Complex criterion for evaluating contractor's activities in the construction industry

Olga Kleshcheva, Farida Sayfullina, Natalya Abdukhanova

Abstract. The assessment of the financial viability of the contractor is of particular interest. However, many of existing criteria which are used for analyzing the economic performance of an enterprise are criticized, as the generalized indicators may provide an accurate estimation only for a definite country, or period. Elaboration of a generalized indicator is related to the following tasks: selecting analytical coefficients, determining the structure and parameters of the generalized indicator, and calculating the critical value. The approach used in this paper implies using all known analytical indicators for solving the first task. These relative indicators are then compared with absolute indicators, namely, balance indicators. In the present work this is done with correlation analysis. When determining the structure and parameters, as well as when calculating the critical value of the complex criteria, we used discriminant analysis. A sample of enterprises of the construction complex was considered as objects. The complex criterion for evaluating contractor's activities can be used both for internal analysis and by external users: banks, investors, and counteragents.

Keywords: evaluating contractors, construction management, failure prediction models, discriminant analysis, default risk, construction businesses.

1 Introduction

The development of the construction industry is based on the development of individual subjects of the industry: enterprises and organizations. The effectiveness of the construction company depends on many factors including economic factors. This work solves the issue of assessing construction contractors' activity based on developing a complex criterion of economic activity estimation.

Financial analysis has many dimensions, including analysis with financial coefficients. Today, there are a lot of analytical indicators. However, this impedes making a final decision, as many coefficients change in various directions. Thus, analytical groupings of coefficients are applied. Financiers have come to the conclusion that financial-economic performance can be characterized with a complex criterion. The issue of estimating the financial state of an enterprise with a complex criterion is of great interest, both theoretically and practically.

W. Beaver [1][2][3] proposed a dichotomous model of companies classification (bankrupt / non-bankrupt), using a set of financial coefficients. The best result of forecasting (accuracy of classification 78 % five years prior to bankruptcy) was shown by a coefficient of cash flow to total debt ratio. The contemporary analysis of bankruptcy risk starts with works by E. Altman [4], who used multiple discriminant analysis to forecast corporate bankruptcy. E. Altman researched the financial state of 33 bankrupt enterprises and compared their indicators with those of profitable enterprises of the same industry and the same size. Five indicators were compared, characterizing various aspects of the financial state. This model included the indicators of liquidity, financial sustainability, profitability (efficiency of using resources), and market activity.

In 1977, E. Altman and colleagues elaborated a more accurate seven-factor model [5]. This model allows forecasting bankruptcy in the offing of five years with the accuracy up to 70 %. The model uses the following variables: assets profitability, changeability (dynamics) of profits, coefficient of interest on credit discharge, cumulative profitability, coefficient of current liquidity (discharge), coefficient of autonomy, and total assets.
Since then, the method of multiple discriminant analysis was used both for large and small companies, also, it was evaluated, criticized and compared with more comprehensive methods [6][7][8].

E. Deakin [9] made a comparative analysis of W. Beavers’ model of 1966 with the results of E. Altman’s model of 1968 and came to a conclusion that E. Altman’s model yields a more accurate short-term prognosis (one year), while W. Beavers’ model gives a more accurate long-term prognosis (five years), from the viewpoint of mistakes of forecasting.

Both classical and modern models of bankruptcy forecasting are based on financial indicators [10]. However, P. Mears [11] asserts that financial coefficients cannot forecast bankruptcy and are only useful for signalizing about financial problems of a company and their potential causes. Based on a hypothesis that usefulness of accounting information is the function of prognostic ability of the information and the capability of users to interpret that information, R. Libby[12] believed that a narrow set of financial coefficients enabled to achieve high accuracy of forecasting.

Application of Altman Z-score for Russian enterprises is not always relevant. There are several reasons for this. First, the model was built with the data of American companies and it is obvious that every state has its own specific ways of doing business. Second, Z-criterion is based, mainly, on the data of 1950-s; in the past years, economic situation all over the world changed, thus, repeating the analysis by E. Altman’s technique with later data would not necessarily leave the structural composition of the model unchanged. Third, E. Altman’s model can be implemented only for large companies whose securities are listed in stock exchanges, as objective market estimation of assets is known for such companies only.

Methods of drawing up a complex criterion for assessing enterprise efficiency also depend on a specific situation, research tasks and can be different: boosting, discriminant analysis, vector support machine and neural networks [13][14][15], analysis of functioning environment [16][17], LASSO [18][19], two-stage classification [20], partial least squares logistic regression [21] and decision tree techniques [22], etc.

In our opinion, a complex index of enterprise's effectiveness should take into account the specifics of doing business. To design it, it is necessary to rely on a sample of enterprises of a particular economic system. Consequently, H. Choi, H. Son, and C. Kim investigate the possibility of forecasting financial setback of construction contractors on the basis of a training sample of South Korean enterprises [23].

2 Methods
Elaboration of the generalized indicator is related to the following tasks:
1. selecting analytical coefficients;
2. determining the structure and parameters of the generalized indicator; and
3. calculating the critical value of the generalized indicator.

The first task was solved by special correlation of the analytical coefficients with balance sheet indicators through correlation analysis. Correlation analysis includes calculation of correlation coefficient using the well-known equation:

\[ r = \frac{\sum (x_i - \bar{x}) \cdot (y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \cdot \sum (y_i - \bar{y})^2}}, \tag{1} \]

where \( r \) is the linear correlation coefficient (r-value),
- \( x_i \) - \text{-i-th value of the variable } x,
- \( y_i \) - \text{-i-th value of the variable } y
- \( \bar{x} \) - the mean value of the variable x,
- \( \bar{y} \) - the average value of the variable y
The number of the variable.

Then the results are interpreted. If the correlation coefficient value is modulo close to one, it is possible to assume that there is a connection.

Based on the results of the correlation analysis, those analytical coefficients that repeat the change in the indicators of the balance sheet were selected, that is, the ones that have high values of the correlation. The proposed method is similar to the method for selecting analytical coefficients based on detailed study of their dynamics. When applying this method, the dynamics of analytical coefficients is compared with the general dynamics of the financial condition of the enterprise. The latter, in its turn, is determined on the basis of the same analytical coefficients or balance indicators. Thus, the alteration dynamics of analytical coefficient are compared to balance indicators. This makes the basis of the proposed method.

Six groups of indicators describing: the property status of a company, its liquidity, financial sustainability, business activity, profitability, position in the securities market are well known. Indicators from different groups do not correlate with each other. As it is advisable that the analytical coefficients with high direct or reverse correlations with each other are not included into the generalized indicator, specific indicators from each group were selected to be included into the generalized indicator.

The algorithm of selecting the analytical coefficients was the following:

1. A sample of enterprises is formed, containing both successful as crisis enterprises.
2. Analytical indicators in each group are calculated with the data of these enterprises.
3. The degree of closeness is estimated between the specific indicators and the balance sheet indicators, through the linear correlation coefficient.
4. Correlation significance is checked.
5. It is accepted that the more significant links the specific indicator has with the main balance sheet indicators, the more reliably it reflects the results of financial-economic performance. The indicators with maximal number of existing correlations are selected.
6. If there are several such analytical indicators in a group, then the indicator with maximal value of correlation coefficients is selected.

The algorithm of determining the parameters of the generalized criterion was the following:

1. The initial sample of enterprises was divided into two groups: enterprises with stable and instable financial position; they are described with the selected financial indicators.
2. The discriminant (dividing, classifying) function is built and identified.

Discriminant function is built using the method of discriminant analysis. This method refers to multidimensional classification methods. The main objective of discriminant analysis is defining criteria for objects classification of the parent entity based on making the discriminant function:

\[ Z = C_1X_1 + C_2X_2 + \ldots + C_mX_m \]  

where \( X_1, X_2, \ldots, X_t \) are the values of analytical coefficients; \( C_1, C_2, \ldots, C_m \) - are discriminant multipliers.

The calculation of discriminant multipliers includes the following steps:

1. Calculating the mean values of indicators \( X_1, X_2, \ldots, X_m \) from the sample of construction companies that are stable in the market. The results are made as a column vector \( \overline{X}_i \):

\[ \overline{X}_i = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_m \end{bmatrix} \]

Here \( X / l = \sum_{j=1}^{n_l} X_j / l / n_l \) (\( i = 1, \ldots, m \)),

\[ (3) \]
where \( n_1 \) is the number of objects in a sample of construction enterprises that are stable in the market.

Similarly, vector \( \overline{X}_2 \) is defined for sample objects of construction enterprises that are fragile in the market. The number of objects in a sample 2 is \( n_2 \).

2. Covariance matrices \( S_1 \) and \( S_2 \) are determined for the first and second samples, respectively. Each covariance matrix has a dimension \( m \times m \). Matrix elements are calculated using the equations:

\[
S_{ij}^{(1)} = \frac{1}{n_1} \sum_{k=1}^{n_1} (X_{ik}^{(1)} - \overline{X}^{(1)})(X_{jk}^{(1)} - \overline{X}^{(1)})
\]

\[
S_{ij}^{(2)} = \frac{1}{n_2} \sum_{x=1}^{n_2} (X_{ix}^{(2)} - \overline{X}^{(2)})(X_{jx}^{(2)} - \overline{X}^{(2)})
\]

3. The total intra-sample dispersion is estimated: determined matrix \( \hat{S} \).

\[
\hat{S} = (1/n_1 + n_2 - 2)^* (n_1 S_1 + n_2 S_2)
\]

4. Elements of the inverse matrix are defined \( \hat{S}^{-1} \)

5. Vector \( C \) of discriminant multipliers is defined:

\[
C = \begin{bmatrix} C1 \\ C2 \\ \vdots \\ Cm \end{bmatrix}
\]

The elements of vector \( C \) are defined from the condition

\[
C = \hat{S}^{-1} (\overline{X}^{(1)} - \overline{X}^{(2)})
\]

6. The average values of the discriminant function for the two samples studied are found. For this purpose, for each sample of construction enterprises that are stable in the market, the value of the discriminant function is calculated

\[
Z^{(1)} = C_1 X_1^{(1)} + C_2 X_2^{(1)} + \ldots + C_m X_m^{(1)}
\]

and the sum of these values is the mean value \( \overline{Z}^{(1)} \). \( \overline{Z}^{(2)} \) is calculated similarly.

7. The boundary of discrimination is defined as the total average

\[
\overline{Z} = (\overline{Z}^{(1)} + \overline{Z}^{(2)}) / 2.
\]

8. The class of enterprises is established, for which the value of the discriminant function is calculated for the studied enterprise and compared with the boundary of discrimination.

3 Results and Discussions

The annual reports of Russian construction companies were used to calculate the summarizing performance indicator of the construction contractor. The situation in the securities market was not considered, due to the fact that the studied enterprises are not open joint-stock companies and their shares are not listed on the exchange.

Coefficients with the largest values of correlation between balance indicators and analytical coefficients are shown in Table 1.
To carry out discriminant analysis, the enterprises should be divided into groups, with the number of features not exceeding the number of elements in a group. We calculated the indicators of all enterprises selected as a result of correlation analysis. Calculation results are shown in Table 2.
Table 2. Values of analytical coefficients.

| Enterprise, № | Current liquidity ratio | Concentration ratio of equity capital | Inventory turnover ratio | Share of inventory in current assets | Net profit per unit |
|---------------|-------------------------|--------------------------------------|--------------------------|--------------------------------------|---------------------|
| 1             | 1.22                    | 0.25                                 | 42                       | 0.37                                 | 0.07                |
| 2             | 0.88                    | 0.28                                 | 102                      | 0.52                                 | 0.06                |
| 3             | 0.6                     | 0.02                                 | 57                       | 0.49                                 | -0.07               |
| 4             | 0.72                    | 0.0001                               | 42                       | 0.51                                 | -0.01               |
| 5             | 3.04                    | 0.74                                 | 180                      | 0.88                                 | 0.16                |
| 6             | 1.09                    | 0.2                                  | 11                       | 0.22                                 | 0.02                |
| 7             | 1.21                    | 0.33                                 | 22                       | 0.24                                 | 0.03                |
| 8             | 0.84                    | 0.19                                 | 60                       | 0.56                                 | 0.01                |
| 9             | 1.07                    | 0.53                                 | 52                       | 0.46                                 | 0.08                |
| 10            | 0.85                    | 0.00001                              | 21                       | 0.29                                 | -0.01               |
| 11            | 0.35                    | 0.01                                 | 310                      | 0.6                                  | 0.03                |
| 12            | 0.47                    | 0.0001                               | 65                       | 0.48                                 | -0.06               |
| 13            | 1.08                    | 0.1                                  | 83                       | 0.53                                 | 0.02                |
| 14            | 1.13                    | 0.19                                 | 79                       | 0.53                                 | 0.06                |
| 15            | 2.54                    | 0.82                                 | 117                      | 0.77                                 | 0.03                |
| 16            | 0.91                    | 0.31                                 | 36                       | 0.52                                 | 0.05                |
| 17            | 1                       | 0.04                                 | 19                       | 0.18                                 | 0.01                |
| 18            | 0.88                    | 0.3                                  | 45                       | 0.41                                 | 0.12                |

Values of analytical coefficients in 2017

Values of analytical coefficients in 2018

*compiled by the authors.
The enterprises were divided into two groups (the first group – satisfactory financial state, the second group – unsatisfactory financial state) as follows. If current liquidity ratio exceeded one, the enterprise was referred to the first group, otherwise to the second group. If concentration ratio of equity capital exceeded 0.24, the enterprise was referred to the first group, otherwise to the second group. If inventory turnover ratio exceeded fifty days, the enterprise was referred to the second group, otherwise to the first group. If share of inventory in current assets exceeded 0.6, the enterprise was referred to the first group, otherwise to the second group. If net profit per unit exceeded 0.03, the enterprise was referred to the first group, otherwise to the second group. Then the enterprises were distributed into two groups according to the values obtained. The threshold values were allocated so that the number of objects in the groups was the same. The results are shown in Table 3.

**Table 3. Distribution of the enterprises into groups.**

| Enterprise | Current liquidity ratio | Concentration ratio of equity capital | Inventory turnover ratio | Share of inventory in current assets | Net profit per unit | Group |
|------------|------------------------|--------------------------------------|-------------------------|--------------------------------------|---------------------|-------|
| 1          | 1                      | 1                                    | 1                       | 1                                    | 1                   | 1     |
| 2          | 2                      | 2                                    | 2                       | 1                                    | 1                   | 1     |
| 3          | 2                      | 2                                    | 2                       | 1                                    | 2                   | 2     |
| 4          | 2                      | 2                                    | 1                       | 1                                    | 2                   | 2     |
| 5          | 1                      | 1                                    | 2                       | 2                                    | 1                   | 1     |
| 6          | 1                      | 2                                    | 1                       | 1                                    | 1                   | 2     |
| 7          | 1                      | 1                                    | 1                       | 2                                    | 1                   | 1     |
| 8          | 2                      | 2                                    | 2                       | 1                                    | 2                   | 2     |
| 9          | 1                      | 1                                    | 2                       | 1                                    | 1                   | 1     |
| 10         | 2                      | 2                                    | 1                       | 1                                    | 2                   | 2     |
| 11         | 2                      | 2                                    | 2                       | 2                                    | 2                   | 2     |
| 12         | 2                      | 2                                    | 2                       | 1                                    | 2                   | 2     |
| 13         | 1                      | 2                                    | 2                       | 1                                    | 2                   | 2     |
| 14         | 1                      | 2                                    | 2                       | 1                                    | 1                   | 1     |
| 15         | 1                      | 2                                    | 1                       | 2                                    | 2                   | 2     |
| 16         | 2                      | 1                                    | 2                       | 1                                    | 1                   | 1     |
| 17         | 2                      | 2                                    | 1                       | 1                                    | 2                   | 2     |
| 18         | 2                      | 1                                    | 1                       | 1                                    | 1                   | 1     |

**Distribution of the enterprises into groups in 2017**

**Distribution of the enterprises into groups in 2018**

*compiled by the authors.*
To determine the structure and parameters of the generalized criteria, we carried out the discriminant analysis for 2017 data. Table 4 shows the primary data for discriminant analysis.

Table 4. Primary data for discriminant analysis.

| Enterprise | Current liquidity ratio | Concentration ratio of equity capital | Inventory turnover ratio | Share of inventory in current assets | Net profit per unit |
|------------|------------------------|--------------------------------------|-------------------------|--------------------------------------|---------------------|
| 1          | 1.22                   | 0.25                                 | 42                      | 0.37                                 | 0.07                |
| 2          | 0.88                   | 0.28                                 | 102                     | 0.52                                 | 0.06                |
| 5          | 3.04                   | 0.74                                 | 180                     | 0.88                                 | 0.16                |
| 6          | 1.09                   | 0.2                                  | 11                      | 0.22                                 | 0.02                |
| 7          | 1.21                   | 0.33                                 | 22                      | 0.24                                 | 0.03                |
| 9          | 1.07                   | 0.53                                 | 52                      | 0.46                                 | 0.08                |
| 14         | 1.13                   | 0.19                                 | 79                      | 0.53                                 | 0.06                |
| 16         | 0.91                   | 0.31                                 | 36                      | 0.52                                 | 0.05                |
| 18         | 0.88                   | 0.3                                  | 45                      | 0.41                                 | 0.12                |

*compiled by the authors.

1. The mean values of indicators in the first and second groups were calculated.

\[
x_1 = \begin{pmatrix} 1.27 \\ 0.35 \\ 63.18 \\ 0.46 \\ 0.07 \end{pmatrix}
\]

\[
x_2 = \begin{pmatrix} 0.94 \\ 0.12 \\ 86.02 \\ 0.49 \\ -0.01 \end{pmatrix}
\]
2. Covariance matrices $S_1$, $S_2$ were calculated.

$$S_1 = \begin{pmatrix} 4 & 1 & 221 & 1 & 0 \\ 1 & 0 & 51 & 0 & 0 \\ 221 & 51 & 21375 & 75 & 14 \\ 1 & 0 & 75 & 0 & 0 \\ 0 & 0 & 14 & 0 & 0 \end{pmatrix}$$

$$S_2 = \begin{pmatrix} 3 & 1 & -50 & 0 & 0 \\ 1 & 1 & 25 & 0 & 0 \\ -50 & 25 & 63729 & 65 & 11 \\ 0 & 0 & 65 & 0 & 0 \\ 0 & 0 & 11 & 0 & 0 \end{pmatrix}$$

3. Matrix $\hat{S}$ was found.

$$\hat{S} = \begin{pmatrix} 7 & 2 & 171 & 1 & 0 \\ 2 & 1 & 76 & 0 & 0 \\ 171 & 76 & 85103 & 140 & 25 \\ 1 & 0 & 140 & 1 & 0 \\ 0 & 0 & 25 & 0 & 0 \end{pmatrix}$$

4. Elements of inverse matrix $\hat{S}^{-1}$ were found.

$$\hat{S}^{-1} = \begin{pmatrix} 0.610 & -1.245 & 0.001 & -0.246 & -2.151 \\ -1.245 & 5.144 & 0.001 & -1.775 & -0.742 \\ 0.001 & 0.001 & 0 & -0.007 & -0.018 \\ -0.246 & -1.775 & -0.007 & 5.728 & 0.491 \\ -2.151 & -0.742 & -0.018 & 0.491 & 76.921 \end{pmatrix}$$

5. Vector $C$ of discriminant multipliers was found.

$$x_1-x_2 = \begin{pmatrix} 0.33 \\ 0.23 \\ -22.84 \\ -0.03 \\ 0.08 \end{pmatrix}$$

$$C = \begin{pmatrix} -0.263 \\ 0.733 \\ -0.001 \\ -0.445 \\ 5.5 \end{pmatrix}$$

As a result, we obtained the following complex criterion for evaluating contractor's activities in the construction industry:

$$K = -0.263 * x_1 + 0.733 * x_2 - 0.001 * x_3 - 0.445 * x_4 + 5.5 * x_5.$$
where $x_1$ – current liquidity ratio;
$x_2$ - concentration ratio of equity capital;
$x_3$ - inventory turnover ratio;
$x_4$ - share of inventory in current assets;
$x_5$ - net profit per unit;
$K$ - the complex criterion for evaluating contractor's activities in the construction industry.

6. The mean values of discriminant function for each group were calculated. To do that, the value of discriminant function for each object was determined. Calculation results are shown in Tables 5 and 6.

**Table 5.** Values of discriminant function for the first group of enterprises.

| Enterprise | Discriminant function K |
|------------|-------------------------|
| 1          | 0.03                    |
| 2          | -0.06                   |
| 5          | 0.00                    |
| 6          | -0.14                   |
| 7          | -0.05                   |
| 9          | 0.28                    |
| 14         | -0.16                   |
| 16         | -0.01                   |
| 18         | 0.41                    |

*compiled by the authors.

The mean value is 0.03.

**Table 6.** Values of discriminant function for the second group of enterprises.

| Enterprise | Discriminant function K |
|------------|-------------------------|
| 3          | -0.82                   |
| 4          | -0.55                   |
| 8          | -0.35                   |
| 10         | -0.48                   |
| 11         | -0.58                   |
| 12         | -0.76                   |
| 13         | -0.44                   |
| 15         | -0.39                   |
| 17         | -0.28                   |

*compiled by the authors.

The mean value is -0.52.

1. The discriminant boundary was found.
The discriminant boundary is equal to $(0.03-0.52)/2=-0.24$.

2. Each object was referred to a certain class. As $K_1>K_2$, the object refers to the first group if $K>-0.24$, and vice versa.
The mean value of the indicator is -0.24.

Using the complex criterion, we determined the financial state of the studied enterprises in 2018. Calculation results and conclusions are shown in Table 7.

**Table 7.** Status of enterprises in 2018 resulting from calculation of the new complex criterion.
Classic unidimensional financial risk analysis is based on financial indicators and includes a static and dynamic analysis of the company's activities at the operational and financial levels of activities [24]. This type of analysis often uses coefficients that measure profitability, liquidity, self-financing capacity, debt and the ability to pay interest and repay loans. This method presents some limitations that have led to the development and application of more advanced statistical methods to analyze and forecast business failures [25][26]. The indicator proposed in this study is calculated for a specific economic system, taking into account all its characteristics. This determines the reliability of its application for assessing the efficiency of the enterprises of the construction industry.

4 Conclusion

To construct the complex criterion, the methods of correlation analysis and discriminant analysis were used. When elaborating the selection technique, its main stages were identified: analysis of changes in the balance structure, calculation of correlation coefficients, analysis of the obtained coefficients, and selection of specific indicators within the complex criterion.

The technique of selecting the analytical coefficients is based on correlation analysis. It enables to compare the changes in the balance indicators with the changes in specific indicators. When elaborating the complex criterion, discriminant analysis was used. For that, all enterprises were divided into two groups. As a result, if the value of the complex criterion exceeded the discriminant boundary, then the financial state of the enterprise is satisfactory – the enterprise belongs to the first group; otherwise, it is unsatisfactory.

The elaborated complex criterion can be used both for internal financial analysis and by external users: banks, investors, and counteragents.

References

[1] Beaver W H Financial Ratios as Predictors of Failure. Empirical Research in Accounting: Selected Studies 1966 J. Account. Res.
[2] Beaver W H Alternative Accounting Measures As Predictors of Failure Account. Rev. 1968
[3] Beaver W H 1968 Market Prices, Financial Ratios, and the Prediction of Failure J. Account. Res. DOI: 10.2307/2490233
[4] Altman E I 1968 Financial ratios, discriminant analysis and the prediction of corporate bankruptcy J. Finance DOI: 10.1111/j.1540-6261.1968.tb00843.x
[5] Altman E I, Haldeman R G and Narayanan P 1977 ZETATM analysis A new model to identify bankruptcy risk of corporations J. Bank. Financ. DOI: 10.1016/0378-4266(77)90017-6
[6] Efrim Boritz J and Kennedy D B 1995 Effectiveness of neural network types for prediction of business failure Expert Syst. Appl. DOI: 10.1016/0957-4174(95)00020-8
[7] Almamy J, Aston J and Ngwa L N 2016 An evaluation of Altman’s Z-score using cash flow ratio to predict corporate failure amid the recent financial crisis: Evidence from the UK J. Corp. Financ. DOI: 10.1016/j.jcorfin.2015.12.009
[8] McKee T E 2003 Rough sets bankruptcy prediction models versus auditor signalling rates J. Forecast. DOI: 10.1002/for.875
[9] Deakin E B 1972 A Discriminant Analysis of Predictors of Business Failure J. Account. Res. DOI: 10.2307/2490225
[10] Ohlson J A 1980 Financial Ratios and the Probabilistic Prediction of Bankruptcy J. Account. Res. DOI: 10.2307/2490395
[11] Mears P K 1966 Discussion of Financial Ratios As Predictors of Failure J. Account. Res. DOI: 10.2307/2490173
[12] Libby R 1975 Accounting Ratios and the Prediction of Failure: Some Behavioral Evidence J. Account. Res. DOI: 10.2307/2490653
[13] Alfaro E, Garcia N, Gámez M and Elizondo D 2008 Bankruptcy forecasting: An empirical comparison of AdaBoost and neural networks Decis. Support Syst. 45 pp 110–122 DOI: 10.1016/j.dss.2007.12.002
[14] Bose I and Pal R 2006 Predicting the survival or failure of click-and-mortar corporations: A knowledge discovery approach Eur. J. Oper. Res. DOI: 10.1016/j.ejor.2005.05.009
[15] Geng R, Bose I and Chen X 2015 Prediction of financial distress: An empirical study of listed Chinese companies using data mining Eur. J. Oper. Res. DOI: 10.1016/j.ejor.2014.08.016
[16] Li Z, Crook J and Andreeva G 2014 Chinese companies distress prediction: An application of data envelopment analysis Journal of the Operational Research Society DOI: 10.1057/jors.2013.67.
[17] Hosaka T 2019 Bankruptcy prediction using imaged financial ratios and convolutional neural networks Expert Syst. Appl. 117 pp 287–299 DOI: 10.1016/j.eswa.2018.09.039
[18] Tian S, Yu Y, Guo H 2015 Variable selection and corporate bankruptcy forecasts J. Bank. Financ. DOI: 10.1016/j.jbankfin.2014.12.003
[19] Dong M C, Tian S, Chen C W S 2018 Predicting failure risk using financial ratios: Quantile hazard model approach North Am. J. Econ. Financ. DOI: 10.1016/j.najef.2018.01.005
[20] Du Jardin P 2016 A two-stage classification technique for bankruptcy prediction Eur. J. Oper. Res. DOI: 10.1016/j.ejor.2016.03.008
[21] Ben Jabeur S 2017 Bankruptcy prediction using Partial Least Squares Logistic Regression J. Retail. Consum. Serv. DOI: 10.1016/j.jretconserv.2017.02.005
[22] Gepp A and Kumar K 2015 Predicting Financial Distress: A Comparison of Survival Analysis and Decision Tree Techniques Procedia Computer Science DOI: 10.1016/j.procs.2015.06.046
[23] Choi H, Son H and Kim C 2018 Predicting financial distress of contractors in the construction industry using ensemble learning Expert Syst. Appl. DOI: 10.1016/j.eswa.2018.05.026.
[24] Alaka H A, Oyedele L O, Owolabi H A, Bilal M, Ajayi S O and Akinade O O 2018 A framework for big data analytics approach to failure prediction of construction firms Appl. Comput. Informatics. DOI: 10.1016/j.aci.2018.04.003
[25] Balsean S, Ooghe H 2006 35 years of studies on business failure: An overview of the classic
statistical methodologies and their related problems *Br. Account. Rev.* DOI: 10.1016/j.bar.2005.09.001

[26] Dimitras A I, Zanakis S H and Zopounidis C 1996 A survey of business failures with an emphasis on prediction methods and industrial applications *Eur. J. Oper. Res.* DOI: 10.1016/0377-2217(95)00070-4