

Article

Application of Optimization to Select Contractors to Develop Strategies and Policies for the Development of Transport Infrastructure

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Received: 9 December 2018; Accepted: 12 January 2019; Published: 18 January 2019



Abstract: Many factors influence the efficiency and quality of transport works. In particular, consultants and construction contractors of these works play important roles, and critical factors directly affect the quality of traffic works. If the quality of consultancy and construction is good, the project will reduce the total investment; if the contractor is good, the completion time of the new project is guaranteed, thus reducing construction costs. The longer the construction time is, the higher the cost of the project. In this study, the authors used optimal algorithms to evaluate past, present, and future contractors' technical, technological, and performance effectiveness. Research results show that bidders are divided into three groups: highly effective bidders, stable contractors, and inefficient groups. Research results for this subject will help the government, regulatory agencies, and investors select good contractors as the basis for developing strategies and policies for the development of transport infrastructure.

Keywords: transport infrastructure; develop strategies; optimal algorithms; business performance

1. Introduction

Contractor Selection Procedure: There are currently many models for selecting contractors for transport infrastructure projects, in which the best bidder selection model by Jyh-Bin Yang and Wei-Chih Wang is utilized (Figure 1).

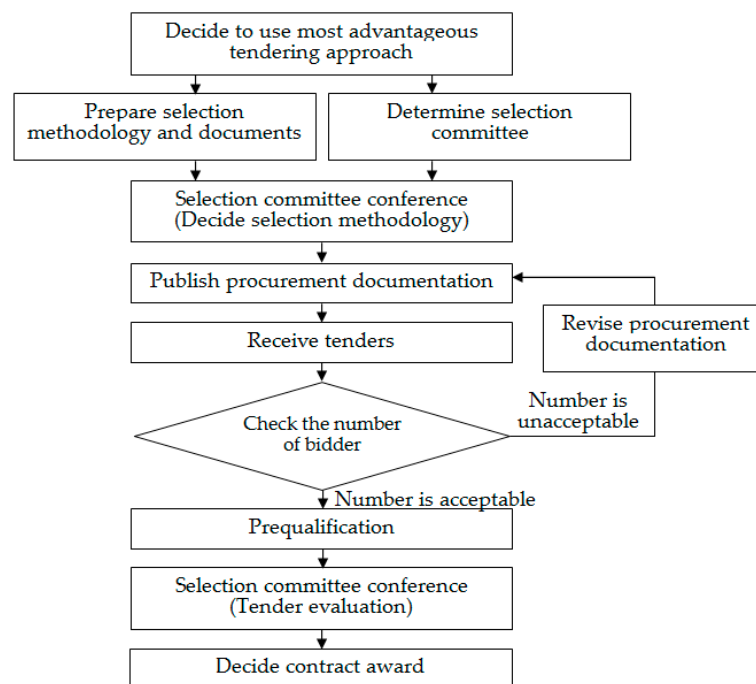


Figure 1. Contractor selection procedure [1].

Choosing a contractor for construction of traffic works is an important issue. Therefore, the contractor must have sufficient professional capacity, human resources, and financial capacity. Depending on the scale, the nature and sources of capital for the construction of traffic works are considered when selecting contractors. In particular, the selection of contractors for transport works is divided into three main forms as follows [2]:

Open bidding: Used to select contractors for construction works in the form of unlimited number of participating contractors.

Restricted bidding: To be used for the selection of contractors for construction of transport works; there are only a number of contractors that meet all the conditions in regard to the capability of construction activities and the capability of practicing the construction of works. Traffic is invited to participate in bidding.

Appointment of contractor: Investment deciders or investors of transport works are entitled to designate contractors directly qualified for construction activities and are capable of practicing construction of traffic works at a reasonable cost.

Each traffic works in different areas require different qualifications, construction techniques, and experience. In order to ensure that construction works are designed to bring economic efficiency for the investor in particular and the community in general, the selection of contractors is made in accordance with the complexity of each project. In this study, the authors use optimal algorithms to forecast and evaluate the economic, technical, and technological efficiency of contractors in the field of construction of traffic works during the period from 2014–2021. This research provides government, managers, and investors with a solid foundation in the development of strategies and policies for the development of transport infrastructure. The results of this research are important to consider when selecting contractors for construction of traffic works in the future.

2. Literature Review

2.1. Related Research

Nowadays, optimal mathematical models have become popular tools for researchers. In particular, there have been many high-impact research projects serving the macroeconomic management decisions

of governments and decisions of investors in strategies and policies for developing products for businesses. In particular, research uses forecasting methods and modern data analysis techniques to find the best solutions for businesses that are of special interest to researchers worldwide. In particular, in 2006, Zhou, Ang, and Poh [3] used the Grey model to forecast electricity demand in Singapore. In 2012, Ze Zhao, Jianzhou Wang, Jing Zhao, and Zhongyue Su [4] used the Grey model to forecast annual net income per capita of rural households in China. In 2010, Guang-Ming Shi, Jun Bi, and Jin-Nan Wang [5] evaluated China's industrial energy efficiency based on DEA models. In 2007, Matthias Staat [6] used DEA models to evaluate the performance of hospitals in Germany. There are also many researchers who combine predictive models and performance assessments.

These studies have yielded good results and high applicability. Among them, Chia-Nan Wang, Han-Khanh Nguyen, and Ruei-Yuan Liao [7] combined the Grey model and DEA model to find a strategic partner in the supply chain of the textile and garment industry in Vietnam. In 2011, Jia-Jane Shuai and Wei-Wen Wu [8] used the DEA model and Grey model to evaluate marketing effectiveness through the website of hotels in Taiwan. In those studies, DEA models were used to analyze and evaluate the business situation of enterprises and economic sectors of countries, together with the forecasting models to forecast the development trend of these enterprises, from which to make appropriate decisions. The results show that these studies have yielded good results and achievements, making an important contribution to the economic growth of businesses and countries.

In the construction industry, the application of optimal mathematical models to find solutions to minimize costs and maximize profits for businesses has also been made by many researchers. In this study, the authors used the GM (1, 1) model to forecast the business situation of contractors of traffic works in Vietnam. Optimal mathematical models are used to simultaneously evaluate the three indicators of technical efficiency, technology efficiency, and business performance of past, present, and future contractors, which give the government, regulators, investors, and business leaders the basis for developing strategies and policymaking for the development of transport infrastructure. This is a new and important application in the selection of qualified contractors for the construction of highly efficient and economically efficient transport works.

2.2. Overview of Transport Infrastructure in Vietnam

Roads: Vietnam's transport infrastructure has changed dramatically in recent years. Many large and modern works have been put into operation. Especially, the road infrastructure has been built and improved. The overview of road transport infrastructure in Vietnam is shown in Table 1.

Table 1. Road infrastructure.

Order	Type of Roads	Total Route	Total Length (km)
1	Highways	13	745
2	Route	146	23,816
3	Provincial road	998	27,176
4	District roads	8680	57,294
5	Commune roads	61,402	173,294
6	Urban road	23,495	27,910
7	Other rural roads	168,888	256,377
8	Specialized road	2476	8528

Source: [9].

Railway: The Vietnam national railway infrastructure is as follows [9]:

- Total length of railway: 3161 km.
- Terminal area: 2,029,837 m².
- Leased area: 1,316,175 m².

Seaway: Maritime transport infrastructure is as follows: There are 44 seaports in the country (14 seaports of type I and IA, 17 seaports of type II, 13 offshore ports of type III). There are 254 harbors with 59.4 km long wharfs and total design capacity of about 500 million tons per year [9].

Inland waterways: At present, Vietnam has 45 inland waterways with a total length of about 7075 km [9].

- Signal systems on the route: 12,539 signaling towers, 18,458 signaling beams, 3070 signaling beams, and 9153 signaling lights.
- Bridges over the route: 251/532 bridges and river crossings located on national inland waterway lanes with less than technical specifications as approved.
- Inland waterway system: By the end of August 2017, Vietnam had 277 ports, of which 220 ports are on national inland waterways and 57 on local inland waterways.

By air: Currently, Vietnam has 21 airports in operation, including eight international airports and 13 domestic airports [9].

3. Data and Methodology

3.1. Data

3.1.1. Contractors Collection

The data collection of contractors to carry out this study plays an important and practical role in the development of strategies and policies for the development of transport infrastructure. Therefore, the authors pay special attention to the conditions of the use of optimal mathematical models. The selected bidders must have complete, continuous data, along with extensive experience in the design and construction of traffic works. These contractors must meet the human, financial, and property requirements. Through the Website of the General Statistics Office, the authors compiled 17 contractors to satisfy the conditions of this study (Table 2).

Table 2. List of contractors.

I_n	Companies
I_1	Construction joint stock company No. 1
I_2	HUD3 investment and construction joint stock company
I_3	Construction joint stock company No. 9
I_4	Coteccons construction joint stock company
I_5	Hoa Binh construction group joint stock company
I_6	Binhduong trade and development joint stock company
I_7	Development investment construction Hoi An joint stock company
I_8	Licogi 14 joint stock company
I_9	Tien Giang investment and construction joint stock company
I_{10}	Construction joint stock company No. 5
I_{11}	Chuong Duong joint stock company
I_{12}	Constrexim No 8 investment and construction joint stock company
I_{13}	Vietnam Construction joint stock company No. 2
I_{14}	Binh Duong construction and civil engineering joint stock company
I_{15}	HUD1 investment & construction joint stock company
I_{16}	Vinaconex 6 joint stock company
I_{17}	Sci E&C joint stock company

Source: [10].

3.1.2. Elements Selection

Considering the characteristics in the business of construction contractors of transport infrastructure with long production cycles, the place of production is frequently changed according to the works, and the production value of the design activities and construction is large. However,

contractors still follow basic economic models. Therefore, in this study, the authors use four inputs and two outputs to analyze the economic, technical, and technological performance of the contractor. These inputs include

Total assets (F_1) are the value of all assets of an enterprise, including tangible assets such as buildings, machinery, equipment, materials, products, and goods, along with other intangible assets such as computer software, patent, commercial advantage, copyright, etc.

Equity (F_2) is the source of capital that makes up the assets of an enterprise that is contributed by the owner and investor or formed from the results of its business.

Cost of sales (F_3) is the total cost of producing a finished product. For a contractor to build consultancy and construction of transportation works, the cost of goods sold is the total cost needed to complete the works or services that the contractor receives for consultancy, design, and construction (purchase prices from suppliers, shipping, insurance, etc.).

Enterprise cost management (F_4) reflects the total administrative expense allocated to the finished product and goods sold in the enterprise's reporting year.

The outputs include

After-tax profit (F_5): The total value of a business's annual turnover, determined by the net of operating profit and other profits subtracting the cost corporate income tax.

Net sales (F_6): Represents the total sales of products, goods, and services in the reporting year of the enterprise.

The inputs and outputs used by these authors fully reflect the assets, costs, and profits of the contractors. After compiling data in local currency (VND), the authors convert to international currency (USD). All data are summarized in Tables 3–6.

Table 3. Data in 2014.

I_n	F_1	F_2	F_3	F_4	F_5	F_6
I_1	27,619.71	10,642.98	18,457.90	937.68	515.42	20,056.04
I_2	28,709.94	7639.48	13,874.53	829.40	555.53	15,705.79
I_3	69,303.22	8152.75	25,489.89	1355.45	492.23	29,433.26
I_4	213,612.52	111,010.37	310,891.73	9433.09	15,701.84	335,310.80
I_5	254,920.91	43,753.02	136,519.46	12,303.89	3021.07	154,538.01
I_6	275,092.39	51,467.31	61,864.00	2470.02	4951.20	76,694.83
I_7	8965.29	2328.10	11,151.77	415.67	132.48	11,794.35
I_8	23,157.62	2239.67	7996.86	179.96	830.19	9456.81
I_9	17,820.80	6940.10	19,197.12	1141.27	747.30	23,063.05
I_{10}	96,207.60	14,653.46	57,300.18	956.57	1465.09	61,143.84
I_{11}	35,509.26	11,122.29	9447.72	526.14	348.99	11,005.28
I_{12}	4032.71	1130.60	5697.05	100.94	57.37	5866.17
I_{13}	70,769.76	11,952.00	23,135.13	2340.04	729.60	26,622.03
I_{14}	41,732.93	15,413.33	25,252.74	273.30	941.02	26,854.88
I_{15}	32,607.10	7802.01	30,375.07	986.96	334.76	31,927.61
I_{16}	23,968.93	4944.83	24,042.54	874.82	342.88	25,566.41
I_{17}	12,052.33	2929.92	8139.35	582.72	357.69	9618.24

Source: [10].

Table 4. Data in 2015.

I_n	F_1	F_2	F_3	F_4	F_5	F_6
I_1	25,427.87	10,544.98	15,046.55	546.92	524.69	16,143.51
I_2	27,240.89	7804.60	16,308.62	935.70	690.64	18,736.61
I_3	58,661.12	8387.84	26,583.99	1288.07	486.56	33,167.85
I_4	343,282.14	142,430.07	551,576.25	15,936.92	32,188.75	600,414.22
I_5	320,271.10	47,193.66	210,066.59	5260.52	3638.61	223,054.97
I_6	323,038.50	52,527.06	50,531.61	2336.35	4789.37	68,593.61
I_7	9782.04	2316.94	9064.47	454.06	131.64	9783.93

Table 4. Cont.

I_n	F_1	F_2	F_3	F_4	F_5	F_6
I_8	21,538.00	2982.72	26,301.02	372.01	896.48	28,106.62
I_9	26,452.39	8868.83	24,122.09	1319.39	2460.31	30,724.63
I_{10}	99,017.47	13,671.11	59,662.10	788.29	1571.26	62,866.42
I_{11}	35,416.75	11,524.74	12,789.79	594.80	753.06	15,497.41
I_{12}	3941.09	1127.26	4227.08	115.57	43.88	4402.08
I_{13}	68,716.47	12,154.76	26,534.48	1686.70	649.75	29,570.57
I_{14}	78,950.45	15,484.49	20,196.87	307.35	1107.01	22,297.69
I_{15}	27,798.57	7888.80	26,135.77	892.70	368.32	27,642.07
I_{16}	23,237.08	4712.94	22,131.74	746.43	102.21	23,132.23
I_{17}	15,926.25	5473.47	10,984.45	731.45	617.42	12,838.24

Source: [10].

Table 5. Data in 2016.

I_n	F_1	F_2	F_3	F_4	F_5	F_6
I_1	35,109.27	10,485.68	22,603.28	1134.68	564.14	24,390.61
I_2	26,796.59	7970.64	22,050.17	1076.09	703.64	24,479.21
I_3	60,403.74	8407.83	34,716.18	1268.74	609.55	37,280.20
I_4	515,723.84	273,815.34	833,852.12	13,056.99	62,468.41	912,891.79
I_5	502,938.31	80,390.64	418,775.39	16,586.71	24,950.27	472,911.18
I_6	319,702.35	53,657.30	45,777.73	2306.88	5634.81	63,677.86
I_7	10,255.38	2320.89	9588.46	493.99	147.59	10,267.46
I_8	19,557.49	3960.06	7722.72	374.11	1183.62	9963.19
I_9	30,463.49	12,107.59	28,276.70	1286.45	3799.47	36,441.09
I_{10}	87,299.68	14,039.25	61,030.95	945.63	1841.62	64,615.23
I_{11}	32,274.41	12,500.76	11,130.81	568.00	710.45	12,491.93
I_{12}	4615.74	1132.18	5321.93	125.01	42.96	5497.76
I_{13}	111,536.69	12,839.03	39,513.77	2294.98	1322.29	45,818.27
I_{14}	55,524.62	15,639.86	36,510.14	341.96	678.34	37,868.28
I_{15}	28,725.27	7715.34	15,890.36	485.60	142.01	16,929.51
I_{16}	30,738.16	4943.11	30,534.96	847.72	332.38	31,949.23
I_{17}	24,888.24	5590.88	13,841.11	1338.85	177.02	15,710.31

Source: [10].

Table 6. Data in 2017.

I_n	F_1	F_2	F_3	F_4	F_5	F_6
I_1	35,716.50	10,548.01	24,608.44	1811.97	666.61	27,375.57
I_2	32,613.60	8584.32	14,505.26	1242.48	842.67	17,305.95
I_3	74,012.57	8369.17	43,573.89	1199.83	553.81	46,708.38
I_4	697,419.42	320,950.06	1,104,166.34	17,331.82	72,594.78	1,192,729.49
I_5	614,888.03	108,362.54	630,370.59	20,780.77	37,798.35	704,445.13
I_6	345,556.56	54,166.49	40,539.08	2031.60	5903.72	59,339.64
I_7	10,254.63	2289.53	7539.38	476.64	105.86	8201.51
I_8	13,150.60	6368.54	9517.91	658.88	2767.79	14,748.52
I_9	37,817.72	14,129.26	30,026.08	2179.23	4033.59	39,965.81
I_{10}	88,450.18	15,173.54	81,247.45	2393.50	2634.74	86,402.59
I_{11}	41,387.15	12,037.26	8806.98	599.72	1272.61	10,050.29
I_{12}	4187.99	1135.78	5589.87	135.07	43.22	5772.25
I_{13}	99,261.08	13,428.69	81,743.76	3821.78	1348.60	92,106.15
I_{14}	50,846.69	15,659.84	24,190.22	410.00	1286.71	25,434.63
I_{15}	42,474.18	7645.81	22,175.67	749.19	230.35	23,825.16
I_{16}	35,662.03	4940.52	25,106.20	795.23	329.79	26,310.29
I_{17}	32,817.24	6018.81	35,321.30	1315.83	673.69	38,384.97

Source: [10].

3.2. Methodology

3.2.1. Grey Forecasting Model

Deng [11] first introduced the grey system theory in 1982. Since its introduction, grey theories have been used extensively in statistics. Models in this theory require only a limited amount of data in the past to predict and estimate future values [11]. So far, grey system theory has been applied in almost all fields of economics, finance, science and industry, and transportation.

In models, the grey system theory is referred to as GM (1, 1); GM (1, n); GM (2, 1); GM (2, n). The general form is GM (n , m), where n is the order of the differential equations, and m is the number of variables. There are many models, but the most commonly used model is GM (1, 1), as this model is an accurate prediction model.

In this study, the steps in the GM (1, 1) model were carried out in the following steps [11]:

From the original data range:

$$X^{(0)} = (x_{(1)}^{(0)}, x_{(2)}^{(0)}, x_{(3)}^{(0)}, \dots, x_{(n)}^{(0)}); n \geq 4. \quad (1)$$

Use the accumulating generation operation (AGO) method to compute $X^{(1)}$ values [11]:

$$X^{(1)} = (x_{(1)}^{(1)}, x_{(2)}^{(1)}, x_{(3)}^{(1)}, \dots, x_{(n)}^{(1)}); n \geq 4. \quad (2)$$

In which,

$$\begin{cases} x_{(1)}^{(0)} = x_{(1)}^{(1)} \\ x_{(k)}^{(1)} = \sum_{i=1}^k x_{(i)}^{(0)}, (k = 1, 2, 3, \dots, n) \end{cases} \quad (3)$$

Calculate the mean values $Z^{(1)}$:

$$Z^{(1)} = (z_{(2)}^{(1)}, z_{(3)}^{(1)}, z_{(4)}^{(1)}, \dots, z_{(n)}^{(1)}); n \geq 4. \quad (4)$$

In which,

$$Z_{(n)}^{(1)} = \frac{x_{(k)}^{(1)} + x_{(k-1)}^{(1)}}{2}, k = 1, 2, 3, 4 \dots; n = 2, 3, 4 \quad (5)$$

From the values of $X^{(0)}$, $Z^{(1)}$ the authors obtain the following system of equations:

$$\begin{cases} x_{(2)}^{(0)} + a \times z_{(2)}^{(1)} = b \\ x_{(3)}^{(0)} + a \times z_{(3)}^{(1)} = b \\ x_{(4)}^{(0)} + a \times z_{(4)}^{(1)} = b \end{cases} \quad (6)$$

From the above equations, transformed into the matrix form as follows:

$$B = \begin{bmatrix} -z_{(2)}^{(1)} \\ \dots \\ -z_{(n)}^{(1)} \end{bmatrix}; Y_N = \begin{bmatrix} x_{(2)}^{(0)} \\ \dots \\ x_{(n)}^{(0)} \end{bmatrix} \quad (7)$$

$$\hat{a} = \begin{bmatrix} a \\ b \end{bmatrix} = \frac{1}{(B^T B)} B^T Y_N \quad (8)$$

Use the values a and b to find the differential equation:

$$\frac{dx^{(1)}_{(k)}}{dt} + ax^{(0)} = b \quad (9)$$

Equation prediction:

$$\hat{x}^{(1)}_{(k+1)} = (\hat{x}^{(0)}_{(1)} - \frac{b}{a}) \times e^{-(ak)} + \frac{b}{a} \quad (10)$$

Use the accumulating generation operation method to calculate predictive values:

$$\hat{x}^{(0)}_{(k+1)} = \hat{x}^{(1)}_{(k+1)} - \hat{x}^{(1)}_k \quad (11)$$

The GM (1, 1) model is used in this study to predict the business performance of contractors consulting, designing, and executing traffic infrastructure works for the period 2018–2021.

3.2.2. Mean Absolute Percentage Error

To test the predictive accuracy, the authors used the mean absolute error (ε) calculated according to the formula and convention below [12].

$$\varepsilon = \frac{1}{n} \sum_{i=1}^n \frac{|\lambda_i - \hat{\lambda}_i|}{\lambda_i} \quad (12)$$

$$\begin{cases} (\varepsilon) \leq 10\% : \text{Excellent}, 10\% < (\varepsilon) \leq 20\% : \text{Good} \\ 20\% < (\varepsilon) \leq 50\% : \text{Qualified}, (\varepsilon) > 50\% : \text{Unqualified} \end{cases}$$

3.2.3. Malmquist Model

Many researchers have used the Malmquist productivity index (EMPI) to evaluate the effectiveness of many areas of the world [13–18]. In this study, the authors evaluated the technical, technology, and business efficiency of the consultants, design, and construction contractors of traffic infrastructure between the two periods $P(x_k^t, y_k^t)$ and $Q(x_k^{t+1}, y_k^{t+1})$ (as shown in Figure 2). In it, the catch-up index (ECA) is used to evaluate the technical efficiency of the contractor. The frontier-shift index (EFR) is used to evaluate the technology efficiency of the contractors. The Malmquist productivity index (EMPI) is used to evaluate the performance of contractors.

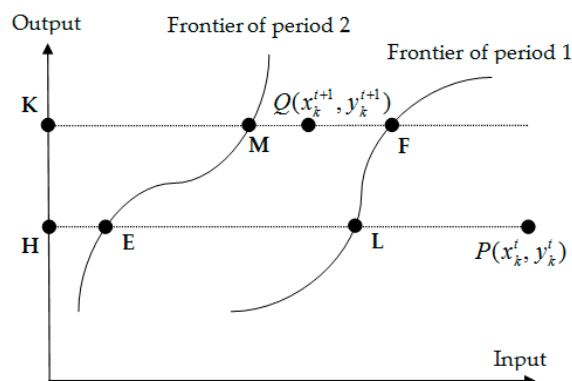


Figure 2. Catch-up terms [18].

The ECA, EFR, and EMPI indexes are used to evaluate the technical efficiency, technology efficiency, and business performance of investors at time $(t + 1)$ is the point $Q(x_k^{t+1}, y_k^{t+1})$, score for where t is the point $P(x_k^t, y_k^t)$ is calculated by the following formula.

$$ECA = \frac{KM}{KQ} \times \frac{HP}{HL} = \left[\frac{D_k^{t+1}(x_k^{t+1}, y_k^{t+1})}{D_k^t(x_k^t, y_k^t)} \right] \quad (13)$$

$$EFR = \sqrt{\frac{HL}{HE}} \times \frac{KF}{KM} = \left[\frac{D_k^t(x_k^{t+1}, y_k^{t+1})}{D_k^{t+1}(x_k^{t+1}, y_k^{t+1})} \times \frac{D_k^t(x_k^t, y_k^t)}{D_k^{t+1}(x_k^t, y_k^t)} \right]^{\frac{1}{2}} \quad (14)$$

$$\begin{aligned} EMPI &= ECA \times EFR \\ &= \left[\frac{D_k^{t+1}(x_k^{t+1}, y_k^{t+1})}{D_k^t(x_k^t, y_k^t)} \right] \times \left[\frac{D_k^t(x_k^{t+1}, y_k^{t+1})}{D_k^{t+1}(x_k^{t+1}, y_k^{t+1})} \times \frac{D_k^t(x_k^t, y_k^t)}{D_k^{t+1}(x_k^t, y_k^t)} \right]^{\frac{1}{2}} \end{aligned} \quad (15)$$

In particular:

The efficiency of investors at point (x_k^t, y_k^t) period t is determined by the following formula [19]:

$$D_k^t(x_k^t, y_k^t) = \text{Max} \varphi_k^t \quad (16)$$

$$\sum_{j=1}^n \lambda_j x_{ij}^t \leq x_{ik}^t, \quad j = 1, 2, 3, \dots, m \quad (17)$$

$$\sum_{j=1}^n \lambda_j y_{rj}^t \geq \varphi_k^t y_{rk}^t, \quad r = 1, 2, 3, \dots, s \quad (18)$$

$$\lambda_j \geq 0 \quad (19)$$

The efficiency of investors at point (x_k^t, y_k^t) period $t + 1$ is determined by the following formula [19]:

$$D_k^{t+1}(x_k^t, y_k^t) = \text{Max} \varphi_k^{t+1} \quad (20)$$

$$\sum_{j=1}^n \lambda_j x_{ij}^{t+1} \leq x_{ik}^t, \quad j = 1, 2, 3, \dots, m \quad (21)$$

$$\sum_{j=1}^n \lambda_j y_{rj}^{t+1} \geq \varphi_k^{t+1} y_{rk}^t, \quad r = 1, 2, 3, \dots, s \quad (22)$$

$$\lambda_j \geq 0 \quad (23)$$

The efficiency of investors at point (x_k^{t+1}, y_k^{t+1}) period t is determined by the following formula [19]:

$$D_k^t(x_k^{t+1}, y_k^{t+1}) = \text{Max} \varphi_k^t \quad (24)$$

$$\sum_{j=1}^n \lambda_j x_{ij}^{t+1} \leq x_{ik}^t, \quad j = 1, 2, 3, \dots, m \quad (25)$$

$$\sum_{j=1}^n \lambda_j y_{rj}^t \geq \varphi_k^t y_{rk}^{t+1}, \quad r = 1, 2, 3, \dots, s \quad (26)$$

$$\lambda_j \geq 0 \quad (27)$$

The efficiency of investors at point (x_k^{t+1}, y_k^{t+1}) period $t + 1$ is determined by the following formula [19]:

$$D_k^{t+1}(x_k^{t+1}, y_k^{t+1}) = \text{Max} \varphi_k^{t+1} \quad (28)$$

$$\sum_{j=1}^n \lambda_j x_{ij}^{t+1} \leq x_{ik}^{t+1}, \quad j = 1, 2, 3, \dots, m \quad (29)$$

$$\sum_{j=1}^n \lambda_j y_{rj}^{t+1} \geq \varphi_k^{t+1} y_{rk}^{t+1}, r = 1, 2, 3, \dots, s \quad (30)$$

$$\lambda_j \geq 0 \quad (31)$$

If the ECA, EFR, EMPI indexes are less than 1 (<1), this reflects that the technical, technological, and financial investment of the consultants, and design and construction contractors in the traffic layer during the assessment period were not effective. If these indicators are greater than 1 (>1), it is clear that the bids achieved the above three indicators during this period. These indicators are equal to 1 (=1) reflecting the performance in the comparison period corresponding to the previous period [20].

3.2.4. Correlation Coefficients

The correlation coefficient (k), first introduced in 1895, is a statistical tool used to test correlations between variables. The formula for calculating the correlation coefficient is as follows [21]:

$$k = \frac{\sum_{i=1}^n (\alpha_i - \bar{\alpha})(\delta_i - \bar{\delta})}{\left[\sum_{i=1}^n (\alpha_i - \bar{\alpha})^2 \sum_{i=1}^n (\delta_i - \bar{\delta})^2 \right]^{\frac{1}{2}}} \quad (32)$$

The value of k depends on the range $(-1; 1)$. The value of negative k denotes the inverse relationship between the two factors (if the value of this factor increases, then the other factor decreases and vice versa). The value of positive k denotes the positive correlation between the two factors (if the value of this factor increases, the value of the other factor increases; if this value decreases, the value of the other factor will decrease accordingly). The value of $k = 0$ denotes independent factors [22].

4. Results

4.1. Forecasting

Designing and executing traffic infrastructure works for the period 2018–2021, the authors use data from factor F_1 of I_{12} (Table 7) to explain the computational steps in the GM (1, 1) model used in this study (as follows).

Table 7. Data of I_{12} .

Year	F_1	F_2	F_3	F_4	F_5	F_6
2014	4032.71	1130.60	5697.05	100.94	57.37	5866.17
2015	3941.09	1127.26	4227.08	115.57	43.88	4402.08
2016	4615.74	1132.18	5321.93	125.01	42.96	5497.76
2017	4187.99	1135.78	5589.87	135.07	43.22	5772.25

From the original data range: $X^{(0)} = (4032.71; 3941.09; 4615.74; 4187.99)$

Use the accumulating generation operation method to compute $X^{(1)}$ values:

$$X^{(1)} = (4032.71; 7973.80; 12589.54; 16777.53)$$

Calculate the mean values $Z^{(1)}$: $Z^{(1)} = (6003.26; 10281.67; 14683.53)$

From the values of $X^{(0)}$, $Z^{(1)}$ the authors obtain the following system of equations:

$$\begin{cases} 3941.0853 + a \times 6003.26 = b \\ 4615.7374 + a \times 10281.67 = b \\ 4187.9907 + a \times 14683.53 = b \end{cases}$$

From the above equations, transformed into the matrix form as follows:

$$B = \begin{bmatrix} -6003.26 \\ -10281.67 \\ -14683.53 \end{bmatrix}; Y_N = \begin{bmatrix} 3941.0853 \\ 4615.7374 \\ 4187.9907 \end{bmatrix}$$

$$\begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} -0.0278 \\ 3960.8791 \end{bmatrix}$$

Use the values a and b to find the differential equation:

$$\frac{dx_{(k)}^{(1)}}{dt} - 0.0278x^{(0)} = 3960.8791$$

Equation prediction:

$$\begin{aligned} \hat{x}_{(k+1)}^{(1)} &= (4032.71 + \frac{3960.8791}{0.0278}) \times e^{0.0278k} - \frac{3960.8791}{0.0278} \\ &= 146510.3755 \times e^{0.0278k} - 142477.6655 \end{aligned}$$

In turn, the values for $k = 0, 1, 2, \dots, 7$ are given, $\hat{x}_{(k+1)}^{(1)}$ by the following values:

$$\hat{x}_{(k+1)}^{(1)} = \{4032.71; 8163.09; 12410.08; 16776.97; 21267.14; 25884.08; 30631.36; 35512.66\} \quad (33)$$

Use the accumulating generation operation method to calculate the predicted values by the formula: $\hat{x}_{(k+1)}^{(0)} = \hat{x}_{(k+1)}^{(1)} - \hat{x}_k^{(1)}$ obtains the predicted values for the years in Table 8.

Table 8. Forecast data F_1 of I_{12} .

Year	2014	2015	2016	2017	2018	2019	2020	2021
Forecast	4032.71	4130.38	4246.99	4366.89	4490.17	4616.94	4747.28	4881.30

As calculated above, the authors obtained predictive values for all elements of bidders for the period 2018–2021 which are summarized in Tables 9–12 below:

Table 9. Forecast data in 2018.

I_n	F_1	F_2	F_3	F_4	F_5	F_6
I_1	43,148.97	10,529.26	31,583.34	3002.34	743.78	35,590.60
I_2	34,876.68	8937.01	16,084.48	1427.70	914.95	18,918.35
I_3	81,722.91	8369.65	55,330.65	1166.97	616.75	54,842.26
I_4	970,992.39	464,410.49	1,528,230.15	17,007.63	105,075.32	1,645,842.91
I_5	837,908.16	158,089.65	1,010,373.13	35,425.99	80,927.61	1,146,236.67
I_6	352,912.66	55,106.43	36,489.40	1941.59	6626.52	55,128.51
I_7	10,574.94	2281.91	7373.88	497.44	106.19	8000.74
I_8	11,396.45	9067.29	2843.32	861.83	4424.96	6251.14
I_9	44,823.14	17,802.49	33,790.76	2746.82	5195.65	45,802.04
I_{10}	81,267.23	15,874.31	92,890.06	3753.24	3361.32	99,281.31
I_{11}	43,105.18	12,531.78	7512.81	592.52	1623.51	8090.65
I_{12}	4490.17	1140.29	6514.66	145.95	42.70	6697.85
I_{13}	124,451.91	14,130.21	132,385.34	5576.55	1904.47	149,909.49
I_{14}	37,470.96	15,770.61	30,520.06	469.61	1254.61	31,322.63
I_{15}	51,484.78	7509.46	17,234.57	555.00	116.78	18,751.01
I_{16}	44,165.08	5095.48	28,770.26	844.86	526.54	30,174.41
I_{17}	45,949.20	6265.79	55,965.60	1772.24	573.39	60,413.53

Table 10. Forecast data in 2019.

I_n	F_1	F_2	F_3	F_4	F_5	F_6
I_1	50,268.76	10,530.78	39,335.96	5135.68	841.40	45,135.29
I_2	38,405.69	9380.65	15,372.27	1645.09	1016.03	18,323.39
I_3	92,406.66	8360.35	70,525.62	1126.83	653.54	65,455.69
I_4	1,362,850.22	652,348.51	2,123,825.36	17,859.22	147,332.03	2,274,415.58
I_5	1,128,340.52	231,141.55	1,650,867.09	57,935.96	161,765.74	1,892,158.68
I_6	365,367.83	55,956.38	32,713.77	1815.37	7327.12	51,272.07
I_7	10,823.35	2268.44	6785.52	509.16	96.74	7383.38
I_8	9129.50	13,497.17	1389.64	1206.79	8428.18	3906.00
I_9	53,806.69	22,183.54	37,561.50	3691.75	6451.81	52,051.24
I_{10}	76,607.59	16,738.56	109,851.23	7293.26	4420.41	117,992.54
I_{11}	47,016.95	12,796.42	6273.92	595.05	2228.47	6521.79
I_{12}	4616.94	1144.59	7428.14	157.77	42.37	7609.37
I_{13}	144,387.22	14,849.66	241,883.95	8566.41	2532.30	272,267.60
I_{14}	29,524.41	15,859.39	32,487.51	544.20	1392.92	32,828.68
I_{15}	65,218.21	7392.40	15,507.31	492.67	82.55	17,042.17
I_{16}	54,172.45	5215.07	30,323.31	870.30	770.08	31,838.47
I_{17}	64,451.77	6575.94	111,382.72	2242.08	621.99	115,378.84

Table 11. Forecast data in 2020.

I_n	F_1	F_2	F_3	F_4	F_5	F_6
I_1	58,563.35	10,532.30	48,991.59	8784.90	951.83	57,239.69
I_2	42,291.79	9846.31	14,691.59	1895.59	1128.26	17,747.14
I_3	104,487.13	8351.07	89,893.44	1088.07	692.53	78,123.11
I_4	1,912,847.87	916,341.45	2,951,541.13	18,753.45	206,582.56	3,143,049.80
I_5	1,519,441.39	337,950.12	2,697,381.85	94,748.97	323,352.64	3,123,494.98
I_6	378,262.58	56,819.44	29,328.81	1697.36	8101.78	47,685.40
I_7	11,077.60	2255.05	6244.11	521.17	88.13	6813.66
I_8	7313.48	20,091.29	679.17	1689.81	16,053.07	2440.64
I_9	64,590.75	27,642.71	41,753.01	4961.74	8011.67	59,153.09
I_{10}	72,215.11	17,649.85	129,909.41	14,172.20	5813.20	140,230.21
I_{11}	51,283.70	13,066.65	5239.32	597.59	3058.84	5257.15
I_{12}	4747.28	1148.90	8469.72	170.56	42.05	8644.94
I_{13}	167,515.87	15,605.75	441,951.10	13,159.30	3367.09	494,496.04
I_{14}	23,263.11	15,948.68	34,581.79	630.64	1546.49	34,407.14
I_{15}	82,615.00	7277.16	13,953.15	437.35	58.35	15,489.06
I_{16}	66,447.39	5337.48	31,960.20	896.51	1126.29	33,594.31
I_{17}	90,404.86	6901.43	221673.89	2836.48	674.71	220,352.59

Table 12. Forecast data in 2021.

I_n	F_1	F_2	F_3	F_4	F_5	F_6
I_1	68,226.59	10,533.82	61,017.34	15,027.11	1076.76	72,590.24
I_2	46,571.11	10,335.09	14,041.06	2184.23	1252.90	17,189.01
I_3	118,146.88	8341.79	114,580.07	1050.65	733.84	93,242.00
I_4	2,684,804.91	1,287,167.27	4,101,841.54	19,692.46	289,661.07	4,343,428.75
I_5	2,046,104.07	494,114.03	4,407,301.41	154,953.26	646,347.78	5,156,132.51
I_6	391,612.42	57,695.82	26,294.10	1587.02	8958.35	44349.63
I_7	11,337.82	2241.74	5745.90	533.45	80.28	6287.90
I_8	5858.70	29,907.01	331.94	2366.17	30,576.11	1525.03
I_9	77,536.16	34,445.35	46,412.26	6668.62	9948.66	67,223.91
I_{10}	68,074.49	18,610.76	153,630.09	27,539.30	7644.83	166,658.94
I_{11}	55,937.66	13,342.59	4375.34	600.14	4198.64	4237.74
I_{12}	4881.30	1153.24	9657.34	184.37	41.73	9821.43
I_{13}	194,349.37	16,400.33	807,497.87	20,214.66	4477.08	898,110.26
I_{14}	18,329.65	16,038.46	36,811.08	730.80	1716.98	36,061.50
I_{15}	104,652.34	7163.71	12,554.75	388.24	41.24	14,077.50
I_{16}	81,503.71	5462.76	33,685.45	923.51	1647.25	35,446.97
I_{17}	126,808.59	7243.04	441,175.36	3588.46	731.90	420,833.36

To test the accuracy of the predicted values, the authors used MAPE to ensure that the results of this study were highly reliable. The results in Table 13 are as follows:

Table 13. Errors results.

I_n	MAPE (%)	I_n	MAPE (%)
I_1	3.82	I_{10}	5.12
I_2	5.01	I_{11}	3.73
I_3	1.92	I_{12}	1.78
I_4	5.38	I_{13}	6.85
I_5	15.13	I_{14}	9.90
I_6	0.99	I_{15}	13.16
I_7	3.35	I_{16}	8.08
I_8	13.55	I_{17}	16.47
I_9	3.80	Average all I_n (%)	6.94

As shown in Table 13, average $\text{all } I_n = 6.94\%$ indicates that the forecasts for contractors' business performance for the period 2018–2021 are high. In particular, the predicted data for 4/17 of contractors ranged from 10 to 20%, while the predicted data for 13 of 17 contractors had errors of less than 10%. This confirms that the GM (1, 1) model used to predict the contractor's business performance in this study is consistent with high reliability.

4.2. Correlation Coefficient

The correlation coefficients are shown in Table 14. Based on the convention mentioned in Section 3.2.4, it was found that the factors used in this study were positive (the increase in inputs would lead to the increase in output). This is in line with economic law. All coefficients are greater than 0.6, indicating that these factors have a strong correlation.

Table 14. Correlation coefficient.

	Time Period 2014						Time Period 2015					
	F_1	F_2	F_3	F_4	F_5	F_6	F_1	F_2	F_3	F_4	F_5	F_6
F_1	1.00	0.81	0.71	0.79	0.67	0.73	1.00	0.85	0.75	0.75	0.68	0.76
F_2	0.81	1.00	0.96	0.77	0.97	0.96	0.85	1.00	0.96	0.97	0.96	0.96
F_3	0.71	0.96	1.00	0.83	0.96	1.00	0.75	0.96	1.00	0.99	0.96	1.00
F_4	0.79	0.77	0.83	1.00	0.67	0.84	0.75	0.97	0.99	1.00	0.97	0.99
F_5	0.67	0.97	0.96	0.67	1.00	0.96	0.68	0.96	0.96	0.97	1.00	0.96
F_6	0.73	0.96	1.00	0.84	0.96	1.00	0.76	0.96	1.00	0.99	0.96	1.00
	Time Period 2016						Time Period 2017					
	F_1	F_2	F_3	F_4	F_5	F_6	F_1	F_2	F_3	F_4	F_5	F_6
F_1	1.00	0.83	0.87	0.92	0.85	0.87	1.00	0.89	0.92	0.93	0.92	0.92
F_2	0.83	1.00	0.97	0.77	0.99	0.97	0.89	1.00	0.97	0.81	0.98	0.96
F_3	0.87	0.97	1.00	0.88	0.99	1.00	0.92	0.97	1.00	0.92	0.99	1.00
F_4	0.92	0.77	0.88	1.00	0.84	0.89	0.93	0.81	0.92	1.00	0.90	0.93
F_5	0.85	0.99	0.99	0.84	1.00	0.99	0.92	0.98	0.99	0.90	1.00	0.99
F_6	0.87	0.97	1.00	0.89	0.99	1.00	0.92	0.96	1.00	0.93	0.99	1.00

This result shows that the data used in this study are consistent with the conditions of use of the optimal mathematical models used in this study. The conclusions of the study have sufficient grounds for assessing the technical, technological, and economic efficiency of contractors in the field of construction of transport infrastructure works.

4.3. Catch-Up Index

The catch-up index reflects the technical efficiency of the consultants, design, and construction contractors for transport infrastructure in Vietnam for the period 2014–2021, as shown in Table 15.

Table 15. The catch-up index.

(ECA)	'14-'15	'15-'16	'16-'17	'17-'18	'18-'19	'19-'20	'20-'21	Average
I ₁	0.9956	0.9211	1.0104	1.0768	1.0419	1.0380	1.0180	1.0146
I ₂	0.9718	0.9855	0.9172	1.0726	1.0179	1.0063	0.9963	0.9954
I ₃	1.0000	0.9404	1.0634	1.0000	0.9599	0.8961	0.9620	0.9745
I ₄	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
I ₅	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
I ₆	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
I ₇	0.9546	1.0145	0.9616	1.0450	1.0276	1.0000	1.0000	1.0005
I ₈	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
I ₉	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
I ₁₀	1.0000	1.0000	0.9769	0.9571	0.9936	1.0014	1.0088	0.9911
I ₁₁	0.9935	0.8856	0.8911	0.9988	1.0654	1.2272	1.0000	1.0088
I ₁₂	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
I ₁₃	0.9167	1.0966	1.0490	1.0000	1.0000	1.0000	1.0000	1.0089
I ₁₄	1.0000	1.0000	1.0000	0.9437	0.9841	0.9882	0.9828	0.9855
I ₁₅	0.9256	0.9967	0.9960	1.0410	1.0017	1.0041	1.0132	0.9969
I ₁₆	0.9121	1.0963	0.9424	1.0088	0.9947	0.9936	0.9950	0.9919
I ₁₇	0.9588	0.9491	1.0989	1.0000	1.0000	1.0000	1.0000	1.0010
Average	0.9782	0.9933	0.9945	1.0085	1.0051	1.0091	0.9986	0.9982
Max	1.0000	1.0966	1.0989	1.0768	1.0654	1.2272	1.0180	1.0146
Min	0.9121	0.8856	0.8911	0.9437	0.9599	0.8961	0.9620	0.9745
SD	0.0323	0.0523	0.0499	0.0342	0.0232	0.0626	0.0120	0.0092

The results in Table 15 and Figure 3 show that the consultants, design, and construction of transport infrastructure have not achieved technical efficiency in the period 2013–2017. Specifically, the catch-up index in this phase is less than 1 (average ECA 2014–2015 = 0.9782; average ECA 2015–2016 = 0.9933; average ECA 2016–2017 = 0.9945). However, according to the results above, in the period 2017–2020, the contractor has made changes and achieved technical efficiency. In the period 2017–2020, the catch-up index is greater than 1 (average ECA 2017–2018 = 1.0085; average ECA 2018–2019 = 1.0051; average ECA 2019–2020 = 1.0091). In particular, there are strong changes and high efficiency of three contractors (I₁, I₁₁, I₁₅). These bidders have not really achieved technical efficiency in the period 2014–2017, but, from the period 2017–2021, there are solutions to create efficiency (catch-up index is greater than 1). In addition, nine out of 17 contractors have maintained stable technical performance in the period 2017–2021, including I₄, I₅, I₆, I₇, I₈, I₉, I₁₂, I₁₃, I₁₇. However, many contractors have not yet achieved technical efficiency (I₁, I₂, I₁₀, I₁₄, I₁₆). Managers rely on this result to set up timely measures, in line with the actual situation, to improve the technical efficiency of their businesses in the future.

In construction, machinery is always a decisive factor in productivity, quality, and efficiency. Therefore, the frequent research and development of new high-tech techniques play a decisive role. On the other hand, the machinery and equipment in construction are typically of great economic value; further, the maintenance of machinery and equipment, ensuring the machinery is always operating properly and takes advantage of the capacity of machinery equipment, plays a huge role in improving the technical efficiency of contractors.

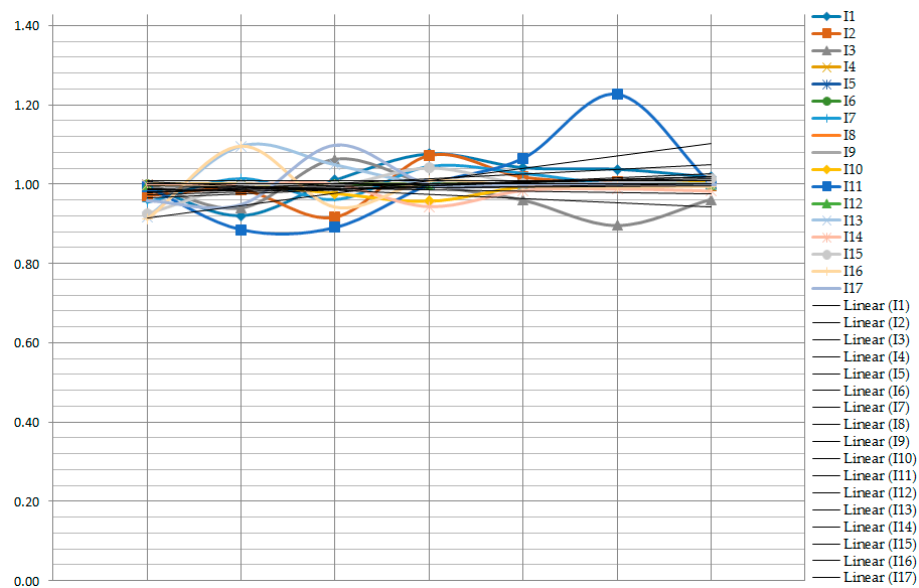


Figure 3. Catch-up index.

4.4. Frontier Index

The CFR index reflects the technological efficiency of construction contractors for transport infrastructure development. The results in Table 16 show that the technology efficiency scores of past contractors (2014–2017) and future predictions (2018–2021) are good. Specifically, the average technology efficiency scores for bidders for the period 2014–2021 are average 2014–2015: 1.0744; average 2015–2016: 1.0764; average 2016–2017: 1.0656; average 2017–2018: 1.0872; average 2018–2019: 1.0928; average 2019–2020: 1.0936; average 2020–2021: 1.0955.

Table 16. Frontier index.

(EFR)	'14-'15	'15-'16	'16-'17	'17-'18	'18-'19	'19-'20	'20-'21	Average
I ₁	1.0368	1.0291	1.0220	0.9833	1.0017	0.9990	1.0124	1.0120
I ₂	1.0407	1.0087	1.0753	0.9297	0.9813	1.0006	1.0128	1.0070
I ₃	1.0844	0.9756	1.0096	1.1078	1.1737	1.2170	1.1320	1.1000
I ₄	1.4438	1.4294	1.0633	1.2018	1.1780	1.1831	1.1799	1.2399
I ₅	1.1949	1.1485	1.1439	1.3345	1.3750	1.4227	1.4220	1.2917
I ₆	1.0948	1.1329	1.0830	1.0965	1.0616	1.0301	1.0293	1.0755
I ₇	1.0183	0.9836	1.0256	0.9536	0.9802	1.0020	1.0005	0.9948
I ₈	0.7654	1.1597	1.7164	0.9066	1.0000	1.0000	1.0000	1.0783
I ₉	1.3344	1.2253	1.0100	1.0820	1.0204	1.0138	1.0119	1.0997
I ₁₀	1.1063	0.9491	0.9558	1.0619	1.0943	1.0855	1.0147	1.0382
I ₁₁	1.0329	1.0480	1.1554	1.1902	0.9499	0.8692	1.0352	1.0401
I ₁₂	1.0000	1.1096	1.0000	1.0743	1.0621	1.0599	1.0562	1.0517
I ₁₃	1.0637	1.0108	1.0723	1.2639	1.3339	1.3365	1.3396	1.2030
I ₁₄	0.8733	1.1119	0.7263	1.0872	1.0017	0.9991	1.0193	0.9741
I ₁₅	1.0672	1.0071	1.0069	0.9640	1.0043	1.0025	0.9947	1.0067
I ₁₆	1.0757	0.9580	0.9814	1.0202	1.0112	1.0106	1.0087	1.0094
I ₁₇	1.0321	1.0111	1.0685	1.2259	1.3474	1.3590	1.3545	1.1998
Average	1.0744	1.0764	1.0656	1.0872	1.0928	1.0936	1.0955	1.0836
Max	1.4438	1.4294	1.7164	1.3345	1.3750	1.4227	1.4220	1.2917
Min	0.7654	0.9491	0.7263	0.9066	0.9499	0.8692	0.9947	0.9741
SD	0.1523	0.1210	0.1920	0.1231	0.1389	0.1545	0.1415	0.0946

Based on the results of the technology efficiency score of the contractors, as shown in Table 16 and Figure 4, the authors created three groups:

1. Highly efficient bidders in the future, including I₃, I₄, I₅, I₆, I₉, I₁₀, I₁₂, I₁₃, I₁₆, I₁₇. These bidders are expected to have a technology efficiency score greater than 1 (>1) over the period 2018–2021.
2. Contractors that maintain stable technology in the future, including I₈. This contractor is expected to be technologically stable ($=1$) over the period 2018–2021.
3. Contractors not effective in terms of technology in the future, including I₁, I₂, I₇, I₁₁, I₁₄, I₁₅. These bidders are predicted to be technologically efficient with high volatility during the period 2018–2021.

In general, construction contractors of transport works in Vietnam have approached and mastered modern technologies, improving the capacity of construction of transport works to meet the requirements of construction works. Along with that is the use of high-quality materials and application of new technology to bring high economic efficiency and longevity for the works.

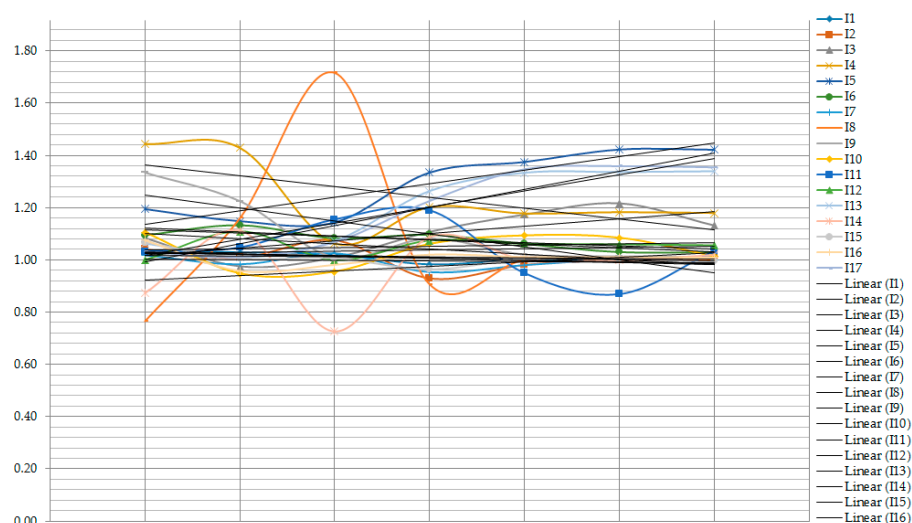


Figure 4. Frontier index.

4.5. Malmquist Index

As shown in Table 17 and Figure 5, EMPI average 2014–2018 = 1.0807, which reflects the business performance of the contractor of traffic works in general and is quite satisfactory. Specifically, according to the forecast results, in the period 2018–2021, 13 out of 17 contractors have achieved high business results, including I₁, I₃, I₄, I₅, I₆, I₉, I₁₀, I₁₁, I₁₂, I₁₃, I₁₅, I₁₆, I₁₇. In addition, 2/17 contractors are expected to maintain stable business performance during this period, including I₇, I₈. However, 2/17 of the contractors whose business results are forecasted to be ineffective include I₂, I₁₄.

Table 17. Malmquist index.

(EMPI)	'14-'15	'15-'16	'16-'17	'17-'18	'18-'19	'19-'20	'20-'21	Average
I ₁	1.0322	0.9480	1.0326	1.0588	1.0436	1.0370	1.0307	1.0261
I ₂	1.0114	0.9941	0.9863	0.9972	0.9989	1.0070	1.0090	1.0005
I ₃	1.0844	0.9174	1.0736	1.1078	1.1266	1.0905	1.0890	1.0699
I ₄	1.4438	1.4294	1.0633	1.2018	1.1780	1.1831	1.1799	1.2399
I ₅	1.1949	1.1485	1.1439	1.3345	1.3750	1.4227	1.4220	1.2917
I ₆	1.0948	1.1329	1.0830	1.0965	1.0616	1.0301	1.0293	1.0755
I ₇	0.9721	0.9979	0.9862	0.9965	1.0072	1.0020	1.0005	0.9946
I ₈	0.7654	1.1597	1.7164	0.9066	1.0000	1.0000	1.0000	1.0783
I ₉	1.3344	1.2253	1.0100	1.0820	1.0204	1.0138	1.0119	1.0997
I ₁₀	1.1063	0.9491	0.9338	1.0163	1.0872	1.0870	1.0236	1.0290
I ₁₁	1.0262	0.9281	1.0296	1.1888	1.0120	1.0667	1.0352	1.0409
I ₁₂	1.0000	1.1096	1.0000	1.0743	1.0621	1.0599	1.0562	1.0517
I ₁₃	0.9751	1.1085	1.1248	1.2639	1.3339	1.3365	1.3396	1.2118
I ₁₄	0.8733	1.1119	0.7263	1.0260	0.9858	0.9872	1.0018	0.9589
I ₁₅	0.9878	1.0038	1.0029	1.0035	1.0060	1.0066	1.0078	1.0026
I ₁₆	0.9812	1.0503	0.9250	1.0292	1.0058	1.0041	1.0037	0.9999
I ₁₇	0.9895	0.9597	1.1741	1.2259	1.3474	1.3590	1.3545	1.2014
Average	1.0513	1.0691	1.0595	1.0947	1.0972	1.0996	1.0938	1.0807
Max	1.4438	1.4294	1.7164	1.3345	1.3750	1.4227	1.4220	1.2917
Min	0.7654	0.9174	0.7263	0.9066	0.9858	0.9872	1.0000	0.9589
SD	0.1590	0.1316	0.1974	0.1128	0.1318	0.1397	0.1407	0.0973

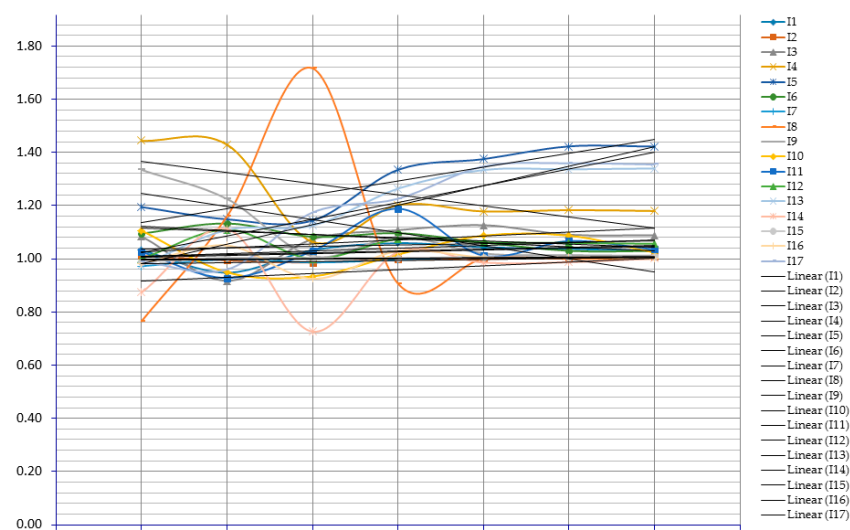


Figure 5. Malmquist index.

In order to maintain and improve business efficiency, contractors themselves must actively create, overcome difficulties, promote advantages, and exploit and make use of favorable conditions and factors of the environment and geographic location, thus combining multiple measures to maximize the use of resources and businesses to achieve optimal efficiency. The economic efficiency of production and business activities in consultancy, design, and construction of traffic works is an integrated category in many fields. In order to improve the economic efficiency of production and business activities, contractors must use the combination of measures from raising the management capacity and managing production and business activities of enterprises in the office to work. In addition to enhancing and improving all the activities within the enterprise, enterprises are always adapting to the changes of the market, i.e., adaptation to each project in different localities. Bidders must regularly maintain and ensure the balance of the relationship between parties from the construction

site, so the new office can enhance the sense of responsibility of each person, i.e., enhance the initiative in production to bring high economic efficiency.

4.6. Contractor Selection

The results of forecasting and evaluating the technical, technological, and business efficiency of the consultants, design, and construction contractors of the transport infrastructure are shown in Table 18.

Table 18. Classify contractor.

	Good Efficiency	Efficiency	Inefficiency
ECA	I ₁ , I ₁₁ , I ₁₅	I ₄ , I ₅ , I ₆ , I ₇ , I ₈ , I ₉ , I ₁₂ , I ₁₃ , I ₁₇	I ₂ , I ₃ , I ₁₀ , I ₁₄ , I ₁₆
EFR	I ₃ , I ₄ , I ₅ , I ₆ , I ₉ , I ₁₀ , I ₁₂ , I ₁₃ , I ₁₆ , I ₁₇	I ₈	I ₁ , I ₂ , I ₇ , I ₁₁ , I ₁₄ , I ₁₅
EMPI	I ₁ , I ₃ , I ₄ , I ₅ , I ₆ , I ₉ , I ₁₀ , I ₁₁ , I ₁₂ , I ₁₃ , I ₁₅ , I ₁₆ , I ₁₇	I ₇ , I ₈	I ₂ , I ₁₄

Based on these results, the government, regulatory authorities in strategy formulation, policy development, selection of consultants, and design and construction contractors have good capacity to implement projects. It is of decisive importance in ensuring the progress and quality of traffic works. The result of this business performance assessment is also a good basis for all self-revising subjects, to see where their businesses are in the overall picture of the construction investment sector to provide timely solutions to improve capacity and more effective implementation of assigned tasks.

5. Conclusions

At present, with the rapid development of the economy, demand for transportation and transportation of goods and people remains large. As a result, road, rail, waterway, and air infrastructure works are being increasingly built. Therefore, the role of contractor consulting, design, and construction of transport infrastructure has become more important and maintains a special position. The main contractor is the decisive factor affecting the quality and progress of construction of the transportation infrastructure. In this study, the authors used a modern, highly accurate forecasting method to forecast contractors' business, design, and construction contractor performance. Also, in this study, the authors used optimized mathematical models to evaluate past, present, and future contractors' technical, technological, and performance effectiveness. The result of this study is a solid basis for the government, regulatory agencies, and investors to use for strategic planning and policy development of transport infrastructure with high efficiency. The best way to do this is through the selection of contractors who have the human, financial, technical, and technological capabilities to meet the requirements of managers and investors.

In addition to the results achieved, this research still has certain limitations: It does not combine with the qualitative factors, weather factors, and government policies. In addition, many of the optimal mathematical models have not been considered in this study. The authors will continue to address these issues in subsequent studies.

Author Contributions: C.-N.W. developed and checked theoretical calculations. T.-M.L. wrote and formatted the manuscript. H.-K.N. contributed to analyzing the data. All authors have read and accepted this research.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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