

Research Article

Farmer's Credit Rating Model and Application Based on Multilayer Unified Network with Linear Classifier

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This article innovatively builds the infrastructure of farmer credit rating index system into a multilevel unidirectional network structure. First, according to the logical structure of the three-level credit rating index system, a four-level unidirectional network is constructed, and the credit rating calculation formulas of all indexes at the four-level network are established. Furthermore, the special cases of the credit rating formula with the first- and second-level farmer credit rating index system are discussed. On this basis, it is extended to a credit rating index system with more than four levels, and the corresponding credit rating formula is established. Finally, the general formula of credit rating formula of the farmer credit rating index system from first level to multilevel is obtained. In order to solve the problem of farmers' credit rating, this paper also designs a linear segmentation classifier to classify the results of multilayer unidirectional network, establishes the rules of farmers' credit rating and the unidirectional network linear segmentation evaluation model of farmers' credit rating, and discusses the properties of bank credit based on farmers' credit rating. Finally, the model established in this paper is applied to the credit rating of farmers in A County, Guangdong Province in China. When the credit rating of 160 farmers is carried out, the evaluation results are in line with the actual credit rating of farmers in A County, with an accuracy of 100%. This research has the maneuverability to carry on the scientific credit rating to the countryside. This study has important method guidance and operability for rural credit rating.

1. Introduction

The difficulty for small enterprises and farmers to obtain loans is a characteristic in mountainous townships in China. This has become a bottleneck for the townships' economic development and farmers' income promotion. With the deep promotion of market economy, the social disharmonious factors, such as rural social management and long-standing debts, have become urgent problems for mountainous townships. How to jump out of the current social management mode and explore a new credit scoring model has become a focus for the current rural financial research studies in China. Especially, how to establish a sound index system for farmer credit rating, to build the financial service

platform, to establish an incentive and restraint mechanism, to guide the farmers to participate in the credit system, to innovate social management style, and to improve management by decreasing social management costs using such credit system are all urgent problems for mountainous townships in China. Based on the current social management-based credit rating method, which is already put into practice on a trial in some mountainous townships in China, and the logic structure of the credit rating index system, this paper firstly uses mathematical techniques to present the general description of credit rating system, and then it constructs a multilayer unidirectional network for farmers' credit rating and establishes a linear segment model to evaluate the farmers' credit grades. Finally, it implements the

proposed method to a case study and effectively solves the credit rating problem for farmers in some mountainous townships of China.

The concepts of rural areas are fundamentally different from China and other countries, and the percentage of population engaged in farming in other countries differs from that in China. Thus, the literatures of credit rating for farmers in other foreign countries do not have so much reference value for us. Especially, in Europe and America, the credit rating for farmers is a part of the general personal credit rating system, and it is not a separate research topic. In China, the percentage of population engaged in farming is still very large. The economic development in mountainous townships lags behind cities and the financial market is not perfect, as well as there are many disharmonious social factors. Thus, the research on credit rating problems based on social management for farmers is necessary and indispensable.

There are many literatures about credit rating or credit evaluation for enterprises (including commercial banks), and most of them are already commercialized. One of the most relevant literatures related to farmer's credit rating proposed a banking credit worthiness evaluation method by combining Fuzzy rough set and Fuzzy C-means clustering. The proposed rule-based method was used to predict farmers' creditworthiness and applied to actual bank data from 2044 farmers within China and used to aid in agricultural load decision-making [1]. There are also neural network models to study the accuracy of credit scoring: multilayer perceptron, mixture-of-experts, radial basis function, learning vector quantization, and fuzzy adaptive resonance, the algorithm of BP network, probabilistic neural network, and self-organizing competitive network [2–4]. In addition, neural networks and statistical models are also used to study the accuracy of credit scoring: SVM algorithms, fuzzy support vector machine algorithm, Logistic regression model, and linear discriminant analysis models [3, 5]. A credit scoring model integrates various financial and nonfinancial factors and thereby improves small- to medium-sized enterprises' (SMEs) knowledge about default risk [6]. The DEMATEL method is used to select the proper financial ratios which are effective on the decision-making process of the experts, and based on these financial ratios, they developed a Mamdani's Fuzzy Expert system which predicts the Customers credit risks [7]. The analysis models can be used to explore the contribution of segmentation data in granting of customer credit [8]. A personal credit scoring model via genetic algorithm is established, and it proved a high efficiency on credit scoring through experiment and evaluated its significant value [9]. An improved algorithm with variable learning rate based on BP algorithm is applied to simulate personal credit scoring [10]. A method for personal credit evaluation based on PSO-RBF neural network, which used PSO algorithm to optimize the parameters of RBF neural network, is applied to the optimized RBF neural network in the personal credit evaluation [11].

Research on microfinance, a meaningful study, is that someone has conducted informal credit rationing and credit demand surveys in four emerging counties in China [12]. It

is found that there are many factors hindering the efficient and sustainable development of rural microfinance in China [13]. By collecting the information of microcredit users, using the logistic binary selection model to calculate the weight of each index, a credit scoring model which can be used to control the credit risk of small agricultural loans was established [14]. Using the method of game theory, we can study the dynamic game relationship between the supply and demand sides of microcredit [15]. Based on the relationship between microcredit and agriculture, rural areas, and farmers, some scholars analyzed the development of microcredit and the importance of serving agriculture, rural areas, and farmers and put forward specific countermeasures for microcredit to serve agriculture, rural areas, and farmers [16]. However, in the operation of small loan companies, the existing credit scoring model cannot effectively and accurately evaluate the credit risk of loan applicants [17].

Research on the credit rating model and credit rating index system, through analysing hierarchy process (AHP) and fuzzy comprehensive evaluation method, establishes the risk evaluation index model of rural credit cooperatives and analyzes the risk level of rural credit cooperatives in Hebei Province [18]. The multiple regression analysis of 15 traditional banks and 13 Islamic banks in Malaysia from 2000 to 2010 shows that the specific determinants of bank credit risk have a unique impact on the formation of credit risk of Islamic banks and traditional banks [19]. In the framework of expert judgment, the multicriteria ranking method electre-trinc is used to construct the internal credit rating model [20]. Taking 687 small-scale wholesale and retail enterprises of China's commercial banks as the research object, this paper uses partial correlation analysis and prohibits regression method to establish a credit rating index system [21]. In order to address the mismatch problem of high grade loans with high loss given default (LGD), a credit rating method by minimizing LGD for higher rated loans is established. The empirical results showed that the created model could solve the mismatch issue [22]. Considering the impact of macroeconomic change on banks' credit decisions, a novel nonlinear programming credit rating model is proposed. The findings can help to alleviate financing problems of low-income groups [23].

This paper mainly studies the linear segment evaluation model of multilayer unidirectional network for farmers' credit rating. Firstly, within the proposed three-level credit rating index system, it derives the calculation formula for each index of the four-layer unidirectional network for farmers' credit rating, as well as the calculation formula for farmers' credit evaluation. Secondly, this paper also derives the credit evaluation formulas for the one-level farmer's credit rating system and the two-level farmer's credit rating system; it further derives the credit evaluation formulas for the four-level farmer's credit rating system. Thirdly, this paper designs a linear segment classifier to classify the credit ratings outputs from the multilayer unidirectional network and establishes the rules of credit rating for farmers and the rules of linear segmentation evaluation model of the unidirectional network for farmer's credit rating. It also discusses the properties of bank loan risk based on the farmers'

credit rating. Finally, this paper applies the theoretical model to evaluate farmer's credit rating in A County, Guangdong Province, China. Though the research of this paper is very innovative, it never applied for Chinese Patent in 2012 [24]. The structure of this paper is arranged as follows. Section 2 establishes a four-layer unidirectional network based on the three-level credit rating index system. Section 3 offers the calculation formula for each index of the three-level credit rating index system. It also provides the special cases of calculation formulas for the one-level and two-level credit rating index system. It further extends the formulas to the credit rating index system with more than four levels, and finally it proposes the general calculation methods for multilevel credit rating index system. Section 4 establishes the rules and the linear segmentation evaluation model of credit rating for farmers. It designs a linear segment classifier and discusses the properties of bank loan risk based on the farmers' credit rating. Section 5 applies the theoretical model to evaluate the 160 farmers' credit rating in A County, Guangdong Province, China. Section 6 gives out the conclusion.

2. Farmer Credit Rating Index and Credit Score Calculating Method

In order to evaluate the farmers' credit grade, firstly we have to select the indexes used to perform the credit rating, namely, we should firstly construct the credit rating index system for farmers. At present, the characteristic of credit rating in rural areas can be described as follows. Firstly, some mountainous townships have been trying out the credible family and credible village and have developed the credit rating index system for farmers which is suitable for the development of rural economic in local area. However, as the rural areas are widely distributed in China, the conditions for agricultural production, the living standards of farmers, and the degree of cultural education vary from area to area; thus, the construction of the farmer's credit rating index system differs from area to area. Secondly, the current popular method adopted in China to conduct farmer's credit rating is the expert evaluation method. It quantifies each of the indexes and takes the summation of scores obtained by each index as the final credit score of the farmer and finally gives the farmer's credit grade using this total score.

Based on the current situation of the farmer's credit rating in China, this paper puts farmer's credit rating index system as an index system with multilayer unidirectional network structure. It combines the credit indexes in each grade through constructing the multilayer unidirectional network, calculates farmer's credit scores by obtaining scores from outputs of the network, and obtains the credit grades of the outputs in the network by designing the linear segment classifier for credit rating, thus finishing the credit rating for farmers.

Let us consider a farmer's credit rating index system with a network structure of four layers. Suppose there are n 1st-level indexes ($n \geq 1 \in Z^+$) and Z^+ is the set of positive integers (similarly hereinafter) which are A_1, A_2, \dots, A_n and

also are $A^{(1)} = \{A_1, A_2, \dots, A_n\}$ when expressed using set $A^{(1)}$. For the i^{th} ($1 \leq i \leq n$) (similarly hereinafter) index A_i in the 1st-level indexes, suppose there are m_i ($m_i \geq 1 \in Z^+$) 2nd-level indexes which are $A_{i1}, A_{i2}, \dots, A_{im_i}$ and also are $A^{(2)} = \{A_{i1}, A_{i2}, \dots, A_{im_i}\}$ when expressed using set $A^{(2)}$. For the j^{th} ($1 \leq j \leq m$) (similarly hereinafter) index A_{ij} in the 2nd-level indexes under the 1st-level index A_i ($1 \leq i \leq m$), suppose there are k_j ($k_j \geq 1 \in Z^+$) 3rd-level indexes (also called attributes) which are $A_{ij}^{(1)}, A_{ij}^{(2)}, \dots, A_{ij}^{(k_j)}$ and also are $A^{(3)} = \{A_{ij}^{(1)}, A_{ij}^{(2)}, \dots, A_{ij}^{(k_j)}\}$ when expressed using set $A^{(3)}$.

To calculate the credit scores and to conduct the credit rating, it is necessary to assign a score to each of the 3rd-level indexes. Suppose the scores of indexes in each rank are represented by $g_s(\cdot)$ ($s = 1, 2, 3$), that is to say, the paper uses $g_1(\cdot)$ to represent the score of indexes in the first level, $g_2(\cdot)$ to represent the score of indexes in the second level, and $g_3(\cdot)$ to represent the score of indexes in the third level. The scores of the third-level indexes $g_3(\cdot)$ are assigned mainly using the expert evaluating method; the scores of the second-level indexes $g_2(\cdot)$ are obtained according to each score of the third-level index, and the scores of the first-level indexes $g_1(\cdot)$ are the summation of the corresponding second-level indexes. For example, the paper uses $g_3(A_{ij}^{(k_j)})$ to represent the score of the third-level index $A_{ij}^{(k_j)}$ and uses $g_1(A_i)$ to represent the score of the first-level index A_i . In the end, the paper uses $\text{grade}|_3$ to represent the total credit score for farmers with three-level indexes, which is also the final result of credit scoring for farmers.

Suppose we divide farmers' credit score into N ($N \geq 2, N \in Z^+$) categories, that is, the number of credit grades are N . The problem now becomes an N -pattern classification, and we can solve this N -pattern classification problem by constructing the four-layer unidirectional network shown in Figure 1.

3. Calculation Formulas for Index in Each Level and for the Credit Scoring of the Multilayer Unidirectional Network

3.1. Three-Level Index Credit Scoring Formula Based on Four-Layer Unidirectional Network. In Figure 1, the 3rd-level index is on the first layer of the network. Each node is actually linked to an index, which means the number of nodes is exactly the same as the number of indexes and the scores of indexes from the third level are the input for the first layer of the network. The 2nd-level indexes are on the second layer of the network. The score of the 2nd-level indexes are obtained as the result of OR operation on the input of the first layer. This is because, in the first layer, the property content of 3rd-level indexes is mutual exclusive. Each farmer can meet only one property of the 3rd-level indexes. The score of this property is the score of the 2nd-level index for this farmer. Thus, in the second layer of the network, its operation is OR. Suppose the operator of OR is

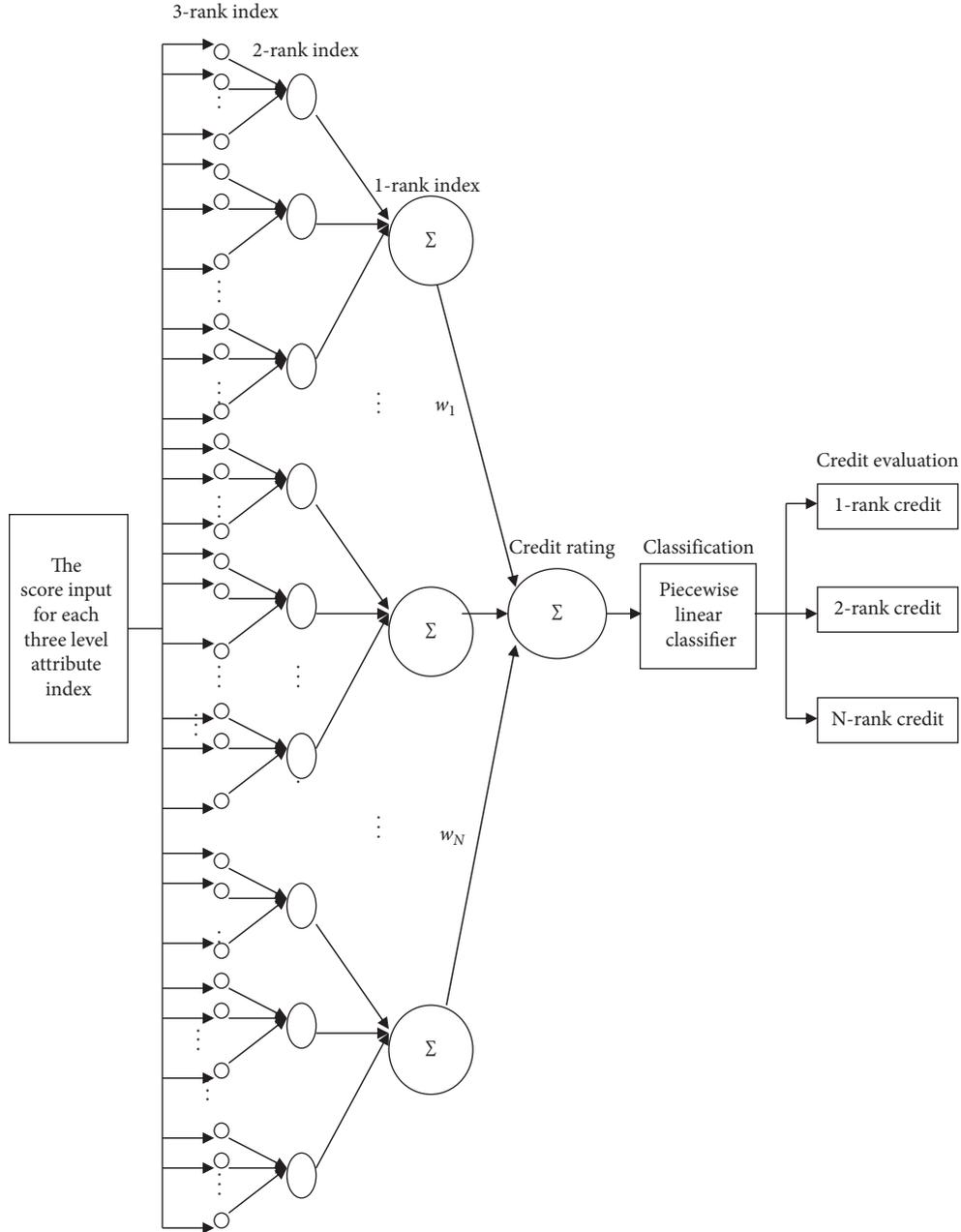


FIGURE 1: Farmer's credit rating system based on four-layer unidirectional network.

\cup ; then, the calculation formula for the scores of the 2nd-level indexes A_{ij} ($1 \leq i \leq n, 1 \leq j \leq m_i$) is

$$g_2(A_{ij}) = \cup_{k_j} g_3(A_{ij}^{(k_j)}), \quad (1)$$

where $m_i, k_j \in \mathbb{Z}^+$ are the number of the 2nd-level indexes under the 1st-level index A_i and the number of the 3rd-level indexes under the 2nd-level index A_{ij} , respectively.

According to the calculation rules of farmers' credit score, the score of each index in the 1st level is the summation of all scores of its 2nd-level indexes. Thus, the calculation formula for the scores of the 1st-level indexes A_i ($1 \leq i \leq n$) is

$$g_1(A_i) = \sum_{j=1}^{m_i} g_2(A_{ij}), \quad (2)$$

and from formula (1), the calculation formula for the scores of the 1st-level indexes A_i ($1 \leq i \leq n$) can be further expressed as

$$g_1(A_i) = \sum_{j=1}^{m_i} \left(\cup_{k_j} g_3(A_{ij}^{(k_j)}) \right), \quad (3)$$

where $m_i, k_j \in \mathbb{Z}^+$ are explained like those above.

Assuming the weights for the 1st-level indexes are w_1, w_2, \dots, w_n , respectively, the calculation formula for the total scores (grade_3) of the farmers' credit scoring with three-level indexes is

$$\text{grade}|_3 = \sum_{i=1}^n w_i g_1(A_i) = \sum_{i=1}^n w_i \left(\sum_{j=1}^{m_i} \left(\bigcup_{k_j \in Z^+} g_3 \left(A_{ij}^{(k_j)} \right) \right) \right). \quad (4)$$

The result calculated from formula (4) is the total credit score of the relevant farmer, and with this score we can get the corresponding credit grade. Now, we have completed the whole process of credit rating for farmers.

3.2. Two-Level Index Credit Scoring Formula Based on Three-Layer Unidirectional Network

3.2.1. Construction of Three-Layer Unidirectional Network.

Currently, various credit index systems are adopted to conduct the credit rating for farmers in the mountainous agricultural counties of China. The common one is the two-level index system. If it is the two-level index system, a three-layer unidirectional network needs to be established to build the farmer's credit rating system, as shown in Figure 2.

The calculation formula of the 1st-level index is

$$g_1(A_i) = \bigcup_{j=1}^{m_i} g_2(A_{ij}), \quad (1 \leq i \leq n), \quad (5)$$

where $m_i \geq 1 \in Z^+$.

3.2.2. *Two-Level Index Credit Scoring Formula.* Similarly, assume that w_1, w_2, \dots, w_n are the weights for each 1st-level index; then, the computational formula of farmer's total credit score $\text{grade}|_2$ with two-level index is expressed as follows:

$$\text{grade}|_2 = \sum_{i=1}^n w_i g_1(A_i) = \sum_{i=1}^n w_i \left(\bigcup_{j=1}^{m_i} g_2(A_{ij}) \right). \quad (6)$$

3.2.3. *Special Case.* More specifically, if the credit index only has one level, the unidirectional network structure is a two-layer network. With direct weighted sum of the score of each attribute index, we can obtain the 1st-level index score. Assuming w_1, w_2, \dots, w_n are the weights for the 1st-level indexes, the formula for calculating the farmer's total credit score $\text{grade}|_1$ is

$$\text{grade}|_1 = \sum_{i=1}^n w_i g_1(A_i). \quad (7)$$

3.3. *Calculation Formula of Farmer Credit Score with M-Level Index.* This session considers the more general case. Suppose there are M ($M \geq 4, M \in Z^+$)-level index in farmers' credit rating index system: $A^{(1)}, A^{(2)}, \dots, A^{(M-1)}, A^{(M)}$; then, we need to assign scores to the M^{th} -level indexes. Let us assume $g_i(A^{(i)})$ is the total score of the i^{th} -level indexes $A^{(i)}$, where i is from 1 to M .

With M -level index, it is necessary to establish a $(M+1)$ -layer unidirectional network to build the farmer's credit rating system. Simply expanding the four-layer unidirectional network, as shown in Figure 1, we can have a $(M+1)$ -layer network. The first layer is the M^{th} -level

indexes. Each node links to one index. The number of the nodes is exactly the same as the number of indexes, and the first layer receives inputs of scores from the M^{th} -level index. The second layer is the $(M-1)$ -level indexes and their scores are the OR operation on the scores of the first layer. Similarly, the third layer is the $(M-2)$ -level indexes and their scores are the OR operation on the scores of the second layer. All the remaining layers can be done in the same manner. As a result, the M^{th} -layer of the network are the 1st-level indexes, and the scores is the summation of the $(M-1)$ -layer. The $(M+1)^{\text{th}}$ layer is the output layer, which has only one node.

On the second layer are the $(M-1)^{\text{th}}$ indexes, and the scores of the $(M-1)^{\text{th}}$ -level indexes are obtained as the result of OR operations (the operator of OR is represented by $\bigcup (\cdot)$ on the scores inputted by the first layer). On the third layer are the $(M-2)^{\text{th}}$ -level indexes, and the scores of the $(M-2)^{\text{th}}$ -level indexes are obtained as the summation of the scores on the second layer. Similarly, on the fourth layer of the network are $(M-3)^{\text{th}}$ -level indexes, and the scores are obtained as the summation of the scores on the third layer. The rest can be done in the same manner. As a result, on the M^{th} layer of the network are the 1st-level indexes, and the scores are obtained as the summation of scores on the $(M-1)^{\text{th}}$ layer. The $(M+1)^{\text{th}}$ is the output layer, which has only one node.

Suppose there are n indexes in the 1st level and w_1, w_2, \dots, w_n are the weights for these indexes; from formula (4), we can get the calculation formula for farmer's total credit scores $\text{grade}|_M$ with M -level indexes ($M \geq 4, M \in Z^+$) as follows:

$$\text{grade}|_M = \sum_{i=1}^n w_i \underbrace{\sum_{g_2} \cdots \sum_{g_{M-1}}}_{M-1 \text{ layers}} \left(\bigcup_{k_j \in Z^+} g_M(A^{(M)}) \right), \quad (8)$$

where $\sum_{g_2}, \sum_{g_3}, \dots, \sum_{g_{M-1}}$ represent the summation of scores of the 2nd-level indexes, the 3rd-level indexes, \dots , and the $(M-1)^{\text{th}}$ -level indexes, respectively.

From (4), (6), and (11), we can get the general calculation formula for farmer's total credit scores $\text{grade}|_M$ with M -level indexes ($M \geq 1, M \in Z^+$) as follows:

$$\text{grade}|_M = \begin{cases} \sum_{i=1}^n w_i g_1(A_i), & M = 1, \\ \sum_{i=1}^n w_i \left(\bigcup_{j=1}^{m_i} g_2(A_{ij}) \right), & M = 2, \\ \sum_{i=1}^n w_i \left(\sum_{j=1}^{m_i} \left(\bigcup_{k_j \in Z^+} g_3 \left(A_{ij}^{(k_j)} \right) \right) \right), & M = 3, \\ \underbrace{\sum_{i=1}^n w_i \sum_{g_2} \cdots \sum_{g_{M-1}} \left(\bigcup_{k_j \in Z^+} g_M(A^{(M)}) \right)}_{M-1 \text{ layers}}, & M \geq 4. \end{cases} \quad (9)$$

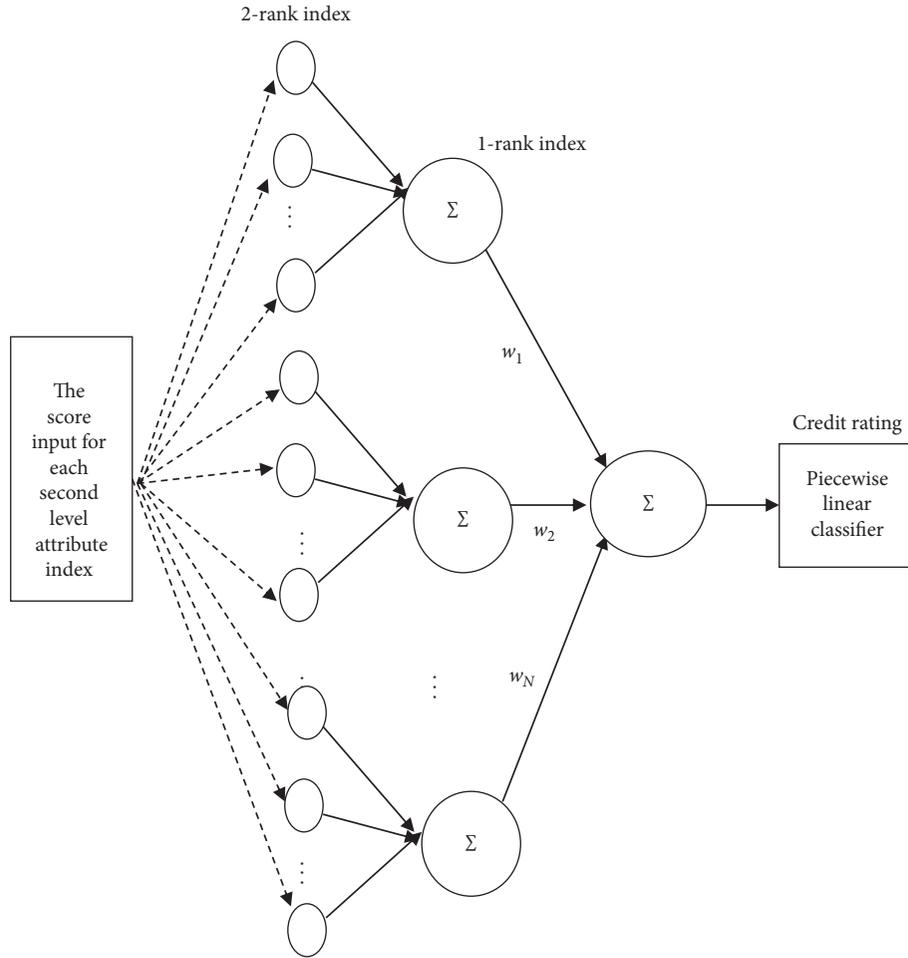


FIGURE 2: Farmer's credit rating system based on three-layer unidirectional network.

Summarize the above practice, and we obtain the following theorem.

Theorem 1. *If a multilayer unidirectional network is established according to the method proposed in this paper, then, for the credit rating system of farmers with M indexes, M is a positive integer, and the calculation formula of the total credit score $grade|_M$ of farmers will be calculated as formula (9).*

Proof. M is divided into the following situations:

- (1) When $M = 1$, it means that farmers have a one-layer index credit rating system. According to Section 3.2.3, it is necessary to establish a two-layer one-way network, and all level indexes are calculated by formula (7).
- (2) When $M = 2$, it means that farmers have a two-layer index credit rating system. According to Section 3.2.2, it is necessary to establish a three-layer one-way network, as shown in Figure 2, and all level indexes are calculated by formula (6).
- (3) When $M = 3$, it means that farmers have a three-layer index credit rating system. According to Section 3.1,

it is necessary to establish a four layer one-way network, as shown in Figure 1, and the scores of indicators at all levels are calculated by formula (4)

- (4) When M is greater than or equal to 4, it means that farmers have an indicator credit rating system of more than 4 levels. According to Section 3.3, it is necessary to establish a one-way network above $M + 1$. The scores of indicators at all levels are calculated by formula (8);

Therefore, for any positive integer M , M is a positive integer, when the farmer credit rating system has a grade index, we can get the calculation method of the farmer credit rating system with M grade index by combining cases (1)–(4) discussed in the proof process of this Theorem 1, and use formula (9) to calculate. \square

4. Linear Segmentation Evaluation Model of the Credit Rating for Farmers

4.1. The Rules of Credit Rating for Farmers. In this session, based on the total credit scores obtained from the calculation formula (12), a linear classifier is proposed to conduct the credit rating for farmers. Suppose there are

$N(N \geq 2, N \in \mathbb{Z}^+)$ credit grades for farmers, and the M -level index system ($M \geq 1, M \in \mathbb{Z}^+$) is adopted, and $V_1, V_2, V_3, \dots, V_{N-1}, V_N$ satisfy the relationship of $0 < V_N < V_{N-1} < \dots < V_2 < V_1$ and represent the minimum credit score of the N grades, respectively. We also suppose that each credit score only can fit into one credit grade; then, the rules for the credit rating are shown in Table 1.

Furthermore, we use x ($x \in \mathbb{Z}^+$) to represent famer's total credit score; then, the linear segment classifier $f(\cdot)$ can be expressed as follows:

$$f(x) = \begin{cases} 1, & x \geq V_1, \\ 2, & V_2 \leq x < V_1 - 1, \\ 3, & V_3 \leq x < V_2 - 1, \\ \dots & \dots \\ N-1, & V_{N-1} \leq x < V_N - 1, \\ N, & x < V_{N-1}. \end{cases} \quad (10)$$

Formula (13) is called the linear segmentation evaluation model of credit rating for farmers. When rating a farmer's credit, firstly we calculate the score $g_1(A_i)$ of each of the first-rank indexes A_i ($1 \leq i \leq n$), then we use formula (12) to calculate the total credit score of the farmer, and at last, through the linear segment classifier (13) we can get the corresponding credit grade of the farmer.

4.2. The Properties of Loan Credit Based on Farmer's Credit Rating. With farmer's credit rating evaluated, the bank can determine the load credit for farmers based on their credit grades. Suppose credit line for the N credit grades $1, 2, 3, \dots, N-1, N$ are $F_1, F_2, F_3, \dots, F_{N-1}, F_N$, respectively, and then two properties about load credits based on farmer's credit rating can be obtained.

Property 1. Suppose the credit grades $1, 2, 3, \dots, N-1, N$ of farmers are ranked from high to low; then, the corresponding credit lines for loans satisfy $F_1 > F_2 > F_3 > \dots > F_{N-1} > F_N$.

Property 2. If the credit lines of credit grade t ($1 < t < N$) satisfies $F_t = 0$; then, we have $F_{t+1} = F_{t+2} = \dots = F_N = 0$.

To achieve the stimulation purpose and to enhance the loan's antirisk ability, the rural credit unions often adopt the co-guarantee policy when they provide load to farmers. Under the co-guarantee policy, if a farmer is not in the highest credit grade and if he is willing to join the co-guarantee program, his credit grade would not change but his credit line could be up for a range. Under the co-guarantee policy, for a farmer whose credit grades is K ($2 \leq K \leq N$), his credit line would be raised for a certain range a_{K-1} if he joins the co-guarantee program. However, for a farmer whose credit grade is the highest, which is the first-grade credit, his credit line would not change even if he joins the co-guarantee program. Table 2 below shows farmer's credit rating and corresponding credit lines, within co-guarantee program and without co-guarantee program.

TABLE 1: The rules of farmers' credit rating.

Credit score	Credit grade
The score is greater than or equal to V_1	The 1 st grade
The score is greater than or equal to V_2 , but smaller than V_1	The 2 nd grade
The score is greater than or equal to V_3 , but smaller than V_2	The 3 rd grade
...	...
The score is greater than or equal to V_N , but smaller than V_{N-1}	The $(N-1)$ th grade
The score is smaller than V_N	The N th grade

Property 3. If credit line for credit grade t ($1 < t < N$) satisfies $F_t = 0$ ($1 < t < N$); then, we have $F_{t+1} + a_t = F_{t+2} + a_{t+1} = \dots = F_N + a_{N-1} = 0$.

5. Case Study

5.1. The Construction Method for Farmer's Credit Index System. A County in Guangdong Province, China, has been the first one to try out "credible family, credible village, and credible town" in Guangdong Province in 2011. When constructing the rural credit rating system, A County establishes a county level committee, which is responsible for the organization and coordination of the township level governments, financial institutions, and other relevant departments, and this committee is responsible to the A County People's Government. The township governments also establish farmer's credit rating committees, together with the village administration as well as the county level committee, to form the special working group for farmer's credit rating. This working group conduct the credit rating for farmers and execute the plan of establish credit village and credible town. Limited by space, this paper only analyzes the farmer credit rating system developed by A County.

The construction of farmer credit index system in A County can be divided into the construction of the three-level indexes as below.

The 1st-level indexes consist of famer's social stability, production and operation, financial income, individual performance, moral character, social credit, and so on, which can be divided into four mutual categorical attributes: social management, basic information, credit quality, and family finance.

The 2nd-level indexes are the further subdivision of each of the 1st-level indexes according to their mutual categorical attributes. For example, the social management in the 1st-level indexes is subdivided into legal compliance, respecting the old and caring for the young, social welfare participation, military service, compliance of the family planning, medical insurance, and so on. The credit quality in the 1st-level indexes is subdivided into the financial institution credit, the quality of farmer, social credit, external guarantee, and so on. The remaining indexes can be done in the same manner.

The 3rd-level indexes are the subdivision description for all cases with optional categories that might appear in the 2nd-level indexes, and the contents of these cases are mutually disjoint. For example, the legal compliance in the 2nd-level indexes are described as three cases: first, all family

TABLE 2: Farmer credit rating with N grades and credit lines with/without co-guarantee program.

Credit score	Credit grade	Credit line	Join co-guarantee program or not
The score is greater than or equal to V_1	1 st grade	F_1	
The score is greater than or equal to V_2 , but smaller than V_1	2 nd grade	$F_2 + a_1$ F_2	Yes No
The score is greater than or equal to V_3 , but smaller than V_2	3 rd grade	$F_3 + a_2$ F_3	Yes No
...
The score is greater than or equal to V_N , but smaller than V_{N-1}	$N - 1$ th grade	$F_{N-1} + a_{N-2}$ F_{N-1}	Yes No
The score is smaller than V_N	N th grade	$F_N + a_{N-1}$ F_N	Yes No

members are legal compliance and there are no gambling phenomena of family members; second, there exist gambling phenomena of family members in the past, but there is no bad behavior during the year; and third, there exist gambling phenomena or behavior of violating the law and discipline of the family members during the year. The social credit in the 2nd-level indexes is described as four cases: fine, good, general, and bad. And the remaining indexes can be done in the same manner.

5.2. The Rules to Assign Value to the 3rd-Level Indexes. In A County's farmer credit rating index system, each credit attribute of the 3rd-level indexes in the credit index system was quantified and assigned score (the scoring method); the farmer's final credit score is obtained by summation on these scores of the 3rd-level indexes.

The scoring method for the 3rd-level indexes in social management category (the 1st level) is incentive based, with positive and negative incentives simultaneously. For a farmer, he/she will get positive score if he/she performs well in the index; he/she will get 0 score if he/she performs OK in the index; he/she will get negative score (penalty) if he/she performs below expectation in the index.

As the scale of farm production and operation, the production and business operation ability, the credit quality, the family income, and so on are different from farmer to farmer; thus, the scores are various from attribute to attribute for each index in the 3rd level. Furthermore, every attribute is ranked from "good" to "bad" and the corresponding scores are ranked from high to low.

For example, in the A County's farmer credit rating index system, the 3rd-level indexes under the legal compliance respect the old and caring for the young in the 2nd-level indexes, and their scores are shown in Table 3.

5.3. The Credit Rating Method. Farmers' credit is divided into five credit grades: excellent, excellent, good, average, and bad based on the results of their credit score. And their credit line can be determined based on their credit grade as well as whether they join the co-guarantee program or not, which is shown in Table 4 below.

From Table 4, we can see that there are five scenarios for credit score, credit grades, credit rating, credit lines, and the conditions for co-guarantee program.

- (1) For farmers whose credit scores are greater than or equal to 105, their credit grade is "Excellent I" and the credit rating is "AAA", with credit line up to 50,000 Chinese Yuan.
- (2) For farmers whose credit scores are from 90 to 104, their credit grade is "Excellent II" and the credit rating is "AA." The credit line is divided into two cases; the first case is that, for the farmers who joint the co-guarantee program, which has three or more families in the program, the credit line is 40,000 Chinese Yuan; the second case is that, for the farmers who do not joint the co-guarantee program, their credit line is 30,000 Chinese Yuan.
- (3) For farmers whose credit scores are from 80 to 89, their credit grade is "Good" and their rating is "A." The credit line is divided into two cases; the first case is that, for the farmers who joint the co-guarantee program, which has three or more families in the program, the credit line is 20,000 Chinese Yuan; the second case is that, for the farmers who do not joint the co-guarantee program, their credit line is 10,000 Chinese Yuan.
- (4) For farmers whose credit scores are from 80 to 89, their credit grade is "General" and their credit rating is "B." For the farmers with joint co-guarantee program, their credit line is 10,000 Chinese Yuan. For the farmers who do not joint co-guarantee, their credit line is 0 Chinese Yuan.
- (5) For farmers whose credit scores are smaller than or equal to 69, their credit grade is "Bad" and their credit rating is "C." Their credit line is 0 Chinese Yuan.

Suppose we use matrix $(a_{ij})_{n \times m}$ ($1 \leq i \leq n, 1 \leq j \leq m$) to show the numbers of indexes from the 1st level to the 3rd level in farmer credit rating index system. Here, the row n represents the number of the 1st-level indexes, and the column m represents the maximal number of the 2nd-level indexes possessed by the n 1st-level indexes, that is,

TABLE 3: The 3rd-level indexes under the legal compliance and their scores.

The 1 st -level indexes	The 2 nd -level indexes	The 3 rd -level indexes	Score
Social management	Legal compliance	All family members are legal compliance and there are no gambling phenomena	2
		There exist gambling phenomena in the family members in the past, but there is no bad behavior during the year	1
		There exist gambling phenomena or behavior of violating the law and discipline in the family members during the year	-2
		Good family solidarity; good relationship with neighbors, and there exist no quarrel phenomena	2
	Respect the old and care for the young	The family solidarity is very good, gets on averagely with the neighbors, and there exist occasional quarrel phenomena	1
		The family solidarity is very good, but gets on averagely with the neighbors; in addition, there exist frequent quarrel phenomena	0
		The family solidarity is good, but there exist frequent quarrel phenomena; or the family gets on bad with the neighbors, and there exist frequent quarrel phenomena	-2

TABLE 4: The credit rating for farmers in A County in 2011.

Credit score	Credit grade	Credit rating	Credit line	Conditions
≥105	Excellent I	AAA	CNY 50,000	
90 to 104	Excellent II	AA	CNY 40,000	With joint guarantee of three or more families
			CNY 30,000	Without joint guarantee
80 to 89	Good	A	CNY 20,000	With joint guarantee of three or more families
			CNY 10,000	Without joint guarantee
70 to 79	Average	B	CNY 10,000	With joint guarantee of three or more families
			CNY 0	Without joint guarantee
69≤	Bad	C		

$m = \max\{m_1, m_2, \dots, m_i\}$, where m_i ($1 \leq i \leq n$) is the number of the 2nd-level indexes possessed by the i th first-level index. The elements of the matrix a_{ij} represent the number of the

3rd-level indexes possessed by the j th second-level index under the i th first-level index. The elements a_{ij} are defined as follows:

$$a_{ij} \begin{cases} \neq 0, & \text{the number of the third - rank indexes possessed by} \\ & \text{the } j\text{th second - rank index under the } i\text{th first - rank index is } a_{ij}, \\ 0, & \text{there exist no third - rank index possessed} \\ & \text{the } j\text{th second - rank index under the } i\text{th first - rank index.} \end{cases} \quad (11)$$

Then, the numbers of the indexes from the 1st level to the 3rd level in the credit scoring table farmers in A County can be represented by the matrix as follows:

$$\begin{bmatrix} 3 & 4 & 3 & 3 & 1 & 1 & 1 & 1 & 1 & 4 & 5 \\ 4 & 4 & 4 & 4 & 4 & 4 & 4 & 4 & 4 & 4 & 0 \\ 4 & 4 & 4 & 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 5 & 5 & 5 & 5 & 5 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}_{4 \times 11}. \quad (12)$$

From matrix (15), we can see that there are four first-level indexes in the credit scoring table for farmers in A County, that is to say $n = 4$. The numbers of the 2nd-level indexes possessed by these four 1st-level indexes are, respectively, 11, 10, 4, and 5, that is, $m_1 = 11$, $m_2 = 10$, $m_3 = 4$, and $m_4 = 5$. The element $a_{11} = 3$ represents there are three third-rank indexes possessed by the first 2nd-level index under the first 1st-level index. The element $a_{1,11} = 5$

represents that there are 5 third-level indexes possessed by the eleventh 2nd-level index under the first 1st-level index. The elements $a_{2j} = 4$ ($1 \leq j \leq 10$) represent there are 4 third-level indexes possessed by each of the 10 second-level indexes under the second 1st-level index. The elements $a_{3j} = 4$ ($1 \leq j \leq 4$) and $a_{3j} = 0$ ($5 \leq j \leq 11$) represent there are 4 third-level indexes possessed by each of the 2nd-level indexes under the third 1st-level index, and there are only four 2nd-level indexes under the third 1st-level index. The rest can be explained in the same manner. The sum ($\sum_{i=1}^n \sum_{j=1}^{m_i} a_{ij}$) of all elements of the matrix is the number of the third-level indexes possessed by the credit rating index system.

5.4. *Sample Selection and Application of the Model.* The proposed model is evaluated with farmers' data from A County in Guangdong Province, China. In 2011, there are 160 farmers in this town applying to join in the credit rating

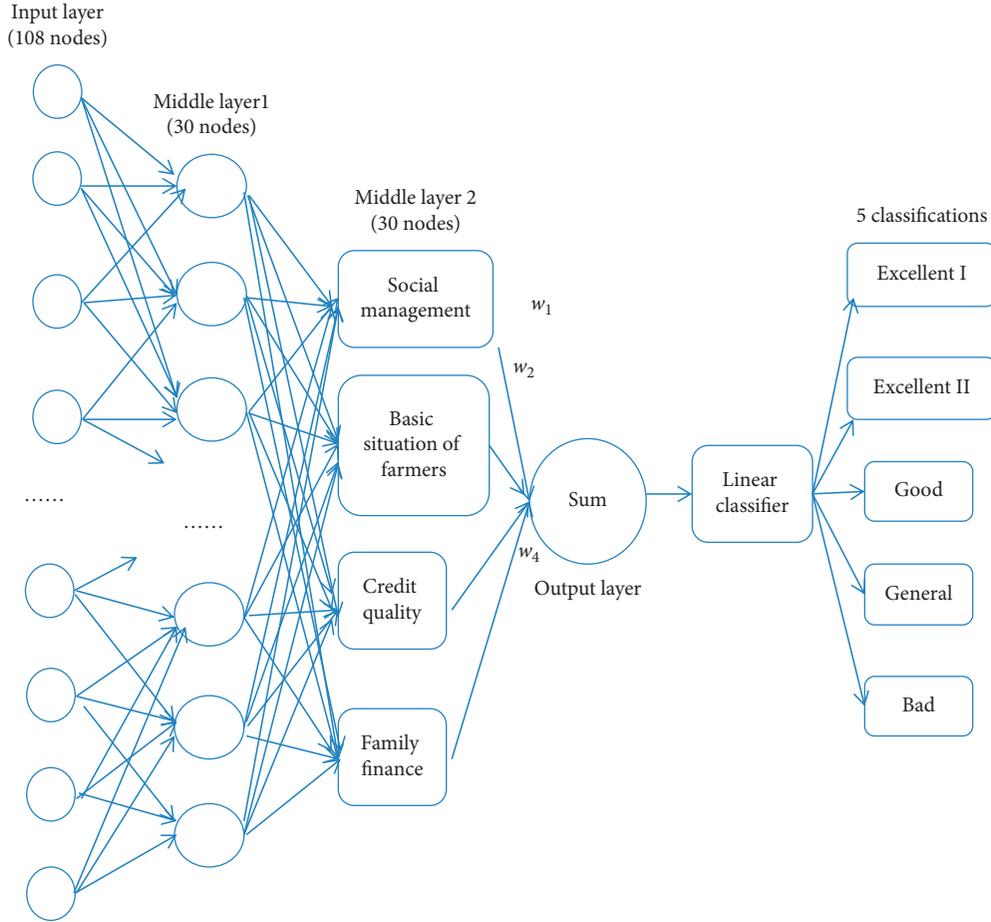


FIGURE 3: A multilayer one-way network of farmer credit rating with 4 inputs and 5 classifications (A County in Guangdong Province).

launched by the county government. These 160 farmers' information are fed into the network, as shown in Figure 1, and based on the analysis from Section 5.1 to Section 5.3, there are four layers in the credit rating network. That is to say, $M = 3$, and the number of the 3rd-level indexes possessed by the credit rating index system is

$$\sum_{i=1}^n \sum_{j=1}^{m_i} a_{ij} = 108. \quad (13)$$

Thus, there are 108 input nodes in the network as there are

$$\sum_{k=1}^4 m_k = m_1 + m_2 + m_3 + m_4 = 11 + 10 + 4 + 5 = 30. \quad (14)$$

2nd-level indexes in the credit rating system and the nodes in the middle layer of the network are composed of each index in the 2nd level; thus, there are 30 nodes in the middle layer of the network. The nodes in the fourth layer of the network are composed of each of the indexes from the first level, and there are four 1st-level indexes possessed by the credit rating index system. That is to say, $n = 4$; thus,

there are 4 nodes in the fourth layer (i.e., 4 input nodes) of the network, as shown in Figure 3.

In the process of credit rating, the rating indicators of the same layer are of equal importance. Therefore, when A County carries out the credit rating, the weights of all levels of indicators in the same hidden layer are equal. Therefore, the weights of all levels may not be considered in the calculation process. Then, when conduct the credit scoring in A County, the weights for the 1st-level indexes is 1, that is,

$$w_1 = w_2 = w_3 = w_4 = 1. \quad (15)$$

From formula (4), the total score $\text{grade}|_3$ of the farmers' credit scoring with three-level indexes, the formula for farmer's credit score is

$$\text{grade}|_3 = \sum_{i=1}^4 g_1(A_i) = \sum_{i=1}^4 \left(\sum_{j=1}^{11} \bigcup_{k_j \in Z^+} g_3 \left(A_{ij}^{(k_j)} \right) \right). \quad (16)$$

Feeding the scores obtained by each of the 3rd-level indexes of the 160 farmers into the network, the credit score of each farmer can be estimated based on formula (9).

From Table 4, there are five credit grades in A County's farmer's credit rating system, that is, $N = 5$. Based on (13), the linear segment classifier is

TABLE 5: Discrimination accuracy.

	Excellent I	Excellent II	Good	General	Bad
Original rating (number)	0	8	31	41	80
Discrimination results (number)	0	8	31	41	80
Discrimination accuracy	100%	100%	100%	100%	100%

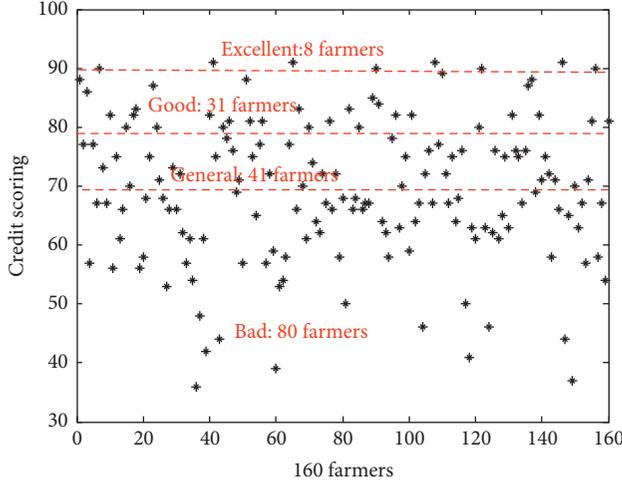


FIGURE 4: Scatter diagram of credit scoring of 160 farmers.

$$f(x) = \begin{cases} 1, & x \geq 105, \\ 2, & 90 \leq x < 105, \\ 3, & 80 \leq x < 90, \\ 4, & 70 \leq x < 80, \\ 5, & x < 70, \end{cases} \quad (17)$$

where $x (x \in \mathbb{Z}^+)$ is farmer's total credit score.

With farmers' credit scores estimated based on (19), these farmers' credit grades can be evaluated using the linear segment classifier (10). Finally the results of the credit rating for these 160 farmers are the number of people in grade "Excellent" (≥ 105) is zero; the number of people in the grade "Excellent" ($90-104$) is 8; the number of people in the grade "Good" ($80-89$) is 31; the number of people in the grade "General" ($70-79$) is 41; and the number of people in the grade "Bad" (≤ 69) is 80. This credit rating result from the proposed method matches the actual rating result in the Town, A County. That is to say, the accuracy rate is 100%, as shown in Table 5.

The Scatter diagram of credit scoring of 160 farmers is shown in Figure 4.

6. Conclusions

Nowadays, the credit rating system, the credit rating method, and the related rating mechanism are still not perfect in the rural areas of China. As the concepts of rural areas of foreign countries are fundamentally different from that of China, and the percentage of population engaged in farming in foreign countries differs from that in China, as well as the fact that the relevant literatures in foreign countries are obviously different

from the actual situations in China. Thus, the proposed methods in these literatures that can be used as references in China are very rare. Therefore, when studying the financial innovation problem of China, we must start with the specific scenarios in rural areas of China, with consideration of different geographic location's living conditions, business environments, and cultural characteristics, and construct the credit rating system and credit rating method which are compliance with history, economy, and culture of rural areas in China. Only in this way we can solve the farmer credit rating problems and the corresponding financial innovation problems in China.

Firstly, based on the logical structure of the three-level credit rating index system, this paper constructs a four-layer unidirectional network and conducts OR operation on the network's inputs. These inputs are the farmer's credit scores assigned to the 3rd-level indexes estimated by the expert scoring method. Then, this paper works out the credit scores of every output nodes in every layer based on the network structure, where the credit scores of the output nodes in the third layer are exactly the credit scores of the 1st-level indexes, and the credit score of the output node in the fourth layer is exactly the final credit score of the farmer.

Furthermore, this paper offers the calculation formula for index in each level of the three-level credit rating index system, as well as the credit score calculation formula for the four-layer unidirectional network. This paper also obtains the special case calculation formulas for the one-level and two-level credit rating index system. Based on these, it extends the formulas to cover the case of four-level credit rating index system and provides the credit score calculation formula for unidirectional network with more than five layers. In the end, it deduces the general calculation formulas for multilayer unidirectional network with the multilevel credit rating index system.

In addition, this paper also designs a linear segment classifier to classify the credit grades of outputs from the multilayer unidirectional network and builds the credit grades rules for farmers. It also discusses the properties of bank credit risk based on the farmers' credit grades. Finally, this paper applies the theoretical model to evaluate the 160 farmers' credit grades in A County, Guangdong Province, China. The result from the approaches proposed by this paper is compliance with the actual rating result in A County, which means the accuracy is 100%.

The studies in this paper involve the construction method for the credit rating index system, the establishment of the multilayer unidirectional network, the build of the credit scoring model, the design of the linear segment classifier for credit grade evaluation, and the application of the model. All of these have important theoretical

innovation and practical application value. This paper can offer specific guidance to the reform and innovation of rural finance and the credit rating for farmers in China. It also has important theoretical research and scientific guidance value to the exploration and perfection of the credit rating system, to promote the credit concept to farmers in China, and to promote economy development in rural areas of China.

Data Availability

All data in the article come from a county sub-branch, Guangdong Province, People's Bank of China.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Sulin Pang contributed in writing the first draft, conceptualization, framework design, collecting data, investigation, data resources, drawing images, formal analysis, tables, establishing the model, project administration, revise, adding content; theorem proving, error correction, partial writing, completing the final draft, and funding. Shouyang Wang contributed in methodology, framework design, establishing the model, analysis data, error correction, partial writing, supervision, and completing the final draft. Lianhu Xia contributed in error correction, quality improvement, theorem proving, and completing the final draft. Dr. Lianhu Xia participated in the discussion of the final revised draft, the proof of the theorem in the process of revising the article, and contributed to the final draft. So, he was added to the final revised version.

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