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# Smart Sales Empower Small Farmers: An Integrated Matching Method between Suppliers and Consumers Based on the Information Axiom

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**Abstract:** Small farmers' sustainable development has important significance for narrowing the gap between urban and rural areas and hastening the promotion of general prosperity in China. Currently, China still has 240 million small farmers. The sale of agricultural products is an important source of their income. Constrained by their small scale, lack of capital, and technology, small farmers often have to adopt a household operation mode. This decentralized agricultural production and operation mode results in significant difficulties for small farmers to benefit from planting and selling agricultural products. Many efforts have been made to help them, such as establishing agricultural product information platforms that can provide supply and demand information to facilitate small farmers' sales. However, imbalances between suppliers and consumers and cross-regional transaction difficulties still exist. To promote the sustainable development of small farmers, this study develops an intelligent matching method for the transaction of agricultural products between suppliers and consumers. Firstly, a unique attribute set for agricultural products was established. Because most agricultural products are fresh, perishable, and not easily preserved, the general attributes (brand, logistics distance, product grade, and price) of commodities and the specific attributes (freshness, maturity, product certification, seasonal products, place of origin, and product safety) of agricultural products were taken into account. Secondly, by combining fuzzy mathematics with the information axiom, improved amount of information calculation methods for both quantitative and qualitative attributes were put forward. Thirdly, based on the amount of information about all attributes and with the goal of maximizing the transaction-matching degree for both the supplier and consumer, a multiobjective optimization model was proposed. Finally, the effectiveness and accuracy of the method were verified through a case study. In order to solve the dilemma of small farmers, this study proposes an integrated matching method for agricultural product transactions based on the information axiom. Through case verification, this method has good feasibility and effectiveness. It has broad application prospects which can be applied to information portals, e-commerce platforms, and other fields. The application of this method can empower small farmers' capabilities, facilitate agricultural product sales, and promote small farmers' sustainable development.

**Keywords:** rural e-commerce; matching problem; sales promotion; small farmer; sustainable development

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## 1. Introduction

At present, there are more than 230,000 small- and medium-sized Chinese agricultural business enterprises. Most of China's rural areas still retain small-scale farmer economies [1]. The majority of agricultural product growers in China are mainly small farmers [2] who are "scattered, small, disorderly and weak". In order to promote the sustainable development of the rural economy and small farmers, many scholars believe that it is important to help small farmers to produce more agricultural products and make them gain more sales benefits [3–6]. In recent years, innovating and upgrading agricultural production technology has lowered production costs, strengthened farmers' production skills, and expanded the scale of agricultural production, leading to more prosperity in the agriculture industry [7]. However, although agricultural production has grown steadily, the pace of sales promotion is obviously lagging behind [8]. As a result, poor sales of agricultural products occur frequently and show an upward trend year by year, even worse when encountering COVID-19 [9]. This has dramatically hindered the progress of the agricultural industry, the prosperity of rural areas, and even the sustainable development of farmers. One reason for this is the lack of proper marketing channels. Small farmers are not the same as organized agricultural companies, farms, and agricultural cooperatives. They are not good at business and do not have enough experience to find suitable marketing channels. Intermediary agents in rural areas and residents of nearby towns and cities are their only choices to sell their produce. The other reason is the lack of bargaining capacity to earn more profits. Due to small-scale family operations, nontransparent price information, and being squeezed by powerful intermediaries, small farmers usually cannot sell their produce at moderate prices. Therefore, how to find a method to facilitate the sales of small farmers becomes a noteworthy research topic.

Actually, with the development of internet technology and the widespread application of mobile smartphones, rural e-commerce has gradually become saturated. Data from the China Business Information Network show that online retail sales in rural areas reached 1.79 trillion yuan in 2020 with a year-on-year growth of 5.3% [10]. Sales of agricultural products in China have been transformed into electronic marketing. Not only a large number of professional e-platforms, such as "vegnet", "chinafarmin", "myagric" and "cnhnb", but also existing top e-commerce platforms, such as jd.com, taobao.com, and pinduoduo.com, have begun to help small farmers to sell agricultural products. The emergence of agricultural e-platforms has profoundly changed the traditional sales mode and reshaped the relationship between the suppliers and consumers of agricultural products [11], which facilitates the trade of agricultural products and provides a new sales method for small farmers. However, both consumers and suppliers are facing the same dilemma in the new transaction method. That is, it is hard for consumers to seek suitable agricultural product schemes that suit their actual needs; meanwhile, it is difficult for suppliers to seek suitable consumers to match their production. Therefore, understanding requirements between consumers and suppliers, solving the problem of matching suppliers and consumers, and building a fast, intelligent, and efficient matching method between suppliers and consumers with the use of an intelligent algorithm and advanced information technology in order to address small farmers' sustainable development has become a large, practical need in the present situation.

## 2. Literature Review

### 2.1. The Matching Problem in Agricultural Products

Before delving into the problem of matching the supply and demand of agricultural products, it is necessary to survey related research on the concept of matching. In the past few decades, the matching problem has attracted extensive attention from many scholars. Matching research originated from marriage matching. In order to try to make both men and women find a satisfactory partner, Gale and Shapley proposed the G–S algorithm for seeking stable match results while Roth [12,13] advanced a two-sided matching concept and analyzed the existing examples in the market using preference information. Since then, scholars have carried out research on matching theory and its practical applications. For example, Shapley and Roth won the 2012 Nobel Prize in Economics for their outstanding contributions to matching research. In addition, the study of matching problems from the perspective of supply and demand began in 1994. Cable and Judge first studied the matching problem between people and organizations; they suggested using a "demand-supply" and "requirement-capability" viewpoint to analyze the matching of individuals and organizations [14]. With the gradual deepening of matching research, it has been applied to many fields and achieved breakthroughs, such as personnel position matching in the labor market [15–18], knowledge service supply and demand matching [19–21], resource supply and demand matching [22–24], etc.

The supply, demand, and price of agricultural products fluctuate greatly in different production cycles. There are often situations in which agricultural products cannot be sold without proper sales channels, and consumers haven't suitable channels to purchase agricultural products they want. It is still difficult to match agricultural supply and demand in the market. Exploring efficient ways to match the supply and demand of agricultural products has always been an urgent problem to be solved in agricultural modernization. Scholars have begun to pay attention to the matching of supply and demand of agricultural products. Gao et al. [25] applied the intelligent internet of things (IIoT) to match agricultural supply and demand information. Li et al. developed a novel sentiment analysis-based method for matching creative agriproduct scheme consumers and suppliers through a case study in China [26]. Verdouw et al. presented a reference model for designing business processes in demand-driven fruit supply chains, aiming to continuously match supply capabilities to changing demand requirements [27]. Zhao et al. proposed the integration of a livestock product supply chain to solve the problem of imbalance and used a duck farm as a case study to show the integration process [28]. Based on location services, web 2.0 concepts, and bilateral trade matching theory, Niu and Zheng designed and implemented an information platform for agricultural trade [29]. Xu et al. used the grey prediction model to conduct demand forecasting for agricultural product logistics in the community to solve the problem of matching the supply and demand of community shops [30]; Kieu et al. proposed an MCDM model for improving the efficiency of agricultural supply chains by selecting the location distribution center [2].

### *2.2. The Matching Method*

In terms of supply and demand matching, there are various optimization methods. To better review the existing findings, matching methods were systematically sorted out, which mainly consist of six matching methods including the Gale–Shapley method, WHIRL method, matching method based on "fuzzy set and utility theory", SMAA method, TODIM method, and VIKOR method. The first well-known method is the Gale–Shapley method which was first introduced in the field of marriage matching [31]. In recent years, the G–S method has been widely used in other fields. For instance, Teo solved the student enrollment problem by using the Gale–Shapley model, explaining why the strategic behavior of students need not be a major concern [32]. Abououf maximized the level of satisfaction of workers by assigning them to their most preferred tasks using a Gale–Shapley model [33]. The second matching method is the WHIRL method. The WHIRL method has been used in the big data field to solve the problem of lacking common object identifiers [34]. It has been proven that the WHIRL method is more accurate, outperforming matching results and requiring less user involvement compared with the other algorithm [35]. However, different usage scenarios determine the choice of method. So, the third matching method based on "the fuzzy set and utility theory" is proposed to find "good" counterparts for a given entry in the marketplace [36]. Ragone also improved this method in the e-marketplace subsequently [37]. The fourth method is SMAA. There are multiple targets and persistent matching in the real world which the SMAA method is well-suited for. So, to help multiple decision makers choose their preferred alternative from a finite set, stochastic multicriteria acceptability analysis (SMAA) was developed [38]. The SMAA methodology is applicable in a broad range of decision-making contexts [39]. By using the SMAA method, Abdellah selected the location for centralizing cargo at the Moroccan airport hub [40]. The fifth and sixth methods are the Topsis method and Vikor method, both of them could handle matching problems in a certain situation and have good performance [41–46].

In conclusion, the above methods have been applied in different fields and have prominent performance. In order to better sort out the advantages and characteristics of the above methods, we have summarized the existing matching methods, as shown in

Table 1. The methods are sorted by three main dimensions, including sides, attributes, and conditions, which could help scholars understand matching methods better.

**Table 1.** Matching Algorithms and Characteristics.

| Matching Methods | Sides | | Attributes | | Conditions | |
|---|---|---|---|---|---|---|
| | Two-Sides | Others | Quantitative | Qualitative | One-Shot | Continuous |
| Gale–Shapley Technique | ✓ | | ✓ | | | ✓ |
| Whirl Technique | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Matching method based on "Fuzzy Set and Utility theory" | ✓ | | ✓ | ✓ | | ✓ |
| SMAA Technique | ✓ | ✓ | ✓ | | ✓ | ✓ |
| TODIM Technique | ✓ | | ✓ | | ✓ | |
| VIKOR Technique | | ✓ | ✓ | ✓ | ✓ | |

All these studies put forward a variety of methods to solve the matching problem and provide a solid foundation for our research framework. With the development of rural e-commerce, research on the matching problem for agricultural products is gradually linked with information technology. However, relevant methods and technologies still have some limitations: (1) Current research mainly solves the problem of matching between supply and demand of agricultural products by integrating supply chains, developing trading platforms, and predicting logistics needs. They rarely explore the matching of supply and demand from the attributes of agricultural products. However, compared with general commodities, agricultural products have lots of unique attributes, such as perishability, freshness, seasonality, etc. These attributes will greatly affect the transaction volume and matching degree of agricultural products; (2) most matching methods have their own specific application scenarios. A matching process of agricultural products has these features: two sides matching between consumers and suppliers, qualitative and quantitative attributes need to be taken into account, and a one-shot deal in the transaction. Although existing matching methods have their own advantages, they cannot fully take into account all the above features(see Table 1). There is no ready method that can be directly used in the matching process of agricultural product transactions. Therefore, it is necessary to propose a new matching method to solve the problems in the process of agricultural product trading to facilitate sales.

Based on the above analysis, the innovations of this study are put forward from the aspects of index attributes and matching algorithms: (1) In terms of index attributes, this study not only considered the general commodity attributes of agricultural products but also their specific attributes and constructed a multiattribute indicator system for agricultural product trading to describe the outstanding characteristics of agricultural products in the process of agricultural product trading from a comprehensive perspective; (2) for the matching algorithm, by fully analyzing the characteristics of each current matching algorithm, this study applies the fuzzy mathematics theory and the information axiom method to the existing research on agricultural product supply and demand matching and establishes a one-time multiattribute agricultural product supply and demand matching model with improved information. This model takes into account the characteristics of a multiattribute indicator system, dynamic trading mechanism, and fuzzy trading language in the actual trading process of agricultural products and solves the problem that existing algorithms cannot fully fit the actual trading process of agricultural products. The method proposed in this study provides a solution for the structural imbalance between the supply and demand of agricultural products and optimizes the matching between suppliers and consumers of agricultural products, which can maximize suppliers' interests and fulfill consumers' needs as much as possible.

## 3. Establishment of the Agricultural Products Matching Model Based on the Information Axiom

### 3.1. Research Framework

In order to achieve smooth transactions for agricultural products, it is necessary to find the best match between suppliers and consumers quickly. This problem can be described as a typical multiobjective matching problem on a binary graph, as shown in Figure 1. To solve this problem, the attributes of agricultural products need to be identified from the perspective of both suppliers and consumers, and a multiattribute optimization model needs to be set up to find the optimal solution. As is shown in Figure 1, let B present the set of consumers consisting of m consumers, $b_i$ is the $i$th consumer, $I$ = 1, 2, 3, . . . , m; let S present the set of suppliers consisting of n suppliers, and $s_i$ is the $j$th supplier, $j$ = 1, 2, 3, . . . , n. The link between B (consumers) and S (suppliers) presents whether there exists a transaction. The width of the line stands for the satisfaction of consumers and suppliers. The wider the line, the more satisfied both sides are. The purpose of a broker is to find the lines of the two types of nodes(such as bold lines) so they satisfy the requirements of both sides. The notation in this study is shown in Table 2.

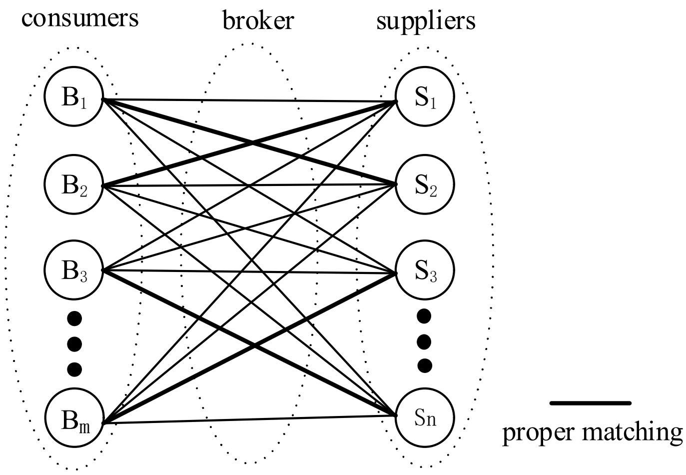


**Figure 1.** Description of the matching problem.

**Table 2.** Notation in this study.

| Variables Symbol | Description of Meaning |
|---|---|
| $B$ | Represents the set of consumers consisting of m consumers |
| $B_i$ | $B_i$ represents the i-th consumer |
| $S$ | Represents the set of suppliers consisting of s suppliers |
| $S_i$ | $S_i$ represents the j-th supplier |
| $S_r$ | Represents the distribution range of attributes required (or provided) by the consumer (supplier), which range from $f^1$ to $f^2$ |
| $D_r$ | Represents the distribution range of attributes expected by the supplier and consumer, which range from $d^1$ to $d^2$ |
| $C_r$ | Represents the common range between $D_r$ and $S_r$, $D_r \cap S_r$ |
| $\overline{f}$ | The formula is $\frac{f^2-f^1}{2}$ represents the intermediate value of system range |
| $I_{kij}$ | The amount of demand-side information when matching the $i$ demand-side with the $j$ supply-side in the $k$ attribute |
| $I_{kji}$ | The amount of supply-side information when matching the $j$ demand-side with the $i$supply-side in the $k$ attribute |
| $Z_1^l$ | The total amount of information of supply-side |
| $Z_2^l$ | The total amount of information of demand-side |
| $X_{ij}$ | Represents whether $i$ consumer is successfully matched with $j$ supplier, if yes, $X_{ij} = 1$; otherwise, $X_{ij} = 0$ |
| $\mu_S(x)$ | $\mu_S(x)$ denotes the supply's membership functions |
| $\mu_D(x)$ | $\mu_D(x)$ denotes the demand's membership functions |

The information axiom can deal with ambiguous information efficiently. Therefore, to achieve a higher matching degree between consumers and suppliers, we adopted the information axiom to establish a supplier and consumer matching model for agricultural products with multiple attributes. The feasibility and effectiveness of the method are illustrated by a comparative analysis of a case study. Referring to previous research [47–50], the detailed research framework is as follows:

1. Attributes were elaborately selected by considering the properties and requirements of agricultural products. These attributes were divided into two categories: general attributes(the common attributes of agricultural products) and specific attributes(the unique attributes of agricultural products). The system range and design range were determined from the perspective of both the supplier and consumer.
2. The attributes of agricultural products were divided into qualitative and quantitative attributes. Different kinds of attributes need to be calculated using different methods. For quantitative attributes, an improved method that introduces an intermediate value was used. For qualitative attributes, the amount of information was calculated by constructing a membership function with the fuzzy mathematics theory.
3. Aiming for the minimum total amount of information between supplier and consumer, after calculating the total amount of information of each supplier and consumer, a multiobjective optimization model was established.
4. To solve the model and obtain the optimal matching scheme, referring to previous research, the membership function and linear weighting method were used [48,51,52]. This method can transform the original multiobjective optimization model into a single-objective optimization model.
5. To testify to the effectiveness of the method, a case study was conducted. Six consumers and 11 suppliers of bananas were selected from a trading platform for agricultural products.

### 3.2. Determination of the Attributes of Agricultural Products

At present, many scholars have explored the research on the attributes of agricultural products. Agricultural products have both the attributes of general commodities and special natural attributes, which together constitute the unique overall attributes of agricultural products. This study follows the principles of comprehensive, systematic, and applicability, considers the availability of data and characteristics of the specific attributes of agricultural products, and determines two types of indicators: general attributes and unique attributes of agricultural products.

General attributes: For ordinary products, price, quality, style, brand, etc. often have a great impact on consumer purchase intention and choice [53]. When exploring the impact of product attributes on consumer purchase decisions, scholars mainly focus on two aspects: external attributes (such as brand, packaging, price, product grade, logistics, service quality, etc.) and internal attributes (such as appearance, performance, quality, etc.) [54–58]. Among all these attributes, price is always one of the most important references for consumers purchasing goods. According to the research results of Mauracher et al. [59], consumers state that price is a very important factor in their willingness to purchase a bottle of organic wine. The importance of price to consumers applies to all products. Products with high quality and low prices are more often loved by consumers [60]. Brandis another factor that influences consumers. Brand often refers to a label recognized by consumers, and it is greatly significant to consumer purchasing behavior. When given the choice to purchase less-familiar products, consumers would rather spend more money to purchase products from brands that have higher brand awareness [30,61–63]. However, for agricultural products, the role of brands has not been proven to be diminished. Product grade and packaging type are the embodiment of product characteristics and individuality. Higher product grades and appealing packaging can enable consumers to quickly select and identify targets among the dazzling array of commodities [64,65]. Logistics quality, service quality, and other related attributes of suppliers also directly affect the shopping experience of consumers [66–68]. Based on the above literature and analysis, price, brand, product grade, packaging type, logistics method, and logistics distance were selected as the general attributes of agricultural products.

Unique attributes: Since fruits, vegetables, meat, and other agricultural products have the features of freshness, seasonality, regionality, high logistics cost, and often large transportation losses, it is difficult to achieve unified standardization. Consumers with poor shopping experiences find it difficult to carry out transactions smoothly. Therefore, the unique attributes, such as fruit shape, freshness, and maturity degree, of agricultural products also need to be considered. Scholars have explored the attributes of agricultural products from many aspects, including brand, price, packaging, appearance, taste, freshness, nutritional quality, origin, safety, etc. [69,70]. Since most agricultural products are perishable and fragile, they cannot be sampled before purchase or use. Similarly, freshness and maturity are also important evaluation indicators for the quality of agricultural products [71,72]. Agricultural products have a fixed cycle of sowing, growing, and harvesting. Their production and consumption have strong seasonal characteristics [73–75]. People tend to choose agricultural products that are in season. With increases in residents' income levels and improvements in dietary structure, the emphasis on consumption is changing from "quantity" to "quality". Consumers are continually raising their expectations and demands for food. Due to the use of chemical fertilizers, antibiotics, pesticides, and other pollutants, people are paying more attention to the safety of agricultural products, especially organic green products [76,77]. Green organic product certification, traceability information, origin, etc. are aspects of the trust attributes of agricultural products, and they play an important role in consumers' purchasing choices [78,79]. In China, the origin of products refers to regional space and geographical indication. The quality of agricultural products is closely related to the natural environment (soil, water, air, etc.) and social integrity. Regions of origin are highly correlated with the quality of agricultural products [80–82].

On the basis of the literature analysis, the unique attributes of agricultural products chosen in this study include freshness, maturity, seasonality, certification, safety, and origin. To further optimize the attributes proposed above, we consider that logistics distance has a strong correlation with logistics method and efficiency [83]. Logistics method usually include air, water, railway, road, and other options, but generally, products that need long-distance transportation usually choose faster logistics method. Therefore, when setting the logistics attribute, we only retain the logistics distance attribute. Attributes related to appearance were not selected either since the research purpose of this study is to put forward a universal agricultural products sales method. After selecting attributes of agricultural products, further analysis is still needed to consider the following:

1. By determining whether the attribute value can be directly quantified, attributes can be divided into quantitative and qualitative attributes. Each type of attribute value needs to be handled in a different way.
2. Considering whether the attribute must be satisfied, attributes can be divided into hard attributes and soft attributes. Hard attributes represent attributes that must meet certain requirements while soft attributes represent attributes that do not. (e.g., "I'd like to buy an organic apple at 3.5~5 yuan". In this sentence, "an organic apple" represents a hard attribute that is satisfied strictly; "3~5 yuan" present a soft attribute that could be satisfied in certain situations.)
3. Considering satisfaction with the attribute's value, attributes can be divided into interval type, benefit type, and cost type. Interval-type attributes are those whose value is closer to a fixed interval (including falling into the specified interval, such as maturity, which includes "live", "fresh", "relatively fresh"," average", and" slightly spoiled"). The closer the value is to the interval, the better it is. Benefit-type attributes are attributes whose value needs to be large. The larger the attribute value is, the better it is(e.g., the brand of an agricultural product).Cost-type attributes are attributes whose value needs to be small. The smaller the attribute value is, the better it is. For example, maturity is an interval-type attribute, brand is a benefit-type attribute, and logistics distance is a cost-type attribute(e.g., the logistics distance of an agricultural product).

Based on the above analysis, the attribute structure of agricultural products, including general and specific attributes, that needs to be considered, which is shown in Table 3.

**Table 3.** Attributes structure of agricultural products.

| Attribute Category | Attribute | Description | Attribute Form | Consumer Attribute Classification | Supplier Attribute Classification | Source |
|---|---|---|---|---|---|---|
| General attributes | Price | Yuan/kg | Quantitative | Cost-type soft attribute | Benefit-type soft attribute | Mauracheret al. [59]; Symmank [54]; Ennekinget al. [56]. |
| | Brand | No brand, common brand, regional brand, famous national brand | Qualitative | Benefit-type soft attribute | According to the consumer's situation | Cheung et al. [61]; Grunert [55]; Shethet al. [62]. |
| | Product grade | Premium, first-class, regular, etc. | Qualitative | Benefit-type soft attribute | According to the consumer's situation | Llavataet al. [64]; Akdeniz et al. [65], |
| | Packaging type | Ordinary packaging, gift packaging | Qualitative | Hard attribute | Hard attribute | Deng&Srinivasan [57]; Waheed et al. [58]. |
| | Logistics distance | Km | Quantitative | Cost-type soft attribute | Cost-type soft attribute | Chen et al. [66]; Galkiet al. [67]; Paciarotti & Torregiani [68]. |
| Unique attributes | Freshness | Live, fresh, relatively fresh, average, slightly spoiled | Qualitative | Benefit-type soft attribute | According to the supplier's situation | Massagliaet al. [69]; Demattè et al. [70]; |
| | Maturity | Fully mature, nearly mature, not mature | Quantitative | As required by the consumer | According to the supplier's situation | Liu et al. [71]; Meng et al. [72]. |
| | Seasonality | Seasonal products, off-season products, cold storage products | Qualitative | Hard attribute | Hard attribute | Kelley et al. [73]; Ardeshiriet al. [74]; Wakjira et al. [75] |
| | Certification | No certification, organic, green, pesticide-free | Qualitative | Benefit-type soft attribute | Hard attribute | Girgentet al. [78]; Bosona & Gebresenbe [79]. |
| | Security | Qualified traceable, Nontraceable | Qualitative | Hard attribute | Hard attribute | Basha et al. [76]; Hughes & Merton [77] |
| | Origin | Origin, no origin | Qualitative | Hard attribute | Hard attribute | Lu et al. [80]; Carzedda et al. [81]; Lambarraa-Lehnhardt et al. [82]. |

### *3.3. Improved Amount of Information Calculation for Both Quantitative and Qualitative Attributes*

Suppose attribute set M includes k attributes. As previously mentioned, agricultural product attributes can be described quantitatively or qualitatively. Quantitative attributes provide an amount of information that can be expressed in the form of a numerical value while qualitative attributes need to be transformed into a numerical value. When calculating the amount of information on agricultural products, system range $S_r$ represents the distribution range of attributes required (provided) by the consumer (supplier). Design range $D_r$ represents the distribution range of attributes expected by the supplier and consumer. $C_r$ is the common range, shown in Figure 2. The design range can be regarded as the expected level, and the system range can be regarded as the actual level. The common range is the overlap between the design range and system range [47,48] (e.g., the price range required by the consumer is [3~5], and the price of the product required by the supplier is [3.5~6]. In this situation, [3~5] represents the "design range", [3.5~6] represents the "system range", and [3.5~5] represents "common range").

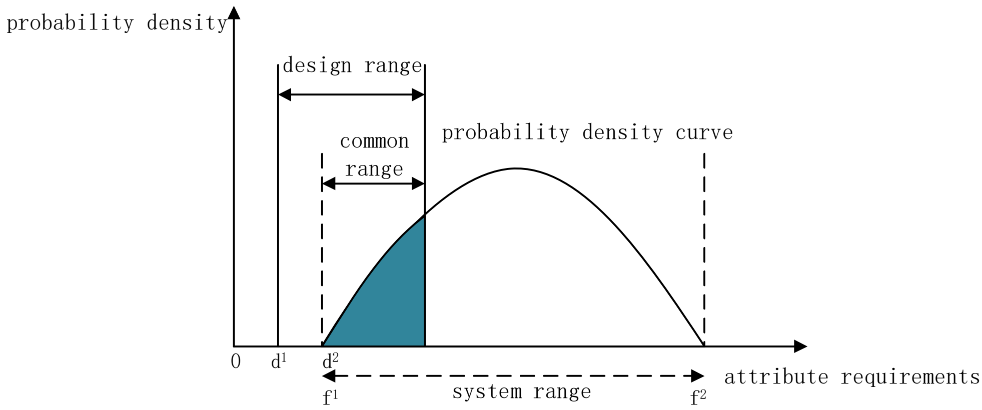


**Figure 2.** System range, design range, and common range based on information axiom.

The probability that the amount of information satisfies the design scope through the system scope (common range) of the attribute can be expressed as [47,50,84,85]:

$$\begin{aligned} & S^r = f = \left[f^1, f^2\right],\ D^r = d = \left[d^1, d^2\right] \\ & I = \log_2 \frac{S_r}{D_r \cap S_r} = \log_2 \frac{S_r}{C_r} \end{aligned} \tag{1}$$

3.3.1. Amount of Information Calculation for Quantitative Attributes

The interval range of quantitative attributes is usually given in the form of a numerical interval and can be directly calculated. However, there could be limitations according to the traditional calculation method for the amount of information [86,87]. According to Equation (1), if all the system range attributes fall in the design range, which means $S^r \leq D^r$, the amount of information will be zero. In this situation, it is impossible to compare match results. An improved method to calculate the amount of information is proposed by scholars. Still, this kind of method does not take into account the situation in which the system range exceeds the design range, $S^r \geq D^r$, which will lead to a negative value for the amount of information. That is obviously not reasonable. Therefore, this study introduces an intermediate value $\bar{f} = \frac{f^2 - f^1}{2}$, and takes an $e$ power operation of the logarithms of the logarithmic function in Equation (1). So, the amount of information in all situations will be non-negative.

Furthermore, according to the different requirements of the consumer on the range of attribute values, quantitative attributes can generally be divided into three types: interval type, benefit type, and cost type. For an interval-type attribute, it is better when the value is closer to a fixed interval (including falling into a specific interval); for a benefit-type attribute, the higher the value, the more satisfied consumers will be; for a cost-type attribute, the lower the value, the more satisfied consumers will be. The calculation formulas of the amount of information of the three attribute types are shown in Table 4.

**Table 4.** The calculation formula for the amount of information for all types of attributes.

| Interval Type Attributes | Benefit Type Attributes | Cost Type Attributes |
| --- | --- | --- |
| $I = \begin{cases} \infty & f^2 \leq d^1 \text{ or } f^1 \geq d^2 \\ \log_2 e^{\frac{C_r}{d^2 - d^1}} & f^1 < d^1 < f^2 \text{ or } f^1 < d^2 < f^2 \\ 0 & d^1 < f^1 < f^2 < d^2 \end{cases}$ | $I = \begin{cases} \infty & f^2 \leq d^1 \\ \log_2 e^{\frac{d^2 - \bar{f}}{d^2 - d^1}} & \bar{f} < d^2 \text{ and } f^2 > d^1 \\ 0 & \bar{f} \geq d^2 \end{cases}$ | $I = \begin{cases} \infty & f^1 \geq d^2 \\ \log_2 e^{\frac{\bar{f} - d^1}{d^2 - d^1}} & \bar{f} > d^1 \text{ and } f^1 < d^2 \\ 0 & \bar{f} \leq d^1 \end{cases}$ |

When the attribute appears to be a single point value, the calculation formula of the amount of information is:

$$I_{kij} = \begin{cases} 0 f^1 = f^2 \in d \\ \infty f^1 = f^2 \notin d \end{cases} \tag{2}$$

### 3.3.2. Amount of Information Calculation for Qualitative Attributes

For when the attribute boundary among various levels is usually not clear, in order to facilitate the calculation, it is necessary to transform the ambiguous statement into an accurate value. The membership function in fuzzy mathematics theory is often used to quantify qualitative attributes. Qualitative attribute information can be changed into a numeric value, making it possible for the amount of information to be calculated. When quantifying qualitative attribute information, the key is to select appropriate membership functions to measure fuzzy information by considering the preferences of both sides. There are many different distribution forms of membership functions. The triangle membership function and trapezoid membership function are easy to understand and can better express qualitative information [88,89]. Additionally, their distribution form is more consistent with the characteristics of qualitative attribute information for agricultural products. For these reasons, this study adopts these two kinds of membership functions to measure qualitative attribute information for agricultural products.

Each attribute has language phrases $L = \{l_1, l_2, \cdots, l_T\}$, where $l_i \in L$ is the $i_{\text{th}}$ language phrase. Attribute $k$ can be represented by language phrases in $L$, e.g., the apple's maturity is a set of languages, which could be seen as $L$, $L$ = [live, fresh, relatively fresh, average, slightly spoiled]. The attribute information can be transformed into a triangular fuzzy number [90]:

$$f_i = \left\{ \max\left(\frac{i-2}{T-1}, 0\right), \frac{i-1}{T-1}, \min\left(\frac{i}{T-1}, 1\right) \right\}, i = 1, 2, \cdots T \tag{3}$$

To calculate the amount of information of each attribute, the area formed by the membership function of the design range is defined as fuzzy design system range $FD_r$, and the area formed by the membership function of system range is defined as fuzzy system range $FC_r$. The intersection of $FD_r$ and $FS_r$ is defined as a fuzzy common range. Similarly, because consumers have different requirements for each attribute, the amount of information calculated for qualitative attributes needs to be discussed in three types.

1. For interval-type attributes, the triangle membership can be directly used to calculate the amount of information, shown in Figure 3. The calculation formula for the amount of information is as follows:

$$I_k = \begin{cases} \infty & f^2 \le d^1 \text{ or } f^1 \ge d^2 \\ \log_2 \frac{FS_r}{FC_r} = \log_2 \frac{\int_{f_1}^{d_2} \mu_S(x)\mu_D(x)dx}{\int_{d_1}^{d_2} \mu_S(x)dx} & f^1 < d^1 < f^2 \text{ or } f^1 < d^2 < f^2 \\ 0 & d^1 < f^1 < f^2 < d^2 \end{cases} \tag{4}$$

2. For benefit-type attributes, the direct use of triangular fuzzy numbers to calculate the amount of information does not conform to the actual situation of the suppliers and consumers in agricultural product transactions. The direct use of the triangular fuzzy number to calculate the amount of information result in the amount of information may be zero, but in fact, it can be bigger than the initial design range, as shown in Figure 4. For example, in fact, "fresh" is obviously better than "relative fresher".To solve this problem, it is necessary to use the left trapezoidal membership function to calculate the amount of information contained in the attribute, which has been shown as Figure 5. The amount of information calculation formula should be modified as follows:

$$I_k = \begin{cases} \infty & d^2 \ge f^2 \\ \log_2 \frac{FS_r}{FC_r} = \log_2 \frac{\int_{f_1}^{d_2} \mu_S(x)\mu_D(x)dx}{\int_{0}^{d_2} \mu_S(x)dx} & f^1 < d^1 < f^2 \\ 0 & d^1 < f^1 < f^2 < d^2 \end{cases} \tag{5}$$

3. For cost-type attributes, the calculation method is similar to the method used for benefit-type attributes. It is merely the opposite of the method used for benefit attributes. Cost-type attributes require the attribute value to be as small as possible. So, when cost-type attributes have a smaller value, they actually contain a small part of the attribute value. Thus, the fuzzy system range of the attribute value should include a larger system range. The fuzzy system range of cost-type attribute has been shown as Figure 6.

$$I_k = \begin{cases} \infty & d^1 \geq f^2 \\ I_k = \log_2 \frac{FS_r}{FC_r} = \log_2 \frac{\int_{d_1}^{f_2} \mu_S(x)\mu_D(x)dx}{\int_{d_1}^{d_2} \mu_S(x)dx} & f^1 < d^1 < f^2 \\ 0 & d^1 \leq f^1 \end{cases} \quad (6)$$

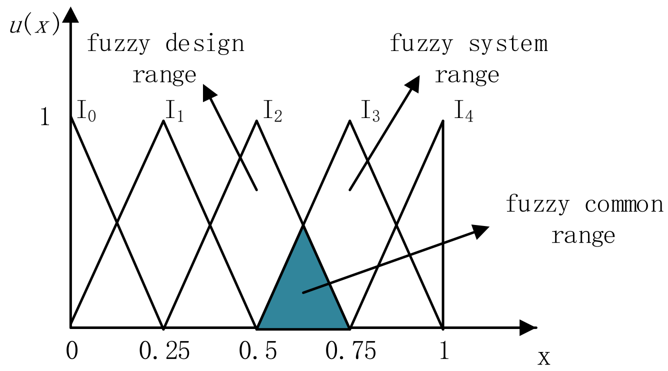


**Figure 3.** Membership function image of an interval-type attribute.

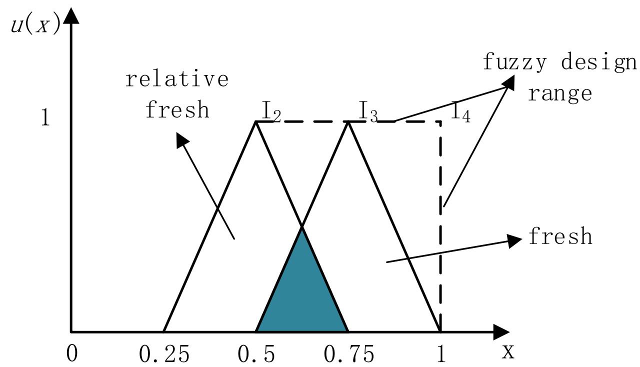


**Figure 4.** Fuzzy system range comparison in membership function.

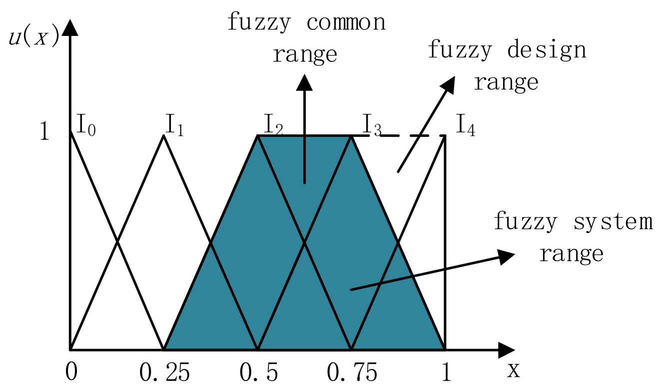


**Figure 5.** Membership function image of a benefit-type attribute.

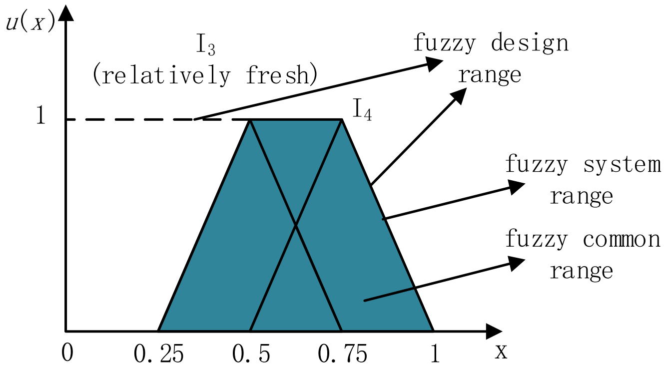


**Figure 6.** Membership function image of a cost-type attribute.

#### 3.3.3. Calculate the Total Amount of Information on Both Sides

Suppose that there are $m$ consumers and $n$ suppliers in the agricultural product transaction, and the products involved in the transaction have $k$ attributes. $I_{kij}$ and $I_{kji}$ are, respectively, the amount of information for the consumer and the amount of information for the supplier in the $k$th attribute when the $i$th consumer matches the $j$th supplier. When the $i$th consumer matches the $j$th supplier, the total amount of information of the consumer is $I_{ij}$, and the total amount of information of the supplier is $I_{ji}$.

$$I_{ij} = \sum_{k=1}^{h} I_{kij},\ i = 1, 2, \cdots, m \quad j = 1, 2, \cdots, n \tag{7}$$

$$I_{ji} = \sum_{k=1}^{h} I_{kji},\ i = 1, 2, \cdots, m \quad j = 1, 2, \cdots, n \tag{8}$$

### *3.4. Construction of the Matching Model*

Suppose there are $m$ suppliers and $n$ consumers in an agricultural product transaction involving $k$ attributes of the agricultural products of concern to both parties. Each supplier and consumer can only trade once. When both parties meet their requirements of the constraint conditions, the transaction is successfully matched.

The model includes two objective functions: the total amount of information of the supplier $Z_1^l$ and the total amount of information of the consumer $Z_2^l$. Among them, $l = \left(1, 2, \cdots, A_{\max(m,n)}^{\min(m,n)}\right)$. The matching result of supplier and consumer is represented by 0–1 variable. $x_{ij} = 1$ indicates the $i$ consumer is successfully matched with the $j$ supplier. Otherwise, $x_{ij} = 0$. The followingmultiobjective optimization model is established according to the amount of information between the $i$th consumer and the $j$th supplier or the $j$th supplier and the $i$th consumer.

$$\min Z_1^l = \min \sum_{i=1}^{m} \sum_{j=1}^{n} I_{ij} x_{ij},\ \min Z_2^l = \min \sum_{j=1}^{n} \sum_{i=1}^{m} I_{ji} x_{ji} \tag{9}$$

$$\text{s.t.} \begin{cases} \sum\limits_{i=1}^{m} x_{ij} \le 1 & j = 1, 2, \cdots, n \quad (10) \\ \sum\limits_{j=1}^{n} x_{ij} \le 1 & i = 1, 2, \cdots, m \quad (11) \\ \sum\limits_{i=1}^{m} \sum\limits_{j=1}^{n} I_{ij} x_{ij} \le t_i \sum\limits_{j=1}^{n} x_{ij} & i = 1, 2, \cdots, m \quad (12) \\ \sum\limits_{j=1}^{n} \sum\limits_{i=1}^{m} I_{ij} x_{ij} \le t_j \sum\limits_{i=1}^{m} x_{ij} & j = 1, 2, \cdots, m \quad (13) \\ x_{ij} = 0 \text{ or } 1 \quad i = 1, 2, \cdots, m \quad j = 1, 2, \cdots n \end{cases}$$

Equation (9) is the objective function, and Equations (10)–(13) are constraint conditions. Equations (10) and (11) represent that each supplier (consumer) can conduct one transaction at most with one consumer (supplier). Equations (12) and (13), respectively, represent the maximum amount of information limitation. Furthermore, $t_i, t_j$ are the upper limits of the amount of information of the consumer and supplier, and $t_i > 0, t_j > 0$. This limit expresses the minimum match requirement for a successful transaction between the consumer and supplier. In the matching process, if the matching degree between both sides is too low, the transaction will be given up.

### *3.5. Model Solution*

To solve the model, the linear weighted sum method of the membership function was employed [83,91]. Suppose $\max Z_1^l$, $\max Z_2^l$, $\min Z_1^l$, $\min Z_2^l$, respectively, are the maximum and minimum target values corresponding to the optimization of the objective function $Z_1^l, Z_2^l$ separately [92]. The membership function corresponding to the objective function Formula (9) can be expressed as:

$$\mu\left(Z_1^l\right) = \frac{\max Z_1^l - Z_1^l}{\max Z_1^l - \min Z_1^l} \mu\left(Z_2^l\right) = \frac{\max Z_2^l - Z_2^l}{\max Z_2^l - \min Z_2^l} \tag{14}$$

Set $\alpha_1, \alpha_2$ respectively as the weight of $\mu\left(Z_1^l\right), \mu\left(Z_2^l\right)$ and meet $0 \le \alpha_1 \le 1, 0 \le \alpha_2 \le 1$, $\alpha_1 + \alpha_2 = 1$. The linear weighting method is used to sum the two membership functions, so the original multiobjective optimization model can be transformed into a single-objective optimization model. Take the objective function $Z^l$ as a matching degree. The maximum $Z^l$ value is the optimization degree of the matching scheme. The original multiobjective optimization model is converted into a single-objective optimization model:

$$\max Z^l = \max\left[\alpha_1 \mu\left(Z_1^l\right) + \alpha_2 \mu\left(Z_2^l\right)\right] \tag{15}$$

### *3.6. Solving Implementation Steps*

Step 1: Identify multiattribute product attribute sets $M = \{M_1, M_2, \cdots, M_h\}$. Hard attributes are rigid requirements for both suppliers and consumers. If a hard attribute is not satisfied, it will be filtered. The system range, design range, and common range of each attribute described by both parties are denoted as $S_r$, $D_r$, and $C_r$;

Step 2: Calculate the amount of information of each attribute $I_{kij}$ and $I_{kji}$, the total amount of information of the consumer $I_{ij}$, and the total amount of information of the supplier $I_{ji}$;

Step 3: Make $\sum_{i=1}^{m} x_{ij} \le 1,\ j = 1, 2, \cdots, n$; $\sum_{j=1}^{n} x_{ij} \le 1,\ i = 1, 2, \cdots, m$, calculate the total amount of information of the supplier $Z_1^l$ and the total amount of information of the consumer $Z_2^l$ in each matching scheme, among them: $Z_1^l = \sum_{i=1}^{m} \sum_{j=1}^{n} I_{ij} x_{ij}$, $Z_2^l = \sum_{j=1}^{n} \sum_{i=1}^{m} I_{ji} x_{ji}$;

Step 4: Iterate over all $Z_1^l$, getting $\max Z_1^l$ and $\min Z_1^l$; iterate over all $Z_2^l$, getting $\max Z_2^l$ and $\min Z_2^l$;

Step 5: Calculate the value of each membership function $\mu\left(Z_1^l\right)$, $\mu\left(Z_2^l\right)$;

Step 6: Retraverse all matching schemes to obtain the optimal matching degree and the optimal matching scheme.

## **4. Case Study**

To verify the effectiveness of the method, six consumers and 11 suppliers of bananas were selected from a trading platform for agricultural products. For the suppliers, the logistics limitations consists of interval-type soft attributes; price consists of benefit-type soft attributes; and all other properties are objective attributes. The basic information of the consumers and suppliers to be matched is shown in Tables 5 and 6.

**Table 5.** Information about each consumer requirement.

| Consumer | Brand | Logistics Distance | Product Grade | Price | Packaging Type | Freshness | Maturity | Certification | Seasonality | Origin | Security |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $A_1$ | regional brand and above | (1,2) | first class and above | (2.5,3.2) | gift packaging | relatively fresh and above | harvest maturity | pesticide-free and above | no request | origin | traceable |
| $A_2$ | no request | (1,3) | second class and above | (2.0,2.8) | ordinary packaging | unlimited | no request | no request | seasonal products | no request | no request |
| $A_3$ | common brand and above | (1,4) | second class and above | (2.0,2.6) | no request | average and above | harvest maturity | no request | seasonal products | origin | traceable |
| $A_4$ | no request | (1,3) | third class and above | (2.0,2.8) | ordinary packaging | no request | harvest maturity | pollution-free and above | no request | no request | no request |
| $A_5$ | no request | (1,4) | third class and above | (1.8,2.5) | no request | no request | no request | no request | seasonal products | no request | no request |
| $A_6$ | regional brand and above | (1,3) | third class and above | (1.9,2.9) | gift packaging | fresh and above | no request | green and above | seasonal products | origin | traceable |

**Table 6.** Information about each supplier′s product.

| Supplier | Brand | Logistics Distance | Product Grade | Price | Packaging Type | Freshness | Maturity | Certification | Seasonality | Origin | Security |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $B_1$ | famous national brand | 1 | first class | (2.75,3.35) | gift packaging | live | harvest maturity | green | seasonal products | origin | traceable |
| $B_2$ | regional brand | 4 | first class | (2.20,2.95) | gift packaging | fresh | harvest maturity | pollution-free | seasonal products | origin | traceable |
| $B_3$ | common brand | 3 | third class | (1.95,2.45) | ordinary packaging | average | edible maturity | pollution-free | seasonal products | no origin | nontraceable |
| $B_4$ | famous national brand | 2 | Premium | (2.55,3.25) | gift packaging | fresh | harvest maturity | organic | seasonal products | origin | traceable |
| $B_5$ | common brand | 3 | second class | (2.10,2.90) | ordinary packaging | relatively fresh | edible maturity | pollution-free | seasonal products | origin | traceable |
| $B_6$ | no brand | 2 | third class | (1.75,2.35) | ordinary packaging | average | edible maturity | nocertification | seasonal products | no origin | nontraceable |
| $B_7$ | famous national brand | 1 | advanced | (2.45,3.95) | gift packaging | live | harvest maturity | organic | seasonal products | origin | traceable |
| $B_8$ | regional brand | 2 | second class | (2.15,2.95) | ordinary packaging | relatively fresh | harvest maturity | green | seasonal products | origin | traceable |
| $B_9$ | no brand | 2 | third class | (1.90,2.45) | ordinary packaging | relatively fresh | harvest maturity | nocertification | seasonal products | origin | nontraceable |
| $B_{10}$ | common brand | 1 | first class | (2.15,2.65) | ordinary packaging | relatively fresh | harvest maturity | green | seasonal products | origin | traceable |
| $B_{11}$ | regional brand | 3 | second class | (2.20,2.95) | gift packaging | live | harvest maturity | pollution-free | seasonal products | origin | traceable |

Based on the above data of agricultural products consumers and suppliers, three matching models were calculated and compared. That was only considering the matching degree of the consumer, only considering the matching degree of the supplier, and considering the matching degree of both parties (based on previous literature and considering the fairness of both sides, $\alpha_1 = 0.5, \ \alpha_2 = 0.5$ [48,49]). Table 7 shows the comparison of matching of three matching models.

**Table 7.** Comparison of matching results of three matching models.

| Matching Model | Optimal Matching | Optimal Match Degree |
|---|---|---|
| Consumer | $A_1 - B_4, A_2 - B_{10}, A_3 - B_{11}, A_4 - B_8, A_5 - B_2, A_6 - B_1$ | 0.837 |
| Supplier | $B_1 - A_5, B_2 - A_3, B_3 - A_4, B_4 - A_1, B_5 - A_6, B_{10} - A_2$ | 0.500 |
| Supply–Demand | $A_1 - B_4, A_2 - B_{10}, A_3 - B_{11}, A_4 - B_8, A_5 - B_2, A_6 - B_7$ | 0.863 |

Comparison results shown in Table 5 indicate that the matching model proposed in this study, which considers both supply and demand, has the highest matching degree and significantly improves the optimization of matching schemes. The reason is that taking into account both the satisfaction of the supplier and consumer eliminates some matching schemes that only meet the requirements of one side, which improves the matching degree of the optimal scheme. In the above matching process, because the upper limit of transaction information of both sides ($t_i = 2, t_j = 1$) is large, more matching pairs were generated. In order to further explore the relationship between the upper limit of transaction information and the optimal matching scheme, the upper limit of the amount of information required by both parties was changed. After that, the optimal matching degree and matching pairs in the different upper limits of the amount of information are shown in Table 8.

**Table 8.** The optimal matching degree and matching pairs under different ($t_i$, $t_j$) conditions.

| First Set of Data | | | Second Set of Data | | |
|---|---|---|---|---|---|
| $(t_i,t_j)$ | Optimal Match | Matching Pairs | $(t_i,t_j)$ | Optimal Match | Matching Pairs |
| (1,1.8) | 0.863 | 6 | (0.9,2) | 0.863 | 6 |
| (1,1.6) | 0.877 | 6 | (0.8,2) | 0.863 | 6 |
| (1,1.4) | 0.877 | 6 | (0.7,2) | 0.876 | 4 |
| (1,1.2) | 0.877 | 6 | (0.6,2) | 0.875 | 3 |
| (1,1) | 0.877 | 6 | (0.5,2) | 0.946 | 2 |
| (1,0.8) | 0.914 | 5 | (0.4,2) | 0.946 | 2 |
| (1,0.6) | 0.977 | 4 | (0.3,2) | 0.946 | 2 |
| (1,0.4) | 0.977 | 3 | (0.2,2) | 0.946 | 2 |
| (1,0.2) | 0.977 | 3 | (0.1,2) | 0.967 | 1 |

As shown in Table 8, with the reduction of the upper limit $t_i(t_j)$ for the amount of information of supplier (consumer) transactions, the overall optimal matching degree is increasing while matching pairs are decreasing. Through analysis of the simulation results, if the upper limit of the amount of information $t_i(t_j)$ is set too high for transaction matching between the supplier and consumer, it will avoid the low degree of transaction matching. However, if $t_i(t_j)$ is set too low, the matching pairs may reduce to zero, and optimal transaction matching cannot be satisfied.

This means when the suppliers and consumers seek the matching degree scheme, the satisfaction of both sides is inversely related to the optimal scheme available. The higher the requirements for the satisfaction of suppliers and consumers, the harder it is to get a well-matched scheme. The solution results are consistent with reality. Therefore, rational and reasonable requirements of both sides are also very important for increasing the matching degree and obtaining a matching scheme.

## 5. Conclusions

Constrained by their small scale, lack of investment, and technology, most small farmers live on a meager income from their sales of agricultural products. The lack of an intelligent method to match consumers and suppliers in the market can hardly sell their produce smoothly, which leads them to a state of relative poverty and a lack of sustainable development opportunities. To solve the matching problem between small farmers and potential buyers of agricultural products, this study proposed a smart, efficient, and accurate matching method between suppliers and consumers. Firstly, considering most agricultural products are fresh, perishable, and not easily preserved, a unique attribute set of agricultural products was established which included general attributes and specific attributes of agricultural products. Secondly, by combining fuzzy mathematics with the information axiom, an improved amount of information calculation method for both quantitative and qualitative attributes was put forward. Thirdly, based on the amount of information about all attributes and with the goal of maximizing the transaction matching degree for both the supplier and consumer, a multiobjective optimization model was developed. Finally, the effectiveness and accuracy of the method were verified through a case study. Compared with the existing studies, this method: (1) fully considered the specific attributes of agricultural products other than general commodity attributes, such as freshness, maturity, and other attributes, and constructed a multiattribute indicator system for agricultural products transaction; (2) combining with fuzzy mathematics theory and the information axiom, developed an improved calculation of information amount for different needs for qualitative and quantitative attributes; (3) considering the dynamics and ambiguity in the agricultural product transaction process, established a one-shot multiattribute agricultural product supply and demand matching method. Through the experimental results, this method can effectively improve the matching degree of agricultural products.

## 6. Implications and Limitations

Smart sales can empower small farmers by increasing sales volume and price by improving matching degrees in the agricultural market. At the present stage, rural commerce platforms can only provide simple information-sharing and transaction functions. They are still not perfect trading markets for agricultural products. To better serve small farmers to sell their produce, the intelligent matching method proposed in this study can be embedded on agricultural e-commerce websites, which can provide a convenient, fast, and efficient way to find the most suitable consumers for them to avoid encountering poor sales. This helps to facilitate the transaction of agricultural products, increase sales income, and promote small farmers' sustainable development capabilities.

However, there are still limitations in our study. Firstly, this study only considers the situation that each consumer can only match with one supplier while in reality, a single consumer can purchase products from multiple suppliers. Secondly, due to the perishable nature of many fresh agricultural products, such as vegetables, fruits, and meat, efficient transactions alone are not enough. The well-organized operation, good infrastructure, and fast logistics are particularly important. Without these efforts, agricultural products will spoil and rot, resulting in the loss of small farmers. Therefore, when studying the matching problem of suppliers and consumers of agricultural products, the above factors should be taken into account, and different contexts should be compared. Thirdly, how to better develop rural e-commerce and put forward more supporting technologies is also an important research direction. All these problems can be further studied.

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