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Research Article

Grading Prediction of Enterprise Financial Crisis Based on Nonlinear Programming Evaluation: A Case Study of Chinese Transportation Industry

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As the core of the effective financial crisis prevention, enterprise finance crisis prediction has been the focal attention of both theorists and businessmen. Financial crisis predictions need to apply a variety of financial and operating indicators for its analysis. Therefore, a new evaluation model based on nonlinear programming is established, the nature of the model is proved, the detailed solution steps of the model are given, and the significance and algorithm of the model are thoroughly discussed in this study. The proposed model can deal with the case of missing data, and has the good isotonic property and profound theoretical background. In the empirical analysis to predict the financial crisis and through the comparison of the analysis of historical data and the real enterprises with financial crisis, we find that the results are in accordance with the real enterprise financial conditions and the proposed model has a good predictive ability.

1. Introduction

Transportation, as a basic part of the integrated economic system, plays a pivotal role in the development of every country. China's transportation industry is now also facing some problems. For example, the financial management level of the transport organization is not high, resulting in the hardships in the operation of the transportation companies [1]. To solve these problems, the enterprise financial crisis prediction in the transportation industry has been the focal attention of both theorists and businessmen.

Meanwhile, the stock market is the "barometer" of the economy. Therefore, the sound and orderly development of the listed transportation companies is important in China's economy. Transportation, a basic industry in every nation, was badly affected in the world financial crisis of 2008. Therefore, it has become significant to predict the financial crisis of listed Chinese transportation companies. An empirical study in the related field can also contribute to the transportation research worldwide.

In order to effectively prevent the enterprise financial crises, experts, scholars, and practitioners have been very interested in the tools that can predict business failures. Based on the in-depth analysis of the theory and the practice of enterprise financial crisis prediction in the Chinese transportation industry, we establish a new enterprise financial crisis prediction model based on the method of nonlinear programming evaluation and conduct the empirical research.

2. Literature Review

The literature on the enterprise financial crisis prediction is very rich. Experts and scholars have done a large number of quantitative researches on enterprise financial crisis since the 1930s [2] and many theoretical studies and empirical studies have emerged in this field [3–6]. In general, the study and the investigation of the financial crisis prediction methods develop from the univariate analysis to the multivariate prediction, from the traditional statistical methods to the statistical analysis based on artificial intelligence. Specifically since the 1980s, along with the rapid development of the computer technology, the advantages of artificial intelligence technology have become prominent and have been successfully broadened and applied to the financial crisis prediction,

and there are a great number of empirical studies of the prediction methods, including the statistical methods based on accounting and the artificial intelligence methods based on data mining. The former includes the univariate analysis (UA) [7], multivariable discriminate analysis (MDA) [8], logistic regression (LR) [9], multivariate probability regression (Probit) [10], and optimality theory (OT). Nonlinear programming, as a part of OT, has been widely applied to various fields of operations researches and management science. Strictly speaking, the above listed MDA, LR, and Probit are essentially a kind of OT, because the solution of the model is ultimately based on the optimization equation. However, the prediction directly based on the optimization methods was not common until Hochbaum published a series of papers in management science and operations management to build an SDM model to solve this kind of problem. Based on the definitions of bias and offsets, the author established a polynomial time solvable composite optimization model and applied it for the customers' adoption behavior [11], financial institution risk assessment [12], resource optimization deployment [13], and so forth.

It can be found through the literature study and comprehensive review of the financial crisis prediction methods that we must overcome the shortcomings of the traditional models so as to build a scientific, fast, and effective model for the enterprise financial crisis prediction, the top priority of which is to learn from the strong points of each model and build an accurate and isotonic model.

3. Methodology

3.1. Nonlinear Programming Evaluation Model. Nonlinear programming (NLP) is the process of solving an optimization problem defined by a series of equalities and inequalities, collectively termed constraints, over a set of unknown real variables, along with an objective function to be maximized or minimized, where some of the constraints or the objective functions are nonlinear. In the nonlinear programming evaluation model, it is necessary to obtain the unknown variables $x_1, x_2, \ldots, x_n$ and ensure that they can meet the following constraints. The general nonlinear optimization problem (NLO) can be stated simply as $\max_{x\in X} f(x)$ to maximize some variables such as product throughput or $\min_{x\in X} f(x)$ to minimize a cost function where $f : R^n \to R$, $x \in R^n$, subject to

$$h_i(x) = 0, \quad i \in I = 1, \ldots, p \tag{1}$$

$$g_i(x) \le 0, \quad j \in J = 1, \ldots, m, \tag{2}$$

where $f(x)$: scalar objective function; x: n vector of variables; $g(x)$: inequality constraints, m vector; $h(x)$: meq equality constraints.

f, g_i, and h_j are,respectively, defined as the function of R_n in the n-dimensional vector space, and there needs to be at least one nonlinear function. The model can be summarized as

$$\begin{aligned} \min_{x\in X} \quad & f(x) \\ \text{s.t.} \quad & g_i(x) \ge 0 \quad i = 1, \ldots, m \\ & h_j(x) = 0 \quad j = 1, \ldots, p. \end{aligned} \tag{3}$$

In Formula (3), $x = (x_1, \ldots, x_n)$ is the constraint in the definition domain D and s.t. represents the constraint relationship. In the domain D, the final result to satisfy the constraints is the feasible solution. The set made up of all the feasible solutions is the feasible set of the issue. In the feasible solution x^*, $f(x^*)$ is the value of the objective function at x^* if there is a neighborhood domain x^*. And x^* will be the local optimal solution if $f(x^*)$ is significantly better than the other feasible solutions. Similarly, if $f(x^*)$ is significantly better than the values of all the other feasible solutions, x^* will be the overall optimal solution of the issue. In the practical nonlinear programming, it is necessary to obtain the overall optimal solution. Convex programming is different from other types of nonlinear programming in the classification. In the above nonlinear programming mathematical models, if f is a convex function, then all the g_i are concave functions and all the h_j belong to a convex programming function. f is a convex function so the definition domain of f is definitely a convex, and in the definition domain, x and y are supposed to be the positive number a and less than 1, as shown in the following inequality:

$$f\left((1-a)_x + a_y\right) a \le (1-a) f(x) + af(y). \tag{4}$$

Reverse the inequality mark in Inequality (4), and we are able to generalize the definition of the convex set, that is, the set of the straight lines to link any of the two points.

In order to clearly describe the two properties, that is, the ordering of the present indicators and the similarities between the evaluation results and value of the indicators, we, firstly, build the following nonlinear programming model:

$$\begin{aligned} \min_{x,z} \quad & \sum_{k=1}^{M}\sum_{i=1}^{N}\sum_{j=i+1}^{N} f_{ij}^k\left(z_{ij} - p_{ij}^k\right) + \sum_{k=1}^{M}\sum_{i=1}^{N} g_i^k\left(x_i - r_i^k\right) \\ \text{s.t.} \quad & z_{ij} = x_i - x_j \quad (i = 1, 2, \ldots, N; j = i+1, \ldots, N) \\ & p_{ij}^k = r_i^k - r_j^k, \end{aligned} \tag{5}$$

where N represents the number of the enterprises, M represents the number of the indicators, and functions f and g are convexes that meet the conditions that the values of the two functions are zero at the point of zero; that is, $f(0) = g(0) = 0$.

The comprehensive evaluation model reflects the following significances.

(1) The constraints express the consistency of the evaluation results; that is, there is never the contradiction logical structure $A > B > C > A$. In fact, the following characteristics can be found in the constraints. If $x_1 > x_2$, then $x_1 > x_3$ because, from the constraint conditions, we can obtain $z_{13} = z_{12} + z_{23}$; where there is $z_{12} > 0$, $z_{23} > 0$, there is $z_{13} > 0$.

Table 1: Indicator values of a counterexample.

	Indicator 1	Indicator 2
Enterprise 1	2	3
Enterprise 2	3	4

(2) The first term of the objective function reflects the consistency degree of the comprehensive evaluation results of the model and the order of the initial information. If they are inconsistent, this part will play a role of punishment.

(3) The second term of the objective function reflects the gap between the evaluation scores and the indicator values, which ensures the consistency between them. In fact, it can be found that, for any transform of x_i, the value of the first term of the objective function will not change. Therefore, in order to ensure that the model has a unique solution, a feasible method is to add the second term of the objective function to limit the scale of the model results.

The discussion of the related properties of the nonlinear programming evaluation model starts with formula (5).

Property 1. The solution of the optimal formula (5) exists.

Proof. Any set of the real numbers x_i can be a solution of the optimal formula (5), so the solution exists. □

Property 2. If the equation is not limited to specific forms, the solution may not be unique for the general form of formula (5).

Proof. A counterexample shown in Table 1 can be the proof. □

Take the absolute value f and g in formula (5), and we can obtain the following nonlinear optimization:

$$\begin{aligned} &\min_{x} |x_1 - 2| + |x_2 - 3| + |x_1 - 3| + |x_2 - 4| \\ &\quad + 2 \cdot |x_1 - x_2 + 1|. \end{aligned} \tag{6}$$

There is no unique optimal solution to this problem, and the following two solutions are the optimal solutions to the initial problem:

$$\begin{aligned} &x_1 = 2.5, \qquad x_2 = 3.5 \\ &\text{or } x_1 = 2.6, \qquad x_2 = 3.6. \end{aligned} \tag{7}$$

Take the absolute value of the above two functions, and get the following programming:

$$\begin{aligned} \min_{x,z} \quad & \sum_{k=1}^{M}\sum_{i=1}^{N}\sum_{j=i+1}^{N} u_{ij}^k \cdot \left|z_{ij} - p_{ij}^k\right| + \sum_{k=1}^{M}\sum_{i=1}^{N} w_i^k \cdot \left|x_i - r_i^k\right| \\ \text{s.t.} \quad & z_{ij} = x_i - x_j \quad (i = 1, 2, \ldots, N; j = i+1, \ldots, N) \\ & p_{ij}^k = r_i^k - r_j^k, \end{aligned} \tag{8}$$

Table 2: Nonisotonic indicator value in formula (8).

	Indicator 1	Indicator 2	Indicator 3
Enterprise 1	1	4	517
Enterprise 2	2	5	3

where u_{ij}^k and w_i^k are the corresponding weights, reflecting the importance degrees of the indicators. Accurately speaking, these two indicators are not related to the individual number i, j, but to k, so they can be written as u^k and w^k who are larger than zero.

Property 3. The first summation term in formula (8) is the following optimization:

$$\begin{aligned} \min_{z} \quad & \sum_{k=1}^{M}\sum_{i=1}^{N}\sum_{j=i+1}^{N} u_{ij}^k \cdot \left|z_{ij} - p_{ij}^k\right| \\ \text{s.t.} \quad & z_{ij} = x_i - x_j \quad (i = 1, 2, \ldots, N; j = i+1, \ldots, N) \\ & p_{ij}^k = r_i^k - r_j^k. \end{aligned} \tag{9}$$

Property 4. The absolute value of the nonlinear programming evaluation model (9) cannot meet the definition of the isotonic nature.

Proof. One case can prove this nature as seen in Table 2. □

Let all the indicators have the same weight, namely, $u_{ij}^k = w_i^k = 1$, solve formula (9), and get the model as

$$\begin{aligned} &\min |x_1 - 1| + |x_2 - 2| + |x_1 - x_2 + 1| + |x_1 - 4| + |x_2 - 5| \\ &\quad + |x_1 - x_2 + 1| + |x_1 - 517| + |x_2 - 3| + |x_1 - x_2 - 514|. \end{aligned} \tag{10}$$

The solution of this equation is $x_1 = 4, x_2 = 3$.

Seen from this property, the initial programming model cannot keep the isotonic nature in the absolute values.

3.2. Improvement of the Nonlinear Programming Evaluation Model. Property 4 reveals that the initial model does not have the isotonic nature, which is a fatal shortcoming for a good nonlinear optimization evaluation model. Therefore, it is necessary to improve and amend the existing model. Therefore, Model (11) is introduced as

$$\begin{aligned} \min_{z} \quad & \sum_{k=1}^{M}\sum_{i=1}^{N}\sum_{j=i+1}^{N} f_{ij}^k \left(z_{ij} - p_{ij}^k\right) \\ \min_{x} \quad & \sum_{k=1}^{M}\sum_{i=1}^{N} g_i^k \left(x_i - r_i^k\right) \\ \text{s.t.} \quad & z_{ij} = x_i - x_j \quad (i = 1, 2, \ldots, N; j = i+1, \ldots, N) \\ & p_{ij}^k = r_i^k - r_j^k. \end{aligned} \tag{11}$$

This model is an optimization model for the multiobjective function. First, we need to solve the optimization of the first objective function and then the second objective function. When the absolute value of Function f is taken, it will be isotonic.

Property 5. For nonlinear programming, formula (11), when we take f as the absolute value function, the formula is isotonic.

Proof. The optimal solution z^* of the first objective function is isotonic. In solving the second objective function, z^* obtained in the first step does not change. The result obtained in the first step meets the following features of the optimal solution of x; that is, if $(x_1^*, x_2^*, \ldots, x_N^*)$ is an optimal solution of the initial issue, then so is $(x_1^* + c, x_2^* + c, \ldots, x_N^* + c)$. Therefore, the second step is equivalent to determine c. This process does not influence the isotonic nature of the first step. Therefore, this multiobjective programming is isotonic. □

In formula (11), we can also take f and g as a quadratic function, and the specific form of formula (11) is as

$$\begin{aligned}
&\min_{z} \quad \sum_{k=1}^{M}\sum_{i=1}^{N}\sum_{j=i+1}^{N} w^k\left(z_{ij} - p_{ij}^k\right)^2 \\
&\min_{x} \quad \sum_{k=1}^{M}\sum_{i=1}^{N} w^k\left(x_i - r_i^k\right)^2 \\
&\text{s.t.} \quad z_{ij} = x_i - x_j \quad \left(i = 1, 2, \ldots, N; j = i+1, \ldots, N\right) \\
&\qquad p_{ij}^k = r_i^k - r_j^k.
\end{aligned} \tag{12}$$

In formula (12), it is in line with most of the modeling features that the coefficients of the two optimization objective functions are the same; namely, the coefficients reflect the weights of the corresponding indicators.

In this objective constraint, we can get a weighted average result, which also shows the generality of this model; that is, it includes the evaluation with a weighted average.

3.3. Characteristics of the Nonlinear Programming Evaluation Model. Based on the theoretical and comparative analysis above, the nonlinear programming evaluation model has the following three obvious characteristics.

(1) Broad Applicability. This model can be applied to the situations with or without preferences, with specific evaluation values, or with the missing data.

(2) Rigorous Theoretical Basis. The proposed objective function directly indicates the isotonic nature and the scope of the controlled variables, making the model more consistent with the existing evaluation criteria. The properties of the model are fully discussed in this study.

(3) Less Space Complexity. Compared to the existing evaluation methods, such as Graph Model [14], the proposed method has a less space complexity, so the above nonlinear programming evaluation problem can be solved by the polynomial algorithm in Matlab 2008.

4. Empirical Analysis of Grading Financial Crisis Prediction Evaluation Model Based on Nonlinear Programming

4.1. Data Collection and Index Construction. The essence of the grading prediction of enterprise financial crisis is to characterize the nature of the financial crisis with a number of complex and various indicators to grade a group so as to get different scores and thereby delineate different grades. In this study, we learn from the existing literature of the weight determination of financial indicators and introduce the concept of Trailing Twelve Months (TTM) in addition to the traditional typical financial indicators. We use the improved fuzzy analytic hierarchy process (FAHP) to filter out small fluctuations automatically, to reflect the true enterprise financial positions, and to get the objective and normalized results.

As listed companies are the interest focus of the Chinese society, the financial data of the listed companies are comparable, open, and normal. Therefore, it is feasible to select the listed companies as a research object. In this study, the listed companies of A Share in Shanghai and Shenzhen Stock Exchange are selected as the main sources of data. Based on the industry representation and the asset size, 40 valid samples are selected from the latest annual report of 2009 and 2010 from the authoritative security websites like Sohu Security (available at http://stock.sohu.com/gegufengyun/).

Based on the definition of financial crisis and the previous researches, this study establishes an objective and rational index system for the financial crisis prediction model. The selected financial indicators are Assets Operation Ability (X_1), including Inventory Turnover (X_{11}), Receivables Turnover Ratio (X_{12}), Current Assets Turnover (X_{13}), Fixed Assets Turnover (X_{14}), and Total Assets Turnover (X_{15}); Debt-paying Ability (X_2), including Current Ratio (X_{21}), Acid-test Ratio (X_{22}), Debt Asset ratio (X_{23}), and Ratio of Cash to Current Liability (X_{24}); Profitability (X_3), including Average ROE (X_{31}), ROE TTM (X_{32}), ROA TTM (X_{33}), Net Profit Ratio TTM (X_{34}), and Net Profit/TOR TTM (X_{35}); Development (X_4), including EPS Growth Rate (X_{41}), Dilute EPS Growth Rate (X_{42}), Increase Rate of Main Business Revenue (X_{43}), Operating Profit Growth Rate (X_{44}), Total Profit Growth Rate (X_{45}), and Net Profit Growth Rate (X_{46}); and Market (X_5), including EPS (X_{51}), NAPS (X_{52}), and Operating Revenue Per Share (X_{53}). The index weights are shown in Table 3.

4.2. Procedures of Model Implementation

Step 1. Process the indicators and get the data normalized.

Table 3: Index weights based on the improved fuzzy analytic hierarchy process.

Indicator	Weight	Indicator	Weight	Indicator	Weight	Indicator	Weight
X_1	0.1845	X_{21}	0.0508	X_{33}	0.0399	X_{44}	0.0352
X_{11}	0.0369	X_{22}	0.0508	X_{34}	0.0399	X_{45}	0.0352
X_{12}	0.0369	X_{23}	0.0508	X_{35}	0.0399	X_{46}	0.0352
X_{13}	0.0369	X_{24}	0.0508	X_4	0.2173	X_5	0.1723
X_{14}	0.0369	X_3	0.195	X_{41}	0.0352	X_{51}	0.0574
X_{15}	0.0369	X_{31}	0.0399	X_{42}	0.0352	X_{52}	0.0574
X_2	0.2033	X_{32}	0.0399	X_{43}	0.0352	X_{53}	0.0574

Table 4: Descriptive statistics of indicators.

	Sample	Min. value	Max. value	Average value	Standard deviation	Variance
X_{11}	37	0.008	32.414	4.73782	5.926520	35.124
X_{12}	38	0.6586	822.6889	63.117285	155.5260584	24188.355
X_{13}	38	0.0016	4.8035	1.207797	1.1022243	1.215
X_{14}	37	0.2252	50.9921	7.179803	9.7856580	95.759
X_{15}	38	0.0016	2.1875	0.645392	0.5910114	0.349
X_{21}	35	0.3402	25.6567	2.454467	4.3723699	19.118
X_{22}	38	0.2148	25.6567	1.779808	4.1654628	17.351
X_{23}	36	3.8248	121.0434	57.857497	25.2679304	638.468
X_{24}	37	−84.3018	1.0359	−2.169953	13.6857142	187.299
X_{31}	35	−87.1165	45.6127	5.827611	25.6430196	657.564
X_{32}	37	−299.1074	45.6127	−0.534708	55.3739147	3066.270
X_{33}	37	−24.047	2200.512	59.97748	356.733666	127258.908
X_{34}	36	−922.4338	1335755.3	36074.373	219601.4718631	48224806444.416
X_{35}	34	−165.4261	1335755.3	38163.717486	225783.9996788	50978414510.938
X_{41}	39	−10962.50	3716.6667	−194.913345	1848.5586555	3417169.103
X_{42}	37	−10962.50	3716.6667	−201.117866	1897.6031169	3600897.589
X_{43}	36	−92.6365	778.0531	32.868792	131.0271981	17168.127
X_{44}	37	−507.069	704.248	−3.89169	192.499040	37055.881
X_{45}	35	−3172.059	710.442	−61.40170	574.683821	330261.494
X_{46}	38	−48692.973	4338.184	−1161.34318	7843.469376	61520011.849
X_{51}	38	−0.7772	5.0484	0.643659	1.0356570	1.073
X_{52}	39	−0.29	13.75	3.4463	3.49247	12.197
X_{53}	35	0.0000	52.5087	8.664581	12.8255405	164.494

Step 2. Determine the indicator weights based on FAHP and calculate them into Model (12), that is, to determine w_{ij}^k and v_i^k as shown in the following model:

$$\begin{aligned} \min_z \quad & \sum_{k=1}^{M}\sum_{i=1}^{N}\sum_{j=i+1}^{N} w_{ij}^k \left|z_{ij} - p_{ij}^k\right| \\ \min_x \quad & \sum_{k=1}^{M}\sum_{i=1}^{N} v_i^k \left|x_i - r_i^k\right| \\ \text{s.t.} \quad & z_{ij} = x_i - x_j \quad (i = 1, 2, \ldots, N; j = i+1, \ldots, N) \\ & p_{ij}^k = r_i^k - r_j^k. \end{aligned} \tag{13}$$

Step 3. Solve Model (13).

Step 4. Rank the enterprises, set the criteria scores for the enterprises with financial crisis, and identify the enterprises with potential financial crises.

4.3. Results and Revelation of the Empirical Analysis. Based on the implementation steps of the model and the weight values obtained with FAHP, we know that the weight of the Kth indicator is the coefficient value w_{ij}^k and v_i^k. And when k is fixed,

$$w_{ij}^k = v_i^k. \tag{14}$$

Put formula (14) into formula (13). In the data normalization, we can find that there are many missing data, so the approach here is applicable. Meanwhile, all the indicators here are positive, which means that the larger the indicator value is, the less likely the financial crisis will happen. Therefore, we can rank the enterprises in accordance with descending order of the values in the model as shown in Table 4.

After normalization of the results, solve the above nonlinear programming problem with formulas (13) and (14). See Table 5 for the score and ranking of the 40 enterprises.

As seen in Table 5, enterprises with the more rearward ranking are more prone to financial crisis. In order to verify the correctness of the proposed model, we compare the relevant data in 2010, 2011, and 2012 and find that the twenty

Table 5: Score and ranking of 40 enterprises.

Stock code	Evaluation score	Rank	Stock code	Evaluation score	Rank
600125	0.923	1	000520	0.241	21
600897	0.921	2	600018	0.201	22
600115	0.917	3	601880	0.177	23
000099	0.905	4	600548	0.150	24
002320	0.900	5	000900	0.108	25
600270	0.873	6	600026	0.102	26
300240	0.872	7	600428	0.087	27
600221	0.841	8	600896	0.086	28
600692	0.830	9	000582	0.081	29
601107	0.828	10	600033	0.066	30
600350	0.801	11	600387	0.059	31
600561	0.789	12	600798	0.050	32
601866	0.780	13	600087	0.033	33
601111	0.776	14	601919	0.031	34
601872	0.698	15	600575	0.019	35
000089	0.664	16	600717	0.011	36
600269	0.650	17	002040	0.008	37
600029	0.601	18	600317	0.007	38
601000	0.537	19	600190	0.004	39
000996	0.515	20	600279	0.002	40

companies that rank lower, such as Yingkou Port Group CORP (stock code: 600317), Jinzhou Port Co., Ltd. (stock code: 600190), Chongqing Gangjiu Co., Ltd. (stock code: 600279), Nanjing Tanker Corporation (stock code: 600087), and Fujian Highway (stock code: 600033), had the financial crisis to some extent. Therefore, the proposed model in this study has a good predictive ability.

5. Conclusions

In this study, a new evaluation model based on the nonlinear programming is established, the properties of the model are proved in details, the specific steps of the solution process are demonstrated, and the significance of the model is discussed. With the good properties of isotonic and the profound theoretical background, the proposed model can deal with the missing data. As shown in the empirical analysis to predict the financial crisis and the comparison of the historical data and the reality of the enterprise financial crisis, the established prediction model of enterprise financial crisis can adapt well to the features of the financial crisis data with a higher predictive accuracy. The method in this study not only provides a new effective model for the prediction of enterprise financial crisis, but also expands the application of nonlinear programming evaluation method. The predication results can inspire the Chinese transportation enterprises and encourage them to find the financial crisis and explore the potential to improve their business. Furthermore, the international transportation enterprises can also make a thorough comparison so as to develop the correspondent competitive strategies.

This research is based on the grading classifications of enterprise financial crisis. The future study can focus on the combinations of the enterprise financial crisis prediction and the information technology and the decision support theory to develop the design and the prototype of the financial crisis prediction support system.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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