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International Journal of Earthquake Engineering
Anno XLIII - Num. 2 - 2026

Construction and Application of Comprehensive Evaluation Model of Multidimensional Financial Indicators Based on Fuzzy Mathematics

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SUMMARY: *Based on the basic principles of fuzzy mathematics, this paper details the application of fuzzy mathematical theory in financial evaluation. Organically combining the fuzzy mathematical matrix with the comprehensive financial evaluation, it synthesizes the subjective assignment method and entropy weight method to calculate the index weights, and establishes a fuzzy comprehensive evaluation model of the enterprise's financial ability based on fuzzy mathematics. The model we put forward is utilized to carry out the empirical research on the solvency, operation ability, profit-making possibility, and growth ability of Company A. The clustering method is employed by us to carry out the evaluation on the similarity degree of the entropy weight vectors which come from experts. This appraisal is helpful for the ascertainment of the weights of experts and the aggregation of the outcomes of decision-making. The experts' cluster decision-making shows that among the four dimensional weight coefficients, solvency>development ability>operating ability>profitability. The evaluation results show that the financial status of Company A is medium and it is necessary to control the risk of operating capacity and profitability within a reasonable range.*

KEYWORDS: *fuzzy mathematics; financial evaluation; cluster analysis; entropy weight method; fuzzy comprehensive evaluation*

1 Introduction

Along with the market economic system being set up and perfected, and along with the complicated economic environment going through alterations, the quantity of all kinds of enterprises has a trend of increase. At the same time, the risk which is connected with investment is being increased greatly. And the comprehensive evaluation of the financial health of enterprises, as a key element of concern for investors, creditors, operators and so on, is widely used in many fields such as investment [1, 2]. The ultimate purpose of financial evaluation is to comprehensively, accurately and objectively reveal and disclose the financial condition and operation of the enterprise, and to make a reasonable evaluation of the strengths and weaknesses of the enterprise's economic performance. Obviously, to achieve the purpose of such an analysis, just measuring a few simple financial ratios, it is impossible to reach a reasonable, correct and comprehensive conclusions, and sometimes even draw the wrong conclusions [3, 4]. It can be seen that only analyzing certain financial indicators or simply superimposing some isolated financial evaluation indicators will not achieve the desired evaluation purpose. Only by organically linking the analytical indicators such as solvency, operating capacity, growth capacity, profitability and non-financial information to make a systematic and comprehensive

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https://doi.org/10.65102/is2026594
Published: 30 April, 2026

evaluation, can we grasp the strengths and weaknesses of the enterprise's financial condition and operation in a general sense [5, 6]. However, the current financial evaluation system focuses on deterministic research and pays little attention to its ambiguity, making the results of comprehensive financial evaluation less than ideal. A quite large degree of uncertainty which comes from accounting in the processes of recognition, measurement, and statement making, among other items, therefore will be directly shown on the results of financial evaluation. The financial evaluation work is dependent on accounting, statement data and other connected information. However, the accounting recognition and measurement have the inherent ambiguity, and each kind of accounting approach can produce different degrees of effect on the overall financial assessment [7-11].

The birth of fuzzy mathematics has built a connecting bridge to the process of mathematizing the solution of some ill-defined qualitative problems, and its use in various fields of business management has amply demonstrated the feasibility of its practical techniques [12]. A great deal of pioneering work has been carried out in fuzzy mathematics for application in the field of financial evaluation. Su [13] introduced fuzzy mathematics into the financial evaluation index system, we have integrated the fuzzy comprehensive assessment model with the financial comprehensive assessment, and thus have put forward a novel financial fuzzy comprehensive assessment model. This model has carried out analysis on the comprehensive index items which are related to profit obtaining, debt paying, operation carrying, development increasing, and non-financial related aspects.Wang [14] compared the analytical ability of fuzzy set-based engineering science model and traditional financial assessment index analysis methods in corporate financial analysis indexes, and the former has higher accuracy in analyzing financial information. Lin and Shang [15] took fuzzy mathematics as the basis and added grey system theory to form a fuzzy grey correlation analysis method, designed a judgment matrix, determined the weights of financial risk indicators, and realized the comprehensive assessment of financial risk.Tsao and Wen [16] have employed a fuzzy comprehensive evaluation method to measure the whole financial situation of universities. Through considering the root reasons and sorts of financial risks, they have built a financial early-alert model for universities and hence worked out measures for the prevention and control of financial risks. The goal of these works was to reduce the money risks which are borne by universities.Azarov and his work companions [17] utilized methods of system analysis and mathematical tools of fuzzy logic in order to construct a model for the assessment of an enterprise’s financial situation. In this model, a group of gathering functions were also designed for the investigation of financial safety, fluidity, working profit ability, and debt paying ability.Ma and colleagues [18] have utilized the entropy weight method to calculate the importance of economic indexes which are connected with the financial condition. They afterwards utilized fuzzy logic for the analysis of these economic index data. After that, they have constructed an all-round evaluation system for the level of the enterprise's monetary condition and have conducted an assessment of the financial position. Lam et al [19] integrated entropy approach, fuzzy concepts, and approximation of ideal solution ordering to develop a multi-criteria decision model for analyzing and evaluating the financial performance of portfolio-based firms, where the fuzzy concepts enhance and extract key information from financial ratios. Lu [20] combined computer vision algorithms and fuzzy mathematics to construct a fuzzy comprehensive evaluation method, and optimized the financial assessment index system to evaluate the enterprise's cash flow and solvency, which assisted the enterprise to understand its own strengths and weaknesses. Therefore, the method of fuzzy mathematics is been put into the overall evaluation system of an enterprise's financial index numbers. Then we carry out the development of a comprehensive evaluation model for financial measurement indexes. Through utilizing the method of fuzzy mathematics, this model is able to effectively carry out assessment on the enterprise's current situation. It offers more precise outcomes of the financial appraisal to investors, managers, and other concerned parties. In addition, this promotes the enterprise's ability to adapt and the effect of related mathematics applications.

In this paper, the representation and operation methods of fuzzy sets in fuzzy mathematics are systematically sorted out, and the steps of fuzzy mathematics to deal with the comprehensive evaluation of enterprise finance are discussed based on its scope of application. Regarding the estimation of business finance risk, the connected assessment quotas are selected. The weight values of these indexes are confirmed through both subjective and objective distribution methods, which thus enables the construction of an enterprise finance fuzzy comprehensive appraisal model. We have selected the financial statement data of Company A, which is an enterprise belonging to the manufacturing industry field, covering the time period from 2020 to 2024, to be the object of our applied research, and the comprehensive weight coefficients of each financial indicator by 10 experts are calculated. Screening the financial indicators in four dimensions of solvency, operating ability, profitability, and development ability, and calculating the values of the financial indicators of Company A for five years. Determine the degree of affiliation of each index, and make a fuzzy comprehensive judgment on the financial risk of Company A.

2 Research on Fuzzy Comprehensive Evaluation of Enterprise Finance Based on Fuzzy Mathematics

When all kinds of risks faced by enterprises accumulate to a certain degree, if they cannot take timely measures to solve them, they will fall into financial crisis. The health of listed companies is related to the relevant interests of investors and creditors, so the study of their financial status is extremely important. The present research paper places emphasis on the current enterprise financial analysis and evaluation system. This paper carries out a deep analysis from many angles, that is to say the choice of fuzzy clustering indexes, the distribution of indexes by using subjective and objective methods, and fuzzy comprehensive evaluation. Through keeping the consistence of the fuzzy mathematics method in the whole process, all the constituent parts of the system are complexly connected with each other. The final goal is that we establish the mathematics model for fuzzy overall finance appraisal, draw the appraisal steps clearly, and put forward the corresponding practical methods.

2.1 Principles and scope of application of fuzzy mathematics

Fuzzy theory includes the utilization of mathematical methods to study and deal with the “ambiguous” mathematical phenomena. In common situations, people call it fuzzy mathematics.

The fuzzy mathematics does not cause mathematics to become not clear. On the contrary, this thing possesses the basic characteristics of mathematics, that is to say, precision and exactitude. In the human society and in many different science fields, people meet with a great many of magnitudes. These measuring magnitudes can on the whole be divided into two big kinds: determined and not determined. Furthermore, the not-sure amounts can be further cut apart into those that have random characters and those that express blurriness.The classification framework of mathematical models is shown in Figure 1, and it is these three kinds of mathematics that people use to study different quantities in the objective world separately.

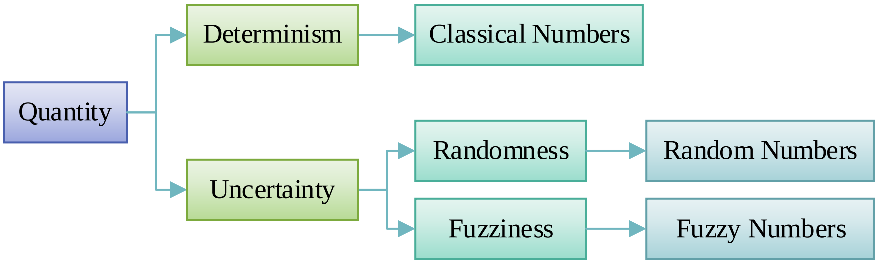


Figure 1: Classification framework of the mathematical model

Within this framework, mathematical models can be divided into three main categories:

The first category, deterministic mathematical models: these models study objects that are deterministic and have a necessary relationship between the objects. The most typical are the mathematical models established by differential methods, differential equations, and difference equations.

The second type, stochastic mathematical model: this type of model study the object of randomness, the object has a chance between. Such as the mathematical model established by probability distribution method, martens chain.

The third category, fuzzy mathematical model: this type of model studied the relationship between the object and the object has fuzzy. This is the model to be discussed in this paper.

People often refer to mathematics as an exact science because it deals with precise concepts, which are well-defined in quantity and require accuracy. But in daily life there are some fuzzy concepts, the extension is not clear, the quantity is difficult to determine, in the past has been unable to apply mathematical methods to deal with, this phenomenon in the valuation of intangible assets, especially goodwill assessment is also seen everywhere. However, with the development of mathematical disciplines, the birth of fuzzy mathematics, so that fuzzy concepts have been possible to quantify to a certain degree of accuracy so as to deal with mathematical methods.

Fuzzy Mathematics Definition: given a theoretical domain U, $\underset{\sim}{A}$ is a fuzzy set on U if, for any $x \in U$, it is possible to determine a number $\mu_{\underset{\sim}{A}}(x) \in [0,1]$ that denotes the degree to which x belongs to $\underset{\sim}{A}$.This hereby shows that one kind of mapping has been created.

$$\begin{aligned} &\mu_{\underset{\sim}{A}} : U \to [0,1] \\ &x \mapsto \mu_{\underset{\sim}{A}}(x) \in [0,1] \end{aligned} \tag{1}$$

This special mapping is called the affiliation function of $\underset{\sim}{A}$, and the number $\mu_{\underset{\sim}{A}}(x)$ is called the degree of affiliation of the element x in U to the fuzzy set $\underset{\sim}{A}$.

By this way, one blurry set is completely depicted by the membership function $\mu_{\underset{\sim}{A}}(x)$. That is, the fuzzy subset $\underset{\sim}{A}$ is uniquely determined by the affiliation function $\mu_{\underset{\sim}{A}}(x)$, and the fuzzy subset is always later regarded as equivalent to the affiliation function. It should also be noted that the idea of degree of affiliation is fundamental to fuzzy mathematics. In particular, when $\mu_{\underset{\sim}{A}}(x)$ takes only 0 or 1, the fuzzy set $\underset{\sim}{A}$ metamorphoses into the ordinary set A, and the affiliation function $\underset{\sim}{A}$ of $\mu_{\underset{\sim}{A}}(x)$ is transformed into the characteristic function $C_A(x)$ of

A. It can be seen that a fuzzy set is a generalization of an ordinary set, while an ordinary set is a special case of a fuzzy set. The full fuzzy set on U is denoted as $\tilde{P}(U)$, and so $\tilde{P}(U) \supset P(A)$.

2.1.1 Representation and operations on fuzzy sets

Let the domain U be a finite set, $U = \{x_1, x_2, \cdots, x_n\}$, and any fuzzy set $\underset{\sim}{A}$ on U with an affiliation function of $\{\mu_{\underset{\sim}{A}}(x_i)\}\left(i = 1, 2, \cdots, n\right)$.

(1) Zadeh representation

$$\underset{\sim}{A} = \frac{\mu_{\underset{\sim}{A}}(x_1)}{x_1} + \frac{\mu_{\underset{\sim}{A}}(x_2)}{x_2} + \cdots + \frac{\mu_{\underset{\sim}{A}}(x_n)}{x_n} \tag{2}$$

Here $\frac{\mu_{\underset{\sim}{A}}(x_i)}{x_i}$ is not a fraction, and the "+" does not indicate summation, but only symbolic meaning, this therefore indicates the degree of connection of this point x_i to the fuzzy set $\underset{\sim}{A}$ is $\mu_{\underset{\sim}{A}}(x_i)$.

(2) Sequence representation

$$\underset{\sim}{A} = \left\{\left[x_1, \mu_{\underset{\sim}{A}}(x_1)\right], \left[x_2, \mu_{\underset{\sim}{A}}(x_2)\right], \cdots, \left[x_n, \mu_{\underset{\sim}{A}}(x_n)\right]\right\} \tag{3}$$

(3) Vector representation

$$\underset{\sim}{A} = \left[\mu_{\underset{\sim}{A}}(x_1), \mu_{\underset{\sim}{A}}(x_2), \cdots, \mu_{\underset{\sim}{A}}(x_n)\right] \tag{4}$$

From the above several representations, it can be seen that the vector representation is the most concise, so in this paper, the vector representation will be used in the future research.

It should be noted that for a fuzzy set $\underset{\sim}{A}$ on an infinite theoretical domain U, it can be written as:

$$\underset{\sim}{A} = \int_{x \in U} \mu_{\underset{\sim}{A}}(x) \big/ x \tag{5}$$

When we extend the operations of classical sets into fuzzy sets, because there does not exist an absolute membership relation between points and sets within fuzzy sets, the definition of their operations can only be determined via the relation that lies between the membership functions.

Let $\underset{\sim}{A}$ and $\underset{\sim}{B}$ be two fuzzy sets on the domain U, define $\underset{\sim}{A} \cup \underset{\sim}{B}$, $\underset{\sim}{A} \cap \underset{\sim}{B}$, $\underset{\sim}{A}^c$ are the fuzzy sets described by the following affiliation functions, respectively:

$$\begin{aligned}&\underset{\sim}{A}(x)\cup\underset{\sim}{B}(x)=\max(\underset{\sim}{A}(x),\underset{\sim}{B}(x))=\underset{\sim}{A}(x)\vee\underset{\sim}{B}(x)\\&\underset{\sim}{A}(x)\cap\underset{\sim}{B}(x)=\min(\underset{\sim}{A}(x),\underset{\sim}{B}(x))=\underset{\sim}{A}(x)\wedge\underset{\sim}{B}(x)\\&\underset{\sim}{A}^c(x)=1-\underset{\sim}{A}(x)\end{aligned}\tag{6}$$

Then each of the above formulas is called a merge, intersection and complement operation of $\underset{\sim}{A}$ and $\underset{\sim}{B}$ respectively. Where $\vee$ means to take the maximum value and $\wedge$ means to take the minimum value. It can be seen that the operation between any two fuzzy sets is actually the corresponding operation between the affiliation of each element of the argument domain U to these two fuzzy sets.

2.1.2 Principle of maximum affiliation

(1) Maximum affiliation principle I: Let the domain $U=\{x_1,x_2,\cdots,x_n\}$ have m fuzzy subsets $\underset{\sim}{A}_1,\underset{\sim}{A}_2,\cdots,\underset{\sim}{A}_m$, which constitute a standard model library, if for any $x_0\in U$, there are $i_0\in\{1,2,\cdots,m\}$ such that

$$\mu_{\underset{\sim}{A}_{i_0}}(x_0)=\max\left\{\mu_{\underset{\sim}{A}_1}(x_0),\cdots,\mu_{\underset{\sim}{A}_m}(x_0)\right\}\tag{7}$$

Then x_0 is considered to be relatively subordinate to $\underset{\sim}{A}_{i_0}$. If there is more than one such i_0, then other criteria should be considered and should not be judged in this way.

(2) Maximum affiliation principle II: Let there be a standard model $\underset{\sim}{A}$ on the domain $U=\{x_1,x_2,\cdots,x_n\}$, and there are n objects to be recognized, $x_1,x_2,\cdots,x_n\in U$. If there is some x_k that satisfies

$$\mu_{\underset{\sim}{A}}(x_k)=\max\left\{\mu_{\underset{\sim}{A}}(x_1),\cdots,\mu_{\underset{\sim}{A}}(x_n)\right\}\tag{8}$$

Then preference should be given to x_k.

The principle of maximum affiliation is characterized by the fact that the given model or library of models is fuzzy, while the object being identified is explicit, and the method of identification using this principle is known as the direct pattern recognition method.

2.2 Application of fuzzy mathematical theory to financial evaluation

2.2.1 Basic elements of fuzzy composite judgments

(1) Establish the set of evaluation factors: $U=\{u_1,u_2,\cdots,u_n\}$

The factor set U consists of each evaluating factor and divides U into several groups

$$U=\bigcup U_i\left(U_i\cap U_j=\varnothing,i\neq j\right)\tag{9}$$

Then there is, the set of sub-factors $U_i=\{u_{i1},u_{i2},\cdots,u_{im}\}$, which are different in each subset.

Thus

$$U=\left\{u_{11},u_{12},\cdots,u_{1n};u_{21},u_{22},\cdots,u_{2n};\cdots;u_{p1},u_{p2},\cdots,u_{pm}\right\} \tag{10}$$

(2) Establishment of comment set: $V=\{v_1,v_2,\cdots,v_n\}$

The comment set is a collection of various evaluation results that the evaluator may make on the factors in the factor set, expressed by $V=\{v_1,v_2,\cdots,v_m\}$. It is actually a division of the change interval of the evaluated object, where v_i represents the i th evaluation result and n is the number of evaluation results.

(3) Establishment of single-factor judgment: each factor is analyzed individually to determine the degree of affiliation of the factor to the evaluation set V, and a fuzzy judgment is made according to the evaluation set, which leads to a fuzzy relationship matrix.

$$\begin{gathered}\tilde{f}:U\to F(U\times V)\\ u_i\mapsto \tilde{f}(u_i)=(r_{i1},r_{i2},\cdots,r_{im})\in F(V)\end{gathered} \tag{11}$$

A fuzzy relation $R_f\in F(U\times V)$ can be induced from $\tilde{f}$, where $R_f(u_i,u_j)=\tilde{f}(u_i)(v_j)=r_{ij}$, and a fuzzy matrix can be constructed from R_f:

$$\underset{\sim}{R}=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n}\\ r_{21} & r_{22} & \cdots & r_{2n}\\ \cdots & \cdots & \cdots & \cdots\\ r_{m1} & r_{m2} & \cdots & r_{mn}\end{bmatrix}$$

2.2.2 Establishment of a fuzzy comprehensive evaluation model

(1) Determine the evaluation factor set and rubric set

Evaluation factor set: $A=\{B_1,B_2,\cdots,B_{i_3},\cdots,B_m\}\ (i=1,2,\cdots,m)$

A is the enterprise financial evaluation set, $B_1,B_2,\cdots,B_{i_3},\cdots,B_m$ is the first level evaluation factor, which consists of $C_1,C_2,\cdots,C_i,\cdots,C_n$ and other specific indexes respectively.

Commentary set: $V=\{V_1,V_2,\cdots,V_k,\cdots,V_n\}\ (k=1,2,\cdots,n)$

Where $V_1,V_2,\cdots,V_k,\cdots,V_n$ denotes the enterprise financial evaluation grade.

(2) Establish the weight assignment vector of m evaluation indexes $\underset{\sim}{A}$

The weights of each main factor layer for the evaluation total objective A constitute the weight set as:

$$\omega=(\omega_1,\omega_2,\cdots,\omega_m)^T \tag{12}$$

where ω_k denotes the weight of indicator B_k on A, $k=1,2,\cdots,m$, and $\sum_{k=1}^{m}\omega_k=1$.

The set of C layer n sub-factor layer indicators under the B_k layer, the single weights of $C_1, C_2, \cdots, C_k$ with respect to the B_k layer $(k = 1, 2, \cdots, m)$, are denoted as $c_1^{(k)}, c_2^{(k)}, \cdots, c_n^{(k)}$, and the set of single weights can be denoted as

$$c^{(k)} = (c_1^{(k)}, c_2^{(k)}, \cdots, c_n^{(k)}), k = 1, 2, \cdots, m \tag{13}$$

where $c_i^{(k)}$ denotes the weight of indicator C_i in B_k, $(i = 1, 2, \cdots, n)$, and $\sum_{i=1}^{n} b_i^k = 1$.

Thereby, a vector $\underset{\sim}{A}$ of weight assignments for the n evaluation factors is established.

2.3 Construction of fuzzy comprehensive evaluation model of enterprise finance

2.3.1 Selection of financial indicators

Due to the relatively weak theoretical foundation of financial early-warning systems and the lack of specific economic theory direction when selecting variables, it is difficult to comprehensively describe the condition by only using a small number of simple financial ratios. In general, many different variables are selected to represent different aspects of the financial situation of companies which have gone public. But, some among these financial indexes are either not practical or not cost-efficient, hence they therefore have difficulty in completing the early-warning function that they were designed for. Therefore, in accordance with the above-mentioned indicator selection principles and indicator analysis, after having discussions with related experts, the impact assessment indicators are respectively inspected and screened. In the end, a comprehensive appraisal indicator system that has universal meaning is constructed, which is composed of a number of valid indicators. These measurement indexes mainly reflect the four aspects of an enterprise's financial condition. To speak specifically, we have 15 financial target indexes in four big aspects: ability of paying debt, operation level, ability of making profit, and potential for growing. Based on above content, a structure-good and theory-valid three-layer frame of the financial evaluation index system is built, which is shown in Figure 2.

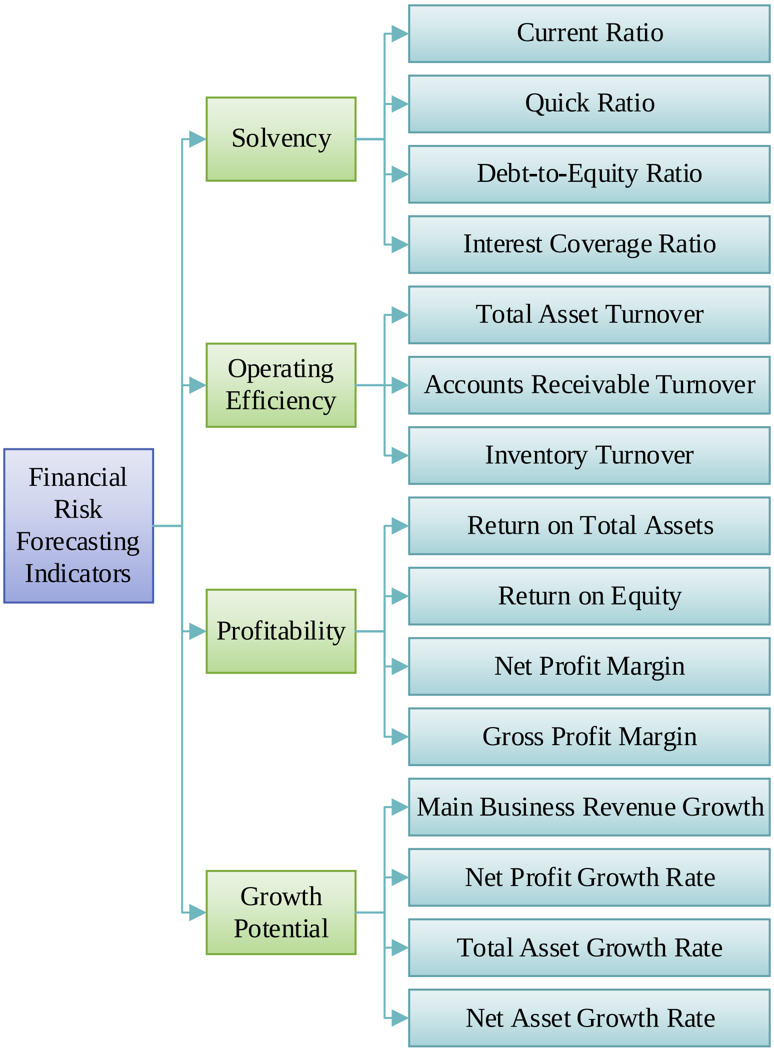


Figure 2: Financial evaluation index system

In a statistical sense, the contribution of each indicator in the indicator set to the overall variance varies, and retaining indicators in the indicator set that contribute very little makes the indicator set more redundant.The goal of principal component analysis lies in decreasing the redundantness inside the group of indicators. This target is reached through gettiCarry out the elimination for those indicators which possess a minimal influence upon the overall variance. Main constituent analysis makes great effort to find a newly made group of variables by means of orthogonal transformation. This new group of variables is a linear combination which comes from the original variables (in this situation, the indexes that are in the starting index system). Generally speaking, the quantity of these newly added variables is smaller than the quantity of the original variables. But, these components can by the biggest feasible degree reflect the information that original variables carry, hence they also at the same time have no mutual correlation. This research paper utilizes principal component analysis in the selection of the final 10 financial appraisal indicators. These indexes are listed below: the current ratio, the acid-test ratio, the debt-to-equity ratio, the total asset turnover rate, the inventory turnover rate, the return on total assets, the return on net assets, the net profit ratio, the net profit increase rate, and the total asset increase rate.

2.3.2 Determine the evaluation object set, factor set and rubric set

(1) Object set $O = \left\{ \begin{array}{l} \text{Debt-paying capacity, operational capability,} \\ \text{profitability, development potential} \end{array} \right\}$

Where O denotes the set of corporate financial evaluation objects, and solvency, operational capability, profitability, and development capability are the first level of evaluation factor level.

(2) Factor set

Set $A = \{A_1, A_2, \cdots, A_n\}$, for the n main factors constitute the evaluation of the main factor level indicator set, this paper takes $n = 4$, the evaluation of the total target for A.

1) With solvency as the evaluation object, the indicators it contains are the factor set.

$$A_1 = \{A_{11}, A_{12}, A_{13}\} \tag{14}$$

where A_{11} is the current ratio, A_{12} is the quick ratio, and A_{13} is the gearing ratio.

2) Taking operating capacity as the object of evaluation, the indicators it contains are the set of factors.

$$A_2 = \{A_{21}, A_{22}\} \tag{15}$$

where A_{21} is the total asset turnover ratio and A_{22} is the inventory turnover ratio.

3) Taking profitability as the object of evaluation, the indicators it contains are the set of factors, the

$$A_3 = \{A_{31}, A_{32}, A_{33}\} \tag{16}$$

where A_{31} is the return on total assets, A_{32} is the return on net assets, and A_{33} is the net profit margin.

4) Taking the development capacity as the object of evaluation, the indicator it contains is the factor set that

$$A_4 = \{A_{41}, A_{42}\} \tag{17}$$

where A_{41} is the growth rate of net profit and A_{42} is the growth rate of total assets.

(3) Comment set

Assume that the fuzzy evaluation result of each financial index of the enterprise is V, and that

$$V = \{v_1, v_2, v_3, v_4, v_5\} = \{\text{Excellent, Good, Medium, Average, Poor}\} \tag{18}$$

2.3.3 Determination of indicator weights

(1) Delphi method for determining subjective weights

The Delphi method is a exploring way that depends on the knowledge, sharp judgment, special skill, information, and rules of a crowd of experts. Its goal is to carry out an analysis, make judgments, do assessments, and distribute appropriate weights to the previously set evaluation metrics. At the beginning, the put-forward overall evaluation frame, together with the particulars of the standards for assessing the assessment indicators and the danger degree, is sent out through letter communication.

Experts are required to assess the weight values of every index on the basis of their own personal judgment of the indexes' comparative importance and in accordance with the stipulated scope of digit values (generally any value in the $[0,1]$ interval). After the experts' opinions are returned, the organizer will process the data of the experts' opinions to check the degree of concentration, dispersion and coordination of the experts' opinions, and after meeting the requirements, the initial weight vector of each evaluation indicator will be obtained:

$$\bar{w}_{ij} = \frac{1}{S}\sum_{j=1}^{S} w_{ij} \left(i = 1, 2, \cdots, n\right) \tag{19}$$

where: $\bar{w}_{ij}$ is the mean of the weights obtained for the i th indicator;

w_{ij} is the value of weights assigned by the j th expert to the i th indicator;

S is the number of experts.

Normalized as:

$$w = \left(\bar{w}_1 \Big/ \sum_{i=1}^{n} \bar{w}_i \, , \bar{w}_2 \Big/ \sum_{i=1}^{n} \bar{w}_i \, , \cdots, \bar{w}_n \Big/ \sum_{i=1}^{n} \bar{w}_i \right) \tag{20}$$

The acquisition of indicators in this paper mainly adopts the expert scoring method, which is carried out through questionnaires, individual interviews, conversations and other ways to quantify the information obtained. This paper adopts the form of questionnaire to obtain the information of the indicators, for each questionnaire, after the respondents fill out the questionnaire, in accordance with the choice of the respondents, the information obtained will be converted into data, A-5 points, B-4 points, C-3 points, D-2 points, E-1 points, the total of the scores of the various issues that is, the scores of each questionnaire, and then seek out the scores of the various surveyed personnel scoring the arithmetic Then the arithmetic mean of the scores of each respondent can be found.

(2) Clustering processing of weights

1) Ming's distance

There are n samples $X_{ij}, i = 1, 2, \cdots, n$, and m indicators $Y_j, j = 1, 2, \cdots, m$. Each sample has observations for these m indicators. For example, the observation values of the i-th sample are $X_{i1}, X_{i2}, \cdots, X_{im}$. Considering the n samples as n points in an m-dimensional space, the similarity degree between two samples can be measured by the distance between two points in the m-dimensional space. Let d_{ij} represent the distance between samples X_i and X_j. The Minkowski distance is defined as:

$$d_{ij}(q) = \left[\sum_{k=1}^{m} \left| x_{ik} - x_{jk} \right|^{q} \right]^{1/q} \left(i, j = 1, 2, \cdots, n\right) \tag{21}$$

When $q = 1$, the Minh's distance becomes an absolute distance:

$$d_{ij}(1) = \sum_{k=1}^{m} \left| x_{ik} - x_{jk} \right| \left(i, j = 1, 2, \cdots, n\right) \tag{22}$$

When $q = 2$, the Münch distance becomes the Euclidean distance:

$$d_{ij}(2) = \left[\sum_{k=1}^{m} \left(x_{ik} - x_{jk} \right)^2 \right]^{1/2} \left(i, j = 1, 2, \cdots, n \right) \tag{23}$$

2) Basic steps of cluster analysis

The following steps should be followed for cluster analysis:

(A) In order to put the data together for comparison, the data shall be subjected to transformation process. In the process of analysis, standard transformations are applied to the data, viz:

$$x'_{ij} = \frac{x_{ij} - \bar{x}_j}{S_j} \ (i = 1, 2, \cdots, n; \ j = 1, 2, \cdots, m) \tag{24}$$

where: $\bar{x}_j = \frac{1}{n} \sum_{i=1}^{n} x_{ij}$;

$$S_j = \frac{1}{n-1} \left[\sum_{i=1}^{n} \left(x_{ij} - \bar{x}_j \right)^2 \right]^{1/2} \tag{25}$$

(B) Starting with each sample in a class of its own, d_{ij} is its distance, and let the minimum non-zero distance between classes G_i and G_j be $D_{pq}, D_{pq} = \min d_{ij}$, and D is called the distance matrix, noting that $d_{ii} = 0$, $d_{ij} > 0$.

$$D = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ d_{n1} & d_{n2} & \cdots & d_{nn} \end{bmatrix} \tag{26}$$

(C) Combining the classes G_p and G_q into a new class, denoted G_r, the distance between any class G_k and G_r is:

$$\begin{aligned} D_{kr} &= \min d_{ij} \quad X_i \in G_k, X_j \in G_r \\ &= \min \left\{ \begin{matrix} \min d_{ij} & \min d_{ij} \\ X_i \in G_k, X_j \in G_p & X_i \in G_k, X_j \in G_q \end{matrix} \right\} \\ &= \min \left\{ D_{kp}, D_{kq} \right\} \end{aligned} \tag{27}$$

(D) Repeat (B) and (C) until all elements are merged into one class.

(E) If there is more than one non-zero smallest element in a step, the classes corresponding to these smallest elements can be merged at the same time.

(3) Entropy method for determining weights

The relative importance of evaluation indicators can be used to assign weights to the indicators, entropy can be used to measure the amount of information, and can measure the useful information provided by the acquisition of data.

There are m evaluation indicators, n evaluation objects, according to the principle that combines qualitative and quantitative methods, one group of objects which are connected with the multi-index evaluation matrix is gotten.

$$R' = \begin{bmatrix} r'_{11} & r'_{12} & \cdots & r'_{1n} \\ r'_{21} & r'_{22} & \cdots & r'_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ r'_{m1} & r'_{m2} & \cdots & r'_{mn} \end{bmatrix} \tag{28}$$

Obtained by normalizing R':

$$R = (r_{ij})_{m\times n} \tag{29}$$

In the formula, r_{ij} is called the value of the j th evaluation object on the index of i, and $r_{ij} \in [0,1]$, and

$$r_{ij} = \frac{r'_{ij} - \min_j \left\{ r'_{ij} \right\}}{\max_j \left\{ r'_{ij} \right\} - \min_j \left\{ r'_{ij} \right\}} \tag{30}$$

After this, the entropy which is connected with the evaluation measures is stipulated to be the entropy of the i-th evaluation measure inside an assessment problem that includes m evaluation measures and n assessment objects.

$$H_i = -k \sum_{j=1}^{n} f_{ij} \ln f_{ij} \quad i = 1, 2, \cdots, m \tag{31}$$

Eq:

$$f_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}} \tag{32}$$

$$k = \frac{1}{\ln n} \tag{33}$$

When $f_{ij} = 0$, $f_{ij} \ln f_{ij} = 0$.

In the (m, n) evaluation problem, the entropy weight ω_i of the i th indicator is defined as:

$$\omega_i = \frac{1-H_i}{m-\sum_{i=1}^{m} H_i} \tag{34}$$

According to the above-mentioned definition and the features of the entropy function, therefore, we can obtain the following properties of the entropy weight.

1) When the numerical values of each evaluated entity upon a specific indicator are exactly the same, the entropy value reaches its maximum value which is 1, hence the entropy weight turns into zero. This just means that the indicator cannot provide any useful message to the person who makes decisions. Therefore, this indicator may be regarded as suitable to be eliminated.

2) When the values of each evaluated object on the indicator j differ from each other, the entropy value is small, and the entropy weight is large, it means that the indicator provides useful information to the decision maker. It also indicates that there is a significant difference between the objects on the indicator in the question, which should be focused on.

3) The larger the entropy of the indicator and the smaller its entropy weight, the less important the indicator is and the satisfaction of the

$$0 \le \omega_i \le 1 \text{ And } \sum_{i=1}^{m} \omega_i = 1 \tag{35}$$

4) This is not an importance coefficient that possesses the real meaning for a specific indicator in a decision-making or evaluation situation. On the contrary, it expresses a coefficient which shows the relative strength of every indicator in one competitive situation. This context is what a given group of objects that are being evaluated and the pre-decided values of many evaluation indicators together decide.

5) When we carry out examination from an informational angle, it therefore shows the extent to which this indicator provides valuable data inside the problem-related context.

6) The big degree of the entropy weight is directly connected with the object that is being evaluated. After the evaluation object has been confirmed, the adjustments, which are either increases or decreases, are carried out on the basis of the entropy weight that the evaluation index possesses. This behavior is carried out for the purpose of conducting a more precise and reliable assessment. At the same time, the entropy weight can be utilized by people to carry out fine adjustment on the accuracy of the evaluation numerical values of the specific indexes. If it is demanded, new evaluation numerical values and precision grades can be re-set up again.

3 Analysis of the application of multidimensional comprehensive evaluation model of financial indicators based on fuzzy mathematics

In this paper, the financial statement data of Company A in a manufacturing industry from 2020 to 2024 are selected as the object of applied research to conduct a comprehensive financial evaluation.

3.1 Calculation of expert composite weighting factors

Ten experts (numbered E1 to E10) rated the importance of the financial position based on solvency, operational capacity, profitability and development capacity. The result of expert scoring is based on a 1-point system, i.e., the sum of the results of each expert's scoring on the importance of the four indicators is 1.

In this research paper, the method of angle cosine is utilized by us to calculate the matching degree between experts. Concretely speaking, the angle cosine of the entropy weight vectors from two experts is used as an index which shows the similarity degree of their objective weight coefficients. When the angle which is between two vectors gets smaller, this means that the two vectors are closer to one another. Therefore, the computation-obtained cosine numerical value becomes more close to 1. This circumstance shows that the difference between the experts is smaller, and their views are more in consistency with each other. On the contrary, it means the higher degree of divergence of opinions between experts. The calculated expert entropy weight vector clip angle cosine value is shown in Table 1. It can be seen that the entropy weight vector angle cosine values of all experts are above 0.9. L2R1=0.9387 indicates that the entropy weight vector angle cosine value of expert E2 and expert E1 is 0.9387, L3R1=0.9802 indicates that the entropy weight vector angle cosine value of expert E3 and expert E1 is 0.9802, and so on.

Table 1: Cosine of the Angle between the expert entropy weight vectors

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
R1	1	0.9387	0.9802	0.9314	0.9662	0.9603	0.9828	0.9441	0.9402	0.9963
R2		1	0.9524	0.9901	0.9425	0.9897	0.9736	0.9912	0.9989	0.9487
R3			1	0.9378	0.9624	0.9805	0.9902	0.8937	0.9332	0.9756
R4				1	0.9903	0.9917	0.9682	0.9552	0.9793	0.9361
R5					1	0.9724	0.9794	0.8783	0.9126	0.9402
R6						1	0.9772	0.9601	0.9931	0.9611
R7							1	0.9454	0.9498	0.9824
R8								1	0.9892	0.9637
R9									1	0.9445
R10										1

Carry out categorization on the values of the clip angle of the entropy weight vector that is presented in Table 1. The concrete step-by-step procedures are as follows.

(1) Inside the table, if we do not count the value of 1, the value that is highest is 0.9989. This numerical result can be obtained in the unit cell which lies at the intersecting place of the L9 column and the R2 row. This result shows that among all experts, E9 and E2 have the maximum degree of compatibility. E9 together with E2 are divided by us into the new category which is called G1. Furthermore, all the remaining numerical values in the column L9 and the row R9 have already been marked out.

(2) In the table with L9 columns and R9 rows removed, find the remaining maximum value of 0.9963, located in L10R1, representing the highest compatibility between E10 and E1 among the remaining data, assign E10 and E1 to the new class G2, and cross out all the remaining numbers in L10 columns and R10 rows.

(3) In the table with L9 columns and R9 rows and L10 columns and R10 rows removed, look for the remaining maximum value of 0.9917, located in L6R4, which represents that among the remaining data, E6 and E4 have the highest compatibility, assign E6 and E4 to the new class G3, and cross out all the remaining digits in L6 columns and R6 rows.

(4) Look for the remaining maximum value of 0.9912 in the table, located in L8R2, representing that of the remaining data, E8 and E2 have the highest compatibility, and since E2 is already in G1, form E8 and G1 into a new class G4, and cross out all the remaining digits in column L8 and row R8.

(5) Find the remaining maximum value of 0.9903 in the table, located in L5R4, which

represents the highest compatibility between E5 and E4 among the remaining data, and since E4 is already in G3, form a new class G5 from E5 and G3, and cross out all the remaining digits in column L5 and row R5:.

(6) In the same way as in the above steps, all experts are sequentially grouped in different clusters.

(7) In the end, a cluster G9 which contains all the experts is got formed. The detailed step order of cluster analysis which this paper gives is shown in Table 2.

Table 2: Specific order of cluster analysis

Join order	Maximum cosine value	Position	Corresponding expert and join step	Cross out rows and columns
1	0.9989	L9R2	G1={E9,E2}	L9+R9
2	0.9963	L10R1	G2={E10,E1}	L10+R10
3	0.9917	L6R4	G3={E6,E4}	L6+R6
4	0.9912	L8R2	G4={E8,G1}	L8+R8
5	0.9903	L5R4	G5={E5,G3}	L5+R5
6	0.9902	L7R3	G6={E7,E3}	L7+R7
7	0.9901	L4R2	G7={G3,G1}	L4+R4
8	0.9802	L3R1	G8={G6,G2}	L3+R3
9	0.9387	L2R1	G9={G1,G2}	/

In this paper, according to the association order and removal order in Table 2, we keep searching for the remaining maximum angle cosine values in the cosine value matrix table, which can realize the clustering and grouping by vector similarity. The associated two experts corresponding to the numbers of rows and columns where the cosine values are found are the experts with the highest compatibility at present, and the two experts are divided into the same cluster, and then the experts corresponding to the maximum compatibility at the present time are removed from the table, and the experts are constantly associated and clustered. Setting different threshold values T, different ways of expert clustering grouping can be obtained. Therefore, in this paper, we take the threshold value T=0.03 to divide 10 experts into 3 clusters, and finally group all experts into a total grouping result as shown in Fig. 3. The total clustering G={G4,G5,G8}, where G4={E2,E8,E9}, G5={E4,E5,E6} and G8={E1,E3,E7,E10}.

Figure 3: Expert clustering results

According to the definition of cluster analysis, the more experts are included in a cluster, the more the cluster represents the opinion of the majority of the experts, and therefore the experts in the cluster should be given a larger weight, and vice versa a smaller weight. To calculate the weights of different clusters, the difference in compatibility of the experts, as well as the difference in compatibility of the clusters, needs to be calculated first.

3.2 Comprehensive weighting results

According to the comprehensive weight coefficients of experts that are obtained through clustering, the entropy weight method is utilized to assign weights to the financial indexes. After that, the overall weight values of the 10 financial evaluation indexes are calculated, and the outcome results are shown in Table 3. Through overall calculation of the decision-making results which come from the expert clustering, the weight coefficients for debt paying ability, operation ability, profit making ability, and development potential are 0.365, 0.204, 0.144, and 0.287 each.

Table 3: Comprehensive weight results of 10 financial evaluation indicators

Dimension	Index	Weight	
Solvency	Current ratio	0.103	0.365
	Quick ratio	0.108	
	Debt-to-Equity ratio	0.154	
Operating Efficiency	Total asset tumover	0.109	0.204
	Inventory tumover	0.095	
Profitability	Return on total assets	0.047	0.144
	Retum on equity	0.055	
	Net profit margin	0.042	
Growth potential	Net profit growth rate	0.138	0.287
	Total asset growth rate	0.149	

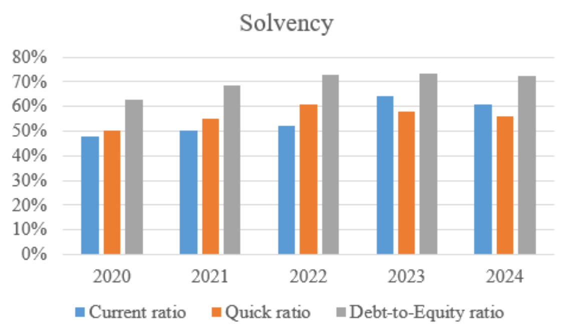
3.3 Calculation of financial indicators

According to the data of Company A's annual report, the financial data from 2020 to 2024 are sorted and selected, and the organized financial data are shown in Table 4.Company A's operating income reaches a trough of RMB 3637,284,000 yuan in 2021 and then rises, and reaches 4088,362,000 yuan in 2024. Synchronized rise in total operating costs eroding margins. Selling expenses stabilize after significant growth in 2022, while administrative expenses continue to increase. Finance costs will fall after reaching a high point in 2022. Overall, the company's revenue maintains growth, but cost control pressure remains, further affecting its profitability.

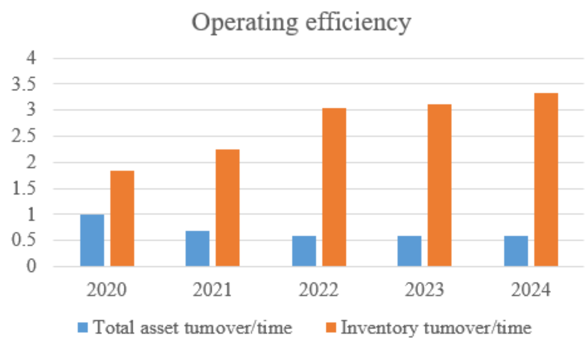
Table 4: Financial data of Company A from 2020 to 2024(Ten thousand yuan)

Key financial data	2020	2021	2022	2023	2024
Operating income	4048473	3637284	3788372	3928644	4088362
Operating cost	3627522	3284763	3386224	3586262	3788621
Selling expense	735	1255	6935	5725	6018
Administrative expense	125864	144257	183751	173659	178893
Financial expense	38275	51863	49276	46275	40184
Operating profit	98473	99018	103772	108365	110937
Non-operating income	9864	20463	13863	14772	15035
Non-operating expenditure	1455	2008	2864	4937	5018
Total profit	128643	133856	134725	132754	130048
Net profit	70386	76463	88462	90463	92756
Total assets	4028642	5375224	6275335	6775532	6904861
Total liabilities	3675224	4736243	5327546	5685311	5903725

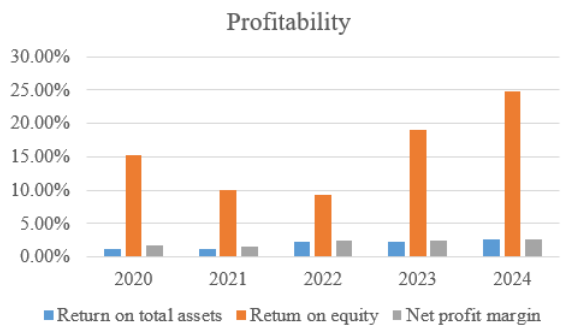
By utilizing the data, the numerical values of the financial assessment indices are further calculated, which are shown in Figure 4(a~d). With regard to its debt-paying capacity, the financial stability of Company A on the whole is comparatively strong. The current ratio and quick ratio show a changing but getting better tendency. With respect to the operational efficiency, the total asset turnover rate has decreased from 1.01 times in 2020 to 0.59 times in 2024. On the opposite side, the inventory turnover ratio has a very big promotion, it increases from 1.83 times to 3.34 times. This shows that the efficiency on asset use of Company A is in a downward trend, but the management of its inventory has obtained good effect.With respect to profit making ability, the rate of return on net assets, net sales profit margin, and net profit increasing rate all display a positive tendency that first has decrease and then has increase. It is worth pointing out that, in the time scope between 2023 and 2024, the rising degree is quite obvious. On the opposite side, the ability of development shows obvious undulating changes. The increase speed of whole assets shrank by -1.38% in the year 2023 but bounced greatly to 36.26% in 2024.



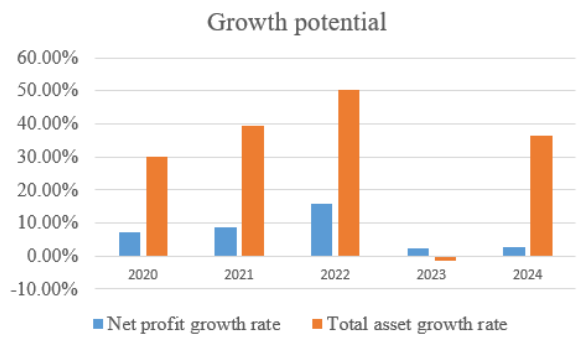
(a)Solvency



(b)Operating efficiency



(c)Profitability



(d)Growth potential

Figure 4: Values of financial evaluation indicators

3.4 Fuzzy synthesized evaluation results

3.4.1 Determining the degree of affiliation

The highest and lowest values of the industry can be calculated for each evaluation level, on the basis of which the degree of affiliation of each indicator is determined. As mentioned earlier, this paper defines the evaluation set in the financial risk evaluation of Company A as V={v1, v2, v3, v4, v5}={excellent, good, medium, average, poor}.

When the actual value of the indicator falls between the standard values corresponding to the two evaluation set elements, we cannot accurately evaluate the indicator's affiliation with any of the evaluation set elements, but can only evaluate the likelihood of the indicator's affiliation with any of the two evaluation set elements (degree of affiliation). The closer the actual world numerical magnitude of an index approaches to the norm numerical magnitude of a component inside an assessment group, the greater the degree of connection of that index with that specific assessment-group component. In the following is a depiction concerning the profit-making ability of Company A within the year 2024. Table 5 shows the calculation results for the correlation degree of each index which is related to its profit ability. It can be seen that the profitability of Company A has the highest probability that the return on total assets and the return on net assets belong to the medium level, while the net profit margin has the highest probability that it belongs to the good level. Similarly, Company A's solvency, operating capacity and development capacity can also be calculated in the same way to obtain the degree of affiliation of each indicator.

Table 5: The membership calculation results of each index

	v1	v2	v3	v4	v5
Return on total assets	0	0.3	0.7	0	0
Retum on equity	0	0	0.8	0.2	0
Net profit margin	0	0.6	0.4	0	0

3.4.2 Analysis of the results of the comprehensive evaluation

Further calculations yielded the affiliation of the level 1 indicators under each evaluation indicator as shown in Table 6. Company A has the highest probability of being considered to have good, medium, moderate and good levels of solvency, operational capacity, profitability and development capacity respectively.

Table 6: The membership of the first-level indicators under each evaluation indicator

	Weight coefficient	v1	v2	v3	v4	v5
Solvency	0.365	0.09	0.45	0.25	0.21	0
Operating efficiency	0.204	0	0.09	0.56	0.32	0.03
Profitability	0.144	0.11	0.27	0.58	0.04	0
Growth potential	0.287	0.18	0.39	0.16	0.14	0.13

When we carry out the second-stage fuzzy comprehensive assessment work, the overall financial evaluation result of Company A in the year 2024 obtains a value of Z = 65.19. This hereby shows that the financial condition of this company is located in a moderate level. To speak specifically, both the working ability and the money-gaining ability bring about relatively higher risks. In these aspects, the ability that earns profit has the biggest possibility of bringing financial risks to Company A.

4 Conclusion

This present research carries the integration of actual reality situations of publicly listed companies in China. This article selects 12 indexes which can reflect an enterprise’s ability of paying debt, operation abilities, profit making possibility, and growth possibility to carry out deep analysis on the enterprise’s financial situation. After that, a financial early-warning model which is based on fuzzy comprehensive assessment is built. Furthermore, the real-world actual cases are utilized by us to verify the effect of this model.

(1) A team of ten specialists who participate in decision-making have ascertained the weight

coefficients for debt paying ability, operation ability, profit obtaining ability, and development potential. They by themselves have set these coefficients to be 0.365, 0.204, 0.144, and 0.287, each one respectively.

(2) On the whole, Company A has abundant short-term liquidity, locally optimized operating capacity, and steadily improving profitability, but we need to pay attention to the stability of financial elasticity and growth quality under the high debt level.

(3) The financial appraisal value of Company A in 2024 is 65.19, which belongs to the medium level, and there is a large risk in Company A's operating ability and profitability.

About the Author

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