(a_i,a_k)=\begin{cases}\sqrt{(p_{ij}-p_{kj})w_j}, & (p_{ij}-p_{kj})>0\\ 0, & (p_{ij}-p_{kj})=0\\ -\frac{1}{\theta}\sqrt{(p_{kj}-p_{ij})/w_j}, & (p_{ij}-p_{kj})<0\end{cases} \quad (4)$$

Where w_j is the weight of the indicator c_j, and θ is the loss avoidance coefficient. On the basis of Equation (4), the comprehensive dominance degree of the alternative a_i can be calculated and the final ranking is obtained.

THE DEVELOPMENT OF THE BI-TODIM METHOD

Bi-TODIM Method

Considering the interactions between indicators, the evaluator's bipolar preference, and psychological behavior, the Bi-TODIM method is proposed by combining the bi-capacity with the TODIM method. Bi-TODIM method is mainly divided into two parts: the dominance degree and the comprehensive dominance degree. We introduce the calculation of the dominance degree of the alternatives firstly.

Based on the existing TODIM method (Gomes& Lima; 1991), the weights of indicators (set) are modeled by bi-capacity, and the dominance degree of the alternative a_i relative to alternative a_l is obtained by Equation (5).

$$\varphi_{il}=-\frac{1}{\theta}\sum_{j=1}^{q}\sqrt{\frac{y_{il}^{(j)}}{\mu(C_{(j)}\cap N^+,C_{(j)}\cap N^-)-\mu(C_{(j+1)}\cap N^+,C_{(j+1)}\cap N^-)}}+\sum_{j=q+1}^{n}\sqrt{y_{il}^{(j)}[\mu(C_{(j)}\cap N^+,C_{(j)}\cap N^-)-\mu(C_{(j+1)}\cap N^+,C_{(j+1)}\cap N^-)]} \quad (5)$$

Where θ is the attenuation factor of the losses, which can be used to describe the evaluator's psychology of "loss avoidance". The smaller θ indicates the higher the evaluator's loss avoidance. $y_{il}^{j}=r_{ij}-r_{lj}$, $y_{il}^{j}\geq 0$ indicating that the alternative a_i is better than the alternative a_l under the indicator c_j; $y_{il}^{j}<0$ indicating that the alternative a_i is inferior to the alternative a_l under the indicator c_j. Let $y_{il}^{1},y_{il}^{2},\cdots,y_{il}^{n}$ order from small to large and get $y_{il}^{(1)}\leq y_{il}^{(2)}\leq\cdots\leq y_{il}^{(q)}\leq 0\leq y_{il}^{(q+1)}\leq\cdots\leq y_{il}^{(n)}$. $y_{il}^{(j)}$ are the gain or loss values ranked in the jth position after reordering from small to large. $C_{(j)}=(c_{(j)},c_{(j+1)},\cdots,c_{(n)})$, $C_{(n+1)}=\phi$, $N^{+}=\{c_j\in C\mid y_{il}^{j}\geq 0\}$, $N^{-}=C\setminus N^{+}$. μ are the bi-capacity value of the indicator.

The comprehensive dominance degree of alternative a_i is calculated by the Equation (6).

$$F_{Bi-TODIM}(a_i) = \varepsilon_i = \sum_{l=1}^{m} \varphi_{il}, i = 1, 2, \cdots, m \tag{6}$$

Standardize the comprehensive dominance degree and obtain overall evaluation value of alternative a_i by Equation (7).

$$\xi_i = \begin{cases} \dfrac{\varepsilon_i - \frac{1}{m}\sum_{i=1}^{m}\varepsilon_i}{\max\{\varepsilon_i\} - \frac{1}{m}\sum_{i=1}^{m}\varepsilon_i}, \varepsilon_i \geq \frac{1}{m}\sum_{i=1}^{m}\varepsilon_i \\ \dfrac{\varepsilon_i - \frac{1}{m}\sum_{i=1}^{m}\varepsilon_i}{\frac{1}{m}\sum_{i=1}^{m}\varepsilon_i - \min\{\varepsilon_i\}}, \varepsilon_i < \frac{1}{m}\sum_{i=1}^{m}\varepsilon_i \end{cases} (i = 1, 2, ..., m) \tag{7}$$

Based on the above steps, we can rank the alternatives according to ξ_i .

Bi-TODIM Method Related Properties

The Bi-TODIM method satisfies the monotonicity, maximum theorem, and independence theorem. These properties further illustrate the rationality of the method.

Property 1: (Monotonicity) Assume that $(y_{il}^1, y_{il}^2, ..., y_{il}^n)$ is a set of data vectors, and for any $y_{il}^j (1 \leq j \leq n)$, $F_{\text{Bi-TODIM}}(y_{il}^1, y_{il}^2, ..., y_{il}^n)$ is an increasing function.

Property 2: (The Maximum Theorem)Assume that $(y_{il}^1, y_{il}^2, ..., y_{il}^n)$ is a set of data vectors, $\forall y_{il}^j \geq 0$, for any set $Y \in P(C), Y \neq \phi$, there exists $\mu(Y, \phi) = 1$, then

$$F_{\text{Bi-TODIM}}(y_{il}^1, y_{il}^2, ..., y_{il}^n) = \sum_{l=1}^{m} \max(\sqrt{y_{il}^1}, \sqrt{y_{il}^2}, ..., \sqrt{y_{il}^n})$$

Property 3: (The Independence Theorem) Assume that $(y_{il}^1, y_{il}^2, ..., y_{il}^n)$ is a set of data vectors, if the indicators are independent, then

$$F_{\text{Bi-TODIM}}(y_{il}^1, y_{il}^2, ..., y_{il}^n) = F_{\text{TODIM}}(y_{il}^1, y_{il}^2, ..., y_{il}^n)$$

The application steps of the Bi-TODIM method are summarized into the following six steps (Figure 1):

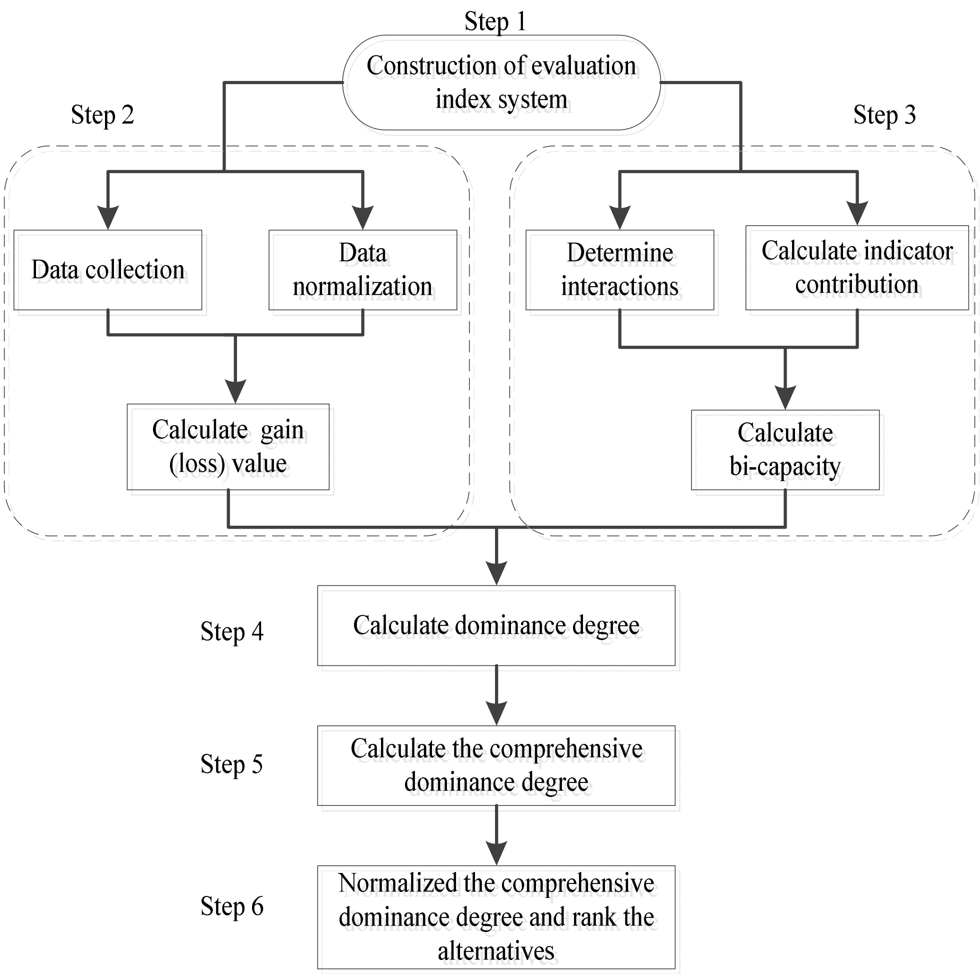

Figure 1: Application Steps of Bi-TODIM Method

SOLVING A URBAN LAND USE EFFICIENCY EVALUATION PROBLEM USING THE BI-TODIM METHOD

The Evaluation Problem

When evaluating urban land use efficiency, evaluators tend to consider whether each indicator has reached the target value set by the government and the indicator requires a bipolar value. The evaluation indicators of urban land use efficiency are not independent of each other. For example, the city with high levels of economic development, land investment will be correspondingly higher. In addition, when evaluating the land use efficiency of each city, it is necessary to take into account the evaluator's psychological behavior of loss avoidance and reference dependence. Therefore, the Bi-TODIM method is used in this paper to evaluate the urban land use efficiency of Jiangsu province.

This paper constructs an evaluation indicator system of urban land use efficiency from three dimensions of economy, society, and environment. According to the existing literature and the availability of data, 10 criteria and 26 indicators were selected (Table 1).

Table 1: Urban Land Use Efficiency Evaluation Indicator System

Dimension	Criteria	Indicator	Benchmark
Economic	Industrial structure	Value added in tertiary industry divide by GDP (%)	53
	Land investment	Construction land area per fixed assets investment (m^2/ten thousand yuan)	3.47
		Foreign investment per m^2 (ten thousand dollar/m^2)	536.45
		Construction land area per GDP (m^2/ten thousand yuan)	5.19
		Retail sales of social consumer goods per km^2 (100 million yuan/km^2)	5.54
	Economic development	GDP per km^2 (100 million yuan/km^2)	0.93
		Value added in secondary and tertiary industry per km^2 (100 million yuan/km^2)	17.02
		Employee average wage (yuan)	95033
Social	Infrastructure	The rate of the road and traffic land (%)	17.5
		The rate of residential land (%)	32.5
		The rate of public facility land (%)	6.5
	Population development	Population density (p/km^2)	1000
		Number of employees in secondary and tertiary industries per square kilometer (p/km^2)	3157
		Urbanization rate (%)	72
	Land intensity	City expansion coefficient	1.12
		Construction land area per capita (m^2/p)	100
		Floor area ratio	3.64
	Social progress	Science education investment per km^2 (ten thousand yuan/km^2)	5159.98
		The number of college students among every ten thousand people	2000
		Number of bed in the hospital per km^2	55
Environmental	Ecological resources	Water resource per square kilometer (ten thousand cubic meters/km^2)	148
		Output value of forestry per km^2 (ten thousand yuan/km^2)	40
	City greening	Green coverage rate of built-up area (%)	38.9
	Environmental quality	Industrial wastewater emission per km^2 (ten thousand tons/km^2)	56.55
		Industrial sulfur dioxide emission per km^2 (tons/km^2)	205.74
		Utilization rate of general industrial solid waste (%)	95

The indicator data in Table 1 is derived from Jiangsu Statistical Yearbook 2017, China City Statistical Yearbook 2017 and China Urban Construction Statistical Yearbook 2016. The last column of Table 1 shows the benchmark performance level for each indicator which is the performance target value set by the city planners for each city to achieve.

The Evaluation Results

According to the steps of the Bi-TODIM method, the evaluation values of economic, social and environmental dimension is shown in Figure 2, and the overall evaluation values of each city is shown in Figure 3.

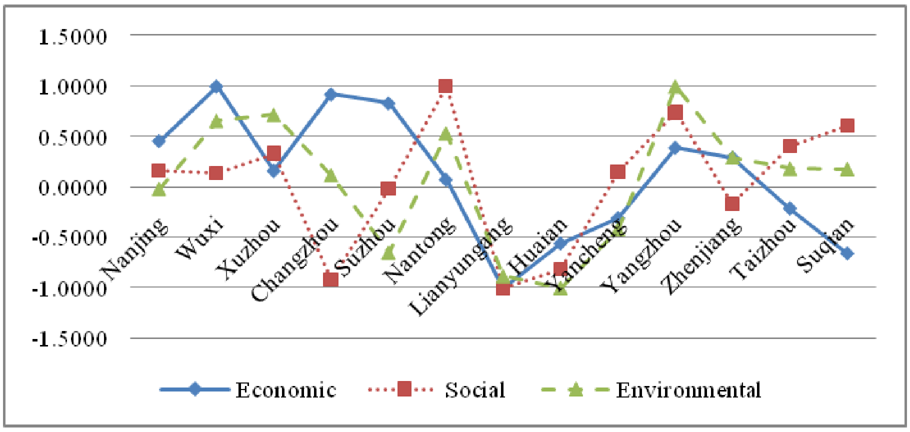

Figure 2: Land Use Economic Efficiency, Social Efficiency and Environmental Efficiency of Each City in Jiangsu Province

According to Figure 2, Wuxi has the highest evaluation value while Lianyungang has the lowest evaluation value from an economic perspective. The economic efficiency of South Jiangsu is higher than that of Central and North Jiangsu. The reason is that cities in southern Jiangsu are superior to cities in northern Jiangsu in terms of industrial structure, land investment, and economic growth. In terms of social efficiency, Nantong has the highest evaluation value while Lianyungang has the lowest evaluation value. The social efficiency of land use in cities in the central Jiangsu is higher than that in southern Jiangsu and northern Jiangsu. The reason is that the cities of centralJiangsu have performed better in terms of infrastructure, population development, land intensity, and social progress. In terms of environmental efficiency, Yangzhou, which is located in the central Jiangsu, has the highest evaluation value; followed by Xuzhou in the northern part of Jiangsu; Wuxi in the southern part of Jiangsu ranks third.

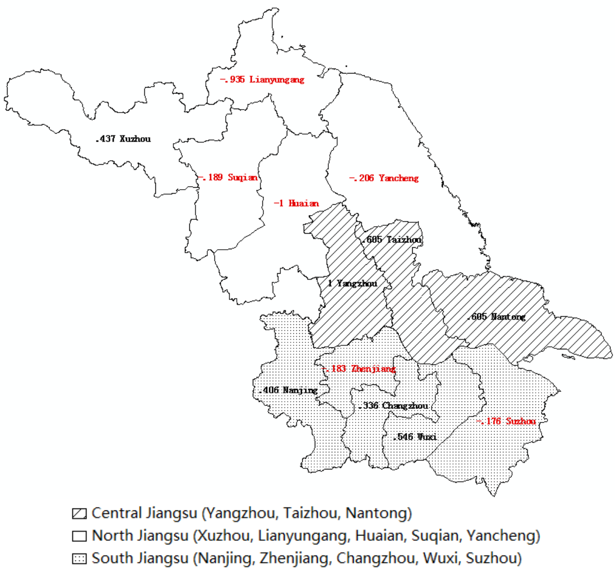

Figure 3: The Overall Evaluation Value of Land Use Efficiency in Jiangsu Province in 2016

It can be seen from Figure 3 that there is a significant spatial difference in the overall merit evaluation value of the overall land use efficiency in each city in Jiangsu Province in 2016. The overall land use efficiency of Yangzhou, Taizhou, Nantong, and Wuxi is relatively high, and the overall advantage evaluation value is higher than 0.5; the land use efficiency of Nanjing, Changzhou, and Xuzhou is acceptable, and the overall advantage evaluation value is in the range of [0, 0.5];

Suzhou The performances of Zhenjiang, Yancheng and Suqian were not good, and the overall advantage evaluation value was in the range of [-0.5, 0]; the worst performance was Huai'an and Lianyungang, and the overall advantage evaluation value was close to -1.

Sensitivity Analysis

In order to explore the influence of different risk attitudes of evaluators on the evaluation results of urban land use efficiency, different values of θ were used for calculation, and the results obtained are shown in Table 2.

Table 2: The Influence of θ on the Evaluation Results

	θ=1		θ=1.5		θ=2		θ=2.5		θ=5	
City	Evaluation Value	Rank	Evaluation Value	Rank	Evaluation Value	Rank	Evaluation Value	Rank	Evaluation Value	Rank
Nanjing	0.406	6	0.378	6	0.356	7	0.338	7	0.282	7
Wuxi	0.546	4	0.525	4	0.508	4	0.494	4	0.452	4
Xuzhou	0.437	5	0.411	5	0.391	5	0.374	6	0.323	6
Changzhou	0.336	7	0.357	7	0.374	6	0.388	5	0.430	5
Suzhou	-0.176	8	-0.168	8	-0.162	8	-0.157	8	-0.140	8
Nantong	0.605	2	0.611	2	0.615	2	0.618	2	0.629	2
Lianyungang	-0.935	12	-0.914	12	-0.897	12	-0.883	12	-0.836	12
Huaian	-1.000	13	-1.000	13	-1.000	13	-1.000	13	-1.000	13
Yancheng	-0.206	11	-0.226	11	-0.243	11	-0.257	11	-0.303	11
Yangzhou	1.000	1	1.000	1	1.000	1	1.000	1	1.000	1
Zhenjiang	-0.183	9	-0.198	9	-0.211	9	-0.221	9	-0.255	9
Taizhou	0.605	3	0.610	3	0.614	3	0.618	3	0.628	3
Suqian	-0.189	10	-0.209	10	-0.225	10	-0.238	10	-0.283	10

According to Table 2, the value of the θ will have an impact on the evaluation results. Specifically, with the increase of θ, the rankings of Nanjing and Xuzhou have declined; the ranking of Changzhou has increased; the ranking of other cities has not changed. Therefore, the evaluator's psychological behavior will have impact on the evaluation results.

CONCLUSIONS

This paper proposes the Bi-TODIM method and uses the Bi-TODIM method to evaluate the land use efficiency of 13 cities in Jiangsu Province in 2016. The conclusions are as follows:

- The Bi-TODIM not only expands the classical TODIM method but also expands the bi-capacity theory. This method does not need to meet the independent requirements of the indicators and has some properties such as monotonicity and independence. In addition, it can describe the impact of evaluators with different risk attitudes on the results.
- In empirical study, the evaluation indicator system of urban land use efficiency was constructed. Based on the Bi-TODIM method, the overall evaluation value and ranking of land use efficiency in 13 cities of Jiangsu Province were obtained, which provided a new idea for the evaluation of urban land use efficiency.
- The Bi-TODIM method is applicable to the multiple indicator evaluation problems in which the type of indicator value is real. However, many problems have uncertainties. The Bi-TODIM method cannot be applied when the type of the indicator value is a fuzzy linguistic or interval number.

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REFERENCES

1. Abdellaoui, M., Han, B., Paraschiv, C. (2007) "Loss aversion under prospect theory: aparameter-free measurement". Management Science, Vol.:53, No.:10, pp. 1659-1674.
2. Bao, X. Z., Liu, C. (2009) "Zhang J B. Evaluation of urban land use comprehensive efficiency". Urban Problem, Vol.:165, No.:4, pp. 46-50.
3. Chiou, H. K., Tzeng, G. H., Cheng, D. C. (2005) "Evaluating sustainable fishing development strategies using fuzzy MCDM approach". Omega, Vol.:33, No.:3, pp. 223-234.
4. Gomes, L. F. A. M., Lima, M. M. P. P. (1991) "TODIM: Basic and application to multicriteria ranking of projects with environmental impacts". Paris, Vol.:16, No.:1, pp. 113-127.
5. Grabisch, M., Labreuche, C. (2005) "Bi-capacities—I: definition, Möbius transform and interaction". Fuzzy Sets and Systems, Vol.:151, No.:2, pp. 211-236.
6. Grabisch, M., Labreuche, C. (2005) "Bi-capacities—II: the Choquet integral". Fuzzy Sets and Systems, Vol.:151, No.:2, pp. 237-259.
7. Grabisch, M., Labreuche, C. (2008). "A decade of application of the Choquet and Sugeno integrals in multi-criteria decision aid", 4OR, Vol.:6, No.:1, pp. 1-44.
8. Greco, S., Rindone, F. (2012) "Bipolar fuzzy integrals". Fuzzy Sets & Systems, Vol.:220, No.:2, pp. 21-33.
9. Kahneman, D., Tversky, A. (1979) "A prospect theory: an analysis of decisions under risk". Econometrica, Vol.:47, No.:2, pp. 263-291.
10. Kojadinovic, I., Labreuche, C. (2009) "Partially bipolar Choquet integrals". IEEE Transactions on Fuzzy Systems, Vol.:17, No.:4, pp. 839-850.
11. Kong, L. Y., Tan, Q. Y. (2017) "Hesitant fuzzy linguistic TODIM method and its application". Statistics and Decision, No.:5, pp. 98-100.
12. Liang, X., Jiang, Y. P., Liang, H. M. (2015) "C-TODIM decision making method considering correlated attributes". Operations Research and Management Science, Vol.:24, No.:2, pp. 101-107.
13. Liang, X., Liu, Z. M., Liu, P. D. (2017). "Pythagorean uncertain linguistic TODIM method based on generalized Choquet integral and its application", Control and Decision, pp. 1-9. doi:10.13195/j.kzyjc.2017.0364.
14. Liu, P. D., Teng, F. (2017) "Assessment of urban ecosystem health in Dongying based on hybrid TODIM". China population, resources and environment, Vol.:27, No.:8, pp. 167-176.
15. Marichal, J. L. (2002) "Entropy of discrete Choquet capacities ". European Journal of Operational Research, Vol.:137, No.:3, pp. 612-624.
16. Tseng, F. M., Chiu, Y. J. (2005) "Hierarchical fuzzy integral stated preference method for Taiwan's broadband service market ". Omega, Vol.:33, No.:1, pp. 55-64.

17. Tsetlin, I., Winkler, R. L. (2006) "On equivalent target-oriented formulations for multi-attribute utility". Decision Analysis, Vol.:3, No.:2, pp. 94-99.
18. Wang, X., Dang, Y. G. (2016) "Multiple attribute decision-making model with interval grey number based on improved TODIM method". Control and Decision, Vol.:31, No.:2, pp. 261-266.
19. Wu, L. G., Wen, L. (2017) "Low carbon supplier selection method based on 2-dimension 2-tuple linguistic information and fuzzy AHP-TODIM". Operations Research and Management Science, Vol.:26, No.:3, pp. 7-16.
20. Xu, Y., Zhang, L., Yeh, C. H., et al. (2018) "Evaluating WEEE recycling innovation strategies with interacting sustainability-related criteria". Journal of Cleaner Production, Vol.:190, No.:20, pp. 618-629.
21. Yang, Y., Chen, F. F., Chen, J., et al. (2015) "Study on selection model of inter-city traveling modes based on C-TODIM decision-making method". Railway Transport and Economy, Vol.:37, No.:12, pp. 62-68.
22. Zhang, L., Chen, Y., Zhang, Q. (2012) "Optimization model for cultivated land allocations based on the Gini coefficient". Economic Geography, Vol.:32, No.:6, pp. 132-137.
23. Zhang, L., Xu, Y., Yeh, C. H., et al. (2016) "City sustainability evaluation using multi-criteria decision making with objective weights of interdependent criteria". Journal of Cleaner Production, Vol.:131, No.:10, pp. 491-499.
24. Zhang, L., Xu, Y., Yeh, C. H., et al. (2017) "Bi-TOPSIS: A new multicriteria decision making method for interrelated criteria with bipolar measurement". IEEE Transactions on Systems Man & Cybernetics Systems, Vol.:47, No.:12, pp. 3272-3283.
25. Zhang, L., Zhou, P., Newton, S., et al. (2015) "Evaluating clean energy alternatives for Jiangsu, China: An improved multi-criteria decision making method". Energy, Vol.:90, No.:1, pp. 953-964.
26. Zhang, X., Fan, Z. P. (2012) "Method for risky hybrid multiple attribute decision making based on prospect theory". Journal of Systems Engineering, Vol.:27, No.:6, pp. 772-781.