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AN IMPROVED INTERVAL TOPSIS AND ITS APPLICATION IN ASSESSING THE PERFORMANCE OF AGRICULTURAL PRODUCT TRACEABILITY SYSTEMS

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Abstract. *It is one important but difficult problem to assess the performance of traceability systems in agricultural product supply chain, due to the conflicting focuses among different related parties (such as farmers, processors, retailers and customers) and incomplete information existing in the quantification of assessment indicators. In this work, we present an improved interval TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution), and apply the improved method into assessing the performance of agricultural product traceability systems with interval information. Application results observe the effectiveness and advantage of the improved interval TOPSIS in comparison with the existing method, and imply practical insights for improving agricultural product traceability systems.*

Keywords: Improved interval TOPSIS, Agricultural products, Traceability systems

1. **Introduction.** Agricultural product traceability systems have received extensive attention as people attach more and more importance to food safety. As Van Rijswijk et al. stated [1], food traceability refers to the ability to trace food and corresponding ingredients through the supply chain. Agricultural products are the main source of our daily food, so their traceability plays a key role in improving the safety of public health [2]. Perfect traceability systems with high performance could secure the whole agricultural product supply chain. Since different related parties (such as farmers, processors, retailers and customers) in agricultural product supply chain have different and even conflicting targets and incomplete information often exists in the real world, it is an urgent but complicated issue to develop effective approaches for assessing the performance of agricultural product traceability systems.

In the real world, it is easier to use interval or fuzzy values to express people's evaluation on something or somebody due to the uncertainty and limited knowledge. Thus, interval and fuzzy techniques are widely used in various fields. In this work, we mainly focus on assessing the performance of agricultural product traceability systems with interval information existing in the quantification of assessment indicators. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), originally proposed by

Hwang and Yoon [3], is an effective and widely-used evaluation approach [4,5]. In order to deal with decision-making issues with interval values, Sengupta and Pal [6] developed an acceptability index which could be used to determine how much one interval is greater or smaller than other one. Further, Giove [7] improved Sengupta and Pal's index to develop an interval TOPSIS, and proved the good merits of the proposed method.

However, Giove's interval TOPSIS as well as Sengupta and Pal's index fails to reflect the preference of decision-makers. The consideration of decision-makers' preference is inconsistent with the real-world decision making process. In our work, considering decision-makers' optimism degree, we propose an improved interval TOPSIS and apply it into assessing the performance of agricultural product traceability systems with interval information. The improved interval TOPSIS provides a more realistic method for multiple criteria decision making problems. Application results in agricultural product supply chains are presented to test the advantage of the improved method.

The rest of the work is organized as follows. In Section 2, we briefly recall some extant acceptability indexes for comparing interval values. Then, Section 3 presents an improved interval TOPSIS which extends the extant method to a generalized one. In Section 4, we identify assessment indicators from the views of farmers, processors, retailers and customers, and develop the framework of applying the improved interval TOPSIS into assessing the performance of agricultural product traceability systems with interval information. Section 5 gives the application results, with conclusions in Section 6.

2. **Extant Acceptability Indexes for Comparing Interval Values.** Let $\bar{A} = [a^{low}, a^{up}]$ and $\overline{B} = [b^{low}, b^{up}]$ represent two interval values, where a^{low} and b^{low} are the lower bounds, a^{up} and a^{up} are the upper bounds, $a^{low} \leq a^{up}$ and $b^{low} \leq b^{up}$. Sengupta and Pal [6] formulated the following acceptability index:

$$\alpha\left(\overline{A} \succ \overline{B}\right) = \frac{m\left(\overline{A}\right) - m\left(\overline{B}\right)}{w\left(\overline{A}\right) + w\left(\overline{B}\right)} \tag{1}$$

where $m\left(\overline{A}\right) = \frac{1}{2}\left(a^{low} + a^{up}\right)$ and $m\left(\overline{B}\right) = \frac{1}{2}\left(b^{low} + b^{up}\right)$ respectively mean the mid-values of $\bar{A}$ and $\overline{B}$, and $w\left(\overline{A}\right) = \frac{1}{2}\left(a^{up} - a^{low}\right)$ and $w\left(\overline{B}\right) = \frac{1}{2}\left(b^{up} - b^{low}\right)$ respectively mean the half-widths of $\bar{A}$ and $\overline{B}$.

Sengupta and Pal's index could compare any two real interval values, but is invalid for comparing mixed precise and interval values. To deal with the shortage, Giove [7] improved index (1) into:

$$\xi\left(\overline{A} \succ \overline{B}\right) = \frac{m\left(\overline{A}\right) - m\left(\overline{B}\right)}{w\left(\overline{A}\right) + w\left(\overline{B}\right) + 1} \tag{2}$$

However, neither index (1) nor (2) could reflect the preference of decision-makers on interval values. Motivated by this, Ruan et al. [8] improved index (2) into:

$$\delta\left(\overline{A} \succ \overline{B}\right) = \frac{o\left(\overline{A}\right) - o\left(\overline{B}\right)}{w\left(\overline{A}\right) + w\left(\overline{B}\right) + 1} \tag{3}$$

where $o(\overline{A}) = \left(\gamma a^{low} + (1-\gamma)a^{up}\right)$ and $o\left(\overline{B}\right) = \left(\gamma b^{low} + (1-\gamma)b^{up}\right)$ are respectively preference-based mid-values of $\bar{A}$ and $\overline{B}$, where an optimism degree γ is introduced, $0 \leq \gamma \leq 1$.

3. **The Improved Interval TOPSIS.** In this section, we integrate Ruan et al.'s preference-based index (3) with Giove's interval TOPSIS to develop an improved interval TOPSIS. For basic knowledge on TOPSIS, readers could refer to some specialized references, such as [3].

Let $O = \{X_i\}$, $i = 1, 2, \ldots, n$ represent the set of alternatives, $C = \{C_j\}$, $j = 1, 2, \ldots, m$ represent the set of assessment indicators, and $D = \left\{\overline{V}_{i\times j}\right\}$ represent the set of interval assessment values for alternatives according to different assessment indicators, where n and m respectively denote the number of assessment targets and alternatives, and $\overline{V}_{i\times j} = \left[v_{i\times j}^{low}, v_{i\times j}^{up}\right]$ denotes the assessment value for alternative X_i according to indicator C_j, $0 < v_{i\times j}^{low} \leq v_{i\times j}^{up}$.

For classic TOPSIS methods with precise information, the first step is to normalize the assessment values, but it is not feasible if the assessment values include interval numbers. According to Giove's work [7], we use Ruan et al.'s index (3) to formulate the following formula:

$$\begin{aligned} IV_{i\times j} &= \sum_{k=1,k\neq i}^{n} \delta\left(\overline{V}_{i\times j} \succ \overline{V}_{k\times j}\right) \\ &= \sum_{k=1,k\neq i}^{n} \frac{o\left(\overline{V}_{i\times j}\right) - o\left(\overline{V}_{k\times j}\right)}{w\left(\overline{V}_{i\times j}\right) + w\left(\overline{V}_{k\times j}\right) + 1}, \quad \forall j \in \{1, 2, \ldots, m\} \end{aligned} \tag{4}$$

which could transfer interval assessment values into corresponding precise ones, denoted by $IV_{i\times j}$. Then, we could compute the ideal and anti-ideal bags, as follows:

$$IMCFB_{>}^{+} = \left\{\max_{i=1}^{n}\{IV_{i\times j}\},\ j = 1, 2, \ldots, m\right\} \tag{5}$$

$$IMCFB_{>}^{-} = \left\{\min_{i=1}^{n}\{IV_{i\times j}\},\ j = 1, 2, \ldots, m\right\} \tag{6}$$

where $IMCFB_{>}^{+}$ and $IMCFB_{>}^{-}$ respectively denote the ideal and anti-ideal bags, that is, the ideal and anti-ideal alternatives. Then, the distances of any alternative from the ideal and anti-ideal alternatives could be determined by:

$$id_{>}^{+} = d\left(IMCFB_{>}^{i}, IMCFB_{>}^{+}\right), \quad \forall i = 1, 2, \ldots, n \tag{7}$$

$$id_{>}^{-} = d\left(IMCFB_{>}^{i}, IMCFB_{>}^{-}\right), \quad \forall i = 1, 2, \ldots, n \tag{8}$$

where $IMCFB_{>}^{i} = \{IV_{i\times j},\ j = 1, 2, \ldots, m\}$ represents the set of corresponding precise assessment values for alternative X_i. Finally, we could determine the ranking of all the alternatives by:

$$\begin{aligned} IC_{>}(X_i) &= \frac{id_{>}^{-}}{id_{>}^{-} + id_{>}^{+}} \\ &= \frac{d\left(IMCFB_{>}^{i}, IMCFB_{>}^{-}\right)}{d\left(IMCFB_{>}^{i}, IMCFB_{>}^{-}\right) + d\left(IMCFB_{>}^{i}, IMCFB_{>}^{+}\right)} \end{aligned} \tag{9}$$

In this work, the Euclidean distance is used, that is,

$$IC_{>}(X_i) = \frac{\sqrt{\sum_{j=1}^{m}\left(w_j\left(IV_{i\times j} - \min_{i=1}^{n}\{IV_{i\times j}\}\right)^2\right)}}{\sqrt{\sum_{j=1}^{m}\left(w_j\left(IV_{i\times j} - \min_{i=1}^{n}\{IV_{i\times j}\}\right)^2\right)} + \sqrt{\sum_{j=1}^{m}\left(w_j\left(IV_{i\times j} - \max_{i=1}^{n}\{IV_{i\times j}\}\right)^2\right)}} \tag{10}$$

where w_j is the weight of indicator j.

After determining $IC_{>}(X_i)$, we could rank the n alternatives according to the m assessment indicators.

4. Assessing the Performance of Agricultural Product Traceability Systems.

4.1. Performance indicators. The assessment of the traceability system is often performed by comparing against the appropriate indicators. Aramyan et al. [9] divided the evaluation indicators of agri-food supply chain performance into four groups: efficiency, flexibility, responsibility, and food quality. As Bosona and Gebresenbet reviewed [2], the performance of full chain traceability should be evaluated against its overall goal, and they identified indicators such as compliance with rules and legislation, food safety and quality, social and stakeholders' satisfactions, economic benefits, and technological and scientific benefits. Van der Vorst [10] deduced three strategic levels of traceability performance: compliance-oriented performance level, process-oriented performance level and market-oriented performance level.

The above work provides helpful supports for us to determine assessment indicators of the performance of agricultural product traceability systems. However, in agricultural product supply chain, different related parties have different and even conflicting targets, so assessment indicators should reflect the focuses of decision-makers. Motivated by this, we summarize the assessment indicators of the performance of agricultural product traceability systems into four aspects: farmers-oriented, processors-oriented, retailers-oriented and customers-oriented. The detailed indicators are as Table 1 shows.

Table 1. The assessment indicators of the performance of agricultural product traceability systems

Focused parties	Assessment indicators	Notations
Farmers	Ease of use	I_1
	Responsibility	I_2
Processors	Cost	I_3
	Operational effectiveness	I_4
	Operational efficiency	I_5
Retailers	Profit	I_6
	Promotion effect	I_7
	Service flexibility	I_8
Customers	Reliability	I_9
	Information integrity	I_{10}

Meanwhile, due to the uncertainty and limited knowledge, it is easier to use interval or fuzzy values to express people's evaluation on something or somebody. To the best of our knowledge, no studies are contributed to assessing the performance of agricultural product traceability systems considering different related parties and interval indicator values.

4.2. Assessment framework. According to the identified assessment indicators in Table 1, we could use the improved interval TOPSIS in Section 3 to formulate the framework and steps of assessing the performance of agricultural product traceability systems, as follows:

Step 1: Obtaining the values of assessment indicators. Expert grading method is used for assessing the indicators into some precise or interval scores between 0 and 100, such as 80 or $[80, 90]$. The bigger the score is, the better the performance is.

Step 2: Normalizing the interval assessment values into $[0, 1]$.

Step 3: Transferring normalized interval assessment values into corresponding precise ones, that is, using Formulas (3) and (4) to calculate $IV_{i\times j}$. In this step, the optimism degree γ will have impact on the results, $0 \leq \gamma \leq 1$, so we will analyze the effect in the application study.

Step 4: Determining the ideal and anti-ideal bags using Formulas (5) and (6), that is, $IMCFB^+_>$ and $IMCFB^-_>$.

Step 5: Using Formula (10) to calculate $IC_>(X_i)$ and rank the alternatives. The indicator weights also have impact on the assessment results, which will be observed in Section 5.

5. **Application Study.** In this section, we applied the improved interval TOPSIS into the assessment of traceability systems implemented in eight agricultural product supply chains. The aim of the assessment is to judge which traceability system exceeds others and which aspects for each traceability system should be enhanced in order to improve the performance of the traceability system. The original expert grading results are as shown in Table 2.

Table 2. The original expert grading results

	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}
X_1	[60, 70]	80	60	[50, 60]	[65, 75]	80	90	[40, 50]	[70, 80]	[60, 70]
X_2	40	[30, 50]	60	[60, 70]	[50, 60]	50	[60, 70]	[70, 80]	[50, 60]	50
X_3	85	[80, 90]	[80, 90]	80	85	[70, 80]	75	[85, 90]	[70, 80]	90
X_4	[75, 85]	80	[65, 75]	[80, 85]	[70, 80]	[50, 60]	65	[70, 75]	[60, 70]	[80, 85]
X_5	[30, 40]	65	[50, 60]	[40, 50]	[60, 70]	65	[30, 40]	[20, 30]	[30, 40]	[50, 60]
X_6	70	[80, 90]	[70, 80]	[75, 85]	[80, 90]	[90, 95]	[75, 85]	[70, 80]	[80, 90]	[70, 80]
X_7	[60, 70]	55	70	[30, 40]	[50, 60]	[70, 80]	[75, 80]	[65, 70]	[60, 70]	[80, 90]
X_8	[70, 90]	85	[80, 90]	[80, 85]	[70, 75]	[60, 70]	[80, 90]	[80, 90]	[75, 85]	[80, 90]

As mentioned above, the indicator weights will have impact on the assessment results, so in the following part we respectively calculate the results with equivalent and different weights.

5.1. **Results with equivalent indicator weights.** Using Formulas (3) and (4), we could obtain $IV_{i\times j}$, as shown in Table 3. Comparing the precise $IV_{i\times j}$s in Table 3 with the original values in Table 2, we could find that the obtained $IV_{i\times j}$s keep the originality of the interval values in Table 2. For example, for indicator I_1, the value of X_5 (i.e., [30, 40]) is the smallest, and its corresponding $IV_{5\times 1}$ (i.e., −3.485) is also the smallest among all the alternatives for indicator I_1.

Table 3. The $IV_{i\times j}$s

	$IV_{i\times 1}$	$IV_{i\times 2}$	$IV_{i\times 3}$	$IV_{i\times 4}$	$IV_{i\times 5}$	$IV_{i\times 6}$	$IV_{i\times 7}$	$IV_{i\times 8}$	$IV_{i\times 9}$	$IV_{i\times 10}$
X_1	0.014	1.001	−1.806	−1.374	−0.086	1.737	2.328	−2.194	0.929	−1.391
X_2	−3.129	−3.557	−1.806	−0.118	−2.535	−3.295	−0.795	0.843	−1.357	−4.320
X_3	2.533	1.523	2.544	1.913	2.627	0.812	0.415	2.176	0.929	3.065
X_4	1.764	1.001	0.044	2.163	0.730	−2.223	−0.860	0.609	−0.214	1.588
X_5	−3.485	−0.925	−2.456	−2.629	−0.902	−0.779	−4.338	−4.218	−3.643	−3.046
X_6	0.646	1.523	0.878	1.766	2.363	3.642	0.977	0.843	2.071	0.264
X_7	0.014	−2.209	0.056	−3.885	−2.535	0.812	0.707	0.086	−0.214	1.919
X_8	1.643	1.643	2.544	2.163	0.337	−0.706	1.567	1.855	1.500	1.919

Then, the final assessment results could be obtained using Step 4 and Step 5 in Section 4.2, as shown in Table 4. The assessment results by Giove's interval TOPSIS [7] are also given.

TABLE 4. The assessment results with different optimism degrees

	Results by our work with different optimism degrees							**Results by Giove's interval TOPSIS [7]**
	$\gamma = 0$	$\gamma = 0.2$	$\gamma = 0.4$	$\gamma = 0.5$	$\gamma = 0.6$	$\gamma = 0.8$	$\gamma = 1.0$	
X_1	0.560	0.563	0.564	0.564	0.563	0.561	0.559	0.564
X_2	0.329	0.332	0.332	0.332	0.331	0.330	0.329	0.332
X_3	0.830	0.830	0.829	0.828	0.827	0.825	0.822	0.828
X_4	0.634	0.631	0.629	0.627	0.625	0.622	0.618	0.627
X_5	0.208	0.206	0.207	0.208	0.209	0.214	0.219	0.208
X_6	0.823	0.815	0.801	0.793	0.785	0.769	0.751	0.793
X_7	0.534	0.529	0.525	0.520	0.516	0.507	0.497	0.520
X_8	0.779	0.773	0.765	0.758	0.750	0.735	0.719	0.758

From the results in Table 4, we can observe the following findings.

(1) The optimism degrees have impact on the assessment results, but the impact makes no change on the final ranking. The ranking by our work with different optimism degrees is always $X_3 > X_6 > X_8 > X_4 > X_1 > X_7 > X_2 > X_5$.

(2) The ranking by our work is consistent with that by Giove's interval TOPSIS, but our work could fully reflect the optimism degrees of decision-makers. These results not only verified the effectiveness of our work but also showed the advantage of our work.

5.2. **Results with different indicator weights.** The results in Section 5.1 are subject to the equivalent indicator weights. In this section we observe the impact of decision-makers' focuses on the assessment results. As mentioned above, different related parties are involved, such as farmers, processors, retailers and customers. In order to reflect decision-makers' focuses, we adjust corresponding indicator weights to make their weights account for 0.5, with other equivalent indicators.

From the results in Table 5, we can observe the following findings:

(1) The decision-makers' focuses have impact on the assessment and ranking results. When decision-makers' optimism degrees keep unchanged, the results with different decision-makers' focuses may be different, such as the results with $\gamma = 0$ in Table 5.

(2) With the same decision-makers' focuses, the assessment and ranking results may be also different. For example, when decision-makers' focus is on the farmers, the ranking

TABLE 5. The ranking results with decision-makers' focuses

		Decision-makers' focuses			
		Farmers	Processors	Retailers	Customers
		$w_1 = w_2 = 1/4$	$w_3 = w_4 = w_5 = 1/6$	$w_6 = w_7 = w_8 = 1/6$	$w_9 = w_{10} = 1/4$
Results by our work	$\gamma = 0$	$X_3 > X_8 > X_6 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_3 > X_6 > X_8 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_6 > X_3 > X_8 > X_1 > X_4 > X_7 > X_2 > X_5$	$X_3 > X_8 > X_6 > X_4 > X_7 > X_1 > X_2 > X_5$
	$\gamma = 0.2$	$X_3 > X_8 > X_6 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_3 > X_6 > X_8 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_6 > X_3 > X_8 > X_1 > X_4 > X_7 > X_2 > X_5$	$X_3 > X_8 > X_6 > X_4 > X_7 > X_1 > X_2 > X_5$
	$\gamma = 0.4$	$X_3 > X_8 > X_6 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_3 > X_6 > X_8 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_6 > X_3 > X_8 > X_1 > X_4 > X_7 > X_2 > X_5$	$X_3 > X_8 > X_6 > X_4 > X_7 > X_1 > X_2 > X_5$
	$\gamma = 0.5$	$X_3 > X_8 > X_6 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_3 > X_6 > X_8 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_6 > X_3 > X_8 > X_1 > X_4 > X_7 > X_2 > X_5$	$X_3 > X_8 > X_6 > X_4 > X_7 > X_1 > X_2 > X_5$
	$\gamma = 0.6$	$X_3 > X_6 > X_8 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_3 > X_6 > X_8 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_6 > X_3 > X_8 > X_1 > X_4 > X_7 > X_2 > X_5$	$X_3 > X_8 > X_6 > X_4 > X_7 > X_1 > X_2 > X_5$
	$\gamma = 0.8$	$X_3 > X_6 > X_8 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_3 > X_6 > X_8 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_3 > X_6 > X_8 > X_1 > X_4 > X_7 > X_2 > X_5$	$X_3 > X_8 > X_6 > X_4 > X_7 > X_1 > X_2 > X_5$
	$\gamma = 1.0$	$X_3 > X_6 > X_8 > X_4 > X_1 > X_7 > X_5 > X_2$	$X_3 > X_6 > X_8 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_3 > X_6 > X_8 > X_1 > X_4 > X_7 > X_2 > X_5$	$X_3 > X_8 > X_6 > X_4 > X_7 > X_1 > X_2 > X_5$
Results by Giove's interval TOPSIS [7]		$X_3 > X_8 > X_6 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_3 > X_6 > X_8 > X_4 > X_1 > X_7 > X_2 > X_5$	$X_6 > X_3 > X_8 > X_1 > X_4 > X_7 > X_2 > X_5$	$X_3 > X_8 > X_6 > X_4 > X_7 > X_1 > X_2 > X_5$

with $\gamma = 0.5$ is $X_3 > X_8 > X_6 > X_4 > X_1 > X_7 > X_2 > X_5$, but the ranking is $X_3 > X_6 > X_8 > X_4 > X_1 > X_7 > X_2 > X_5$ when $\gamma = 0.6$.

(3) In comparison with Giove's interval TOPSIS [7], the results by our work could simultaneously reflect decision-makers' optimism degrees and focuses. In general, Giove's interval TOPSIS is a special situation of our method, that is, when decision-makers are neutral.

6. **Conclusions.** This paper considered decision-makers' optimism degree to formulate an improved interval TOPSIS, and applied the method into assessing the performance of agricultural product traceability systems. Application results verified the effectiveness and advantage of the method in comparison with extant interval TOPSIS, and observed the impact of decision-makers' optimisms and focuses on the assessment results of agricultural product traceability systems. Our improved interval TOPSIS is a generalized method which could be used for other decision-making issues with interval information. In future studies, we will apply the proposed method into more real-world problems, and extend the proposed method to decision making with fuzzy information.

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