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Debt Risk Evaluation of Toll Freeways in Mainland China Using the Grey Approach

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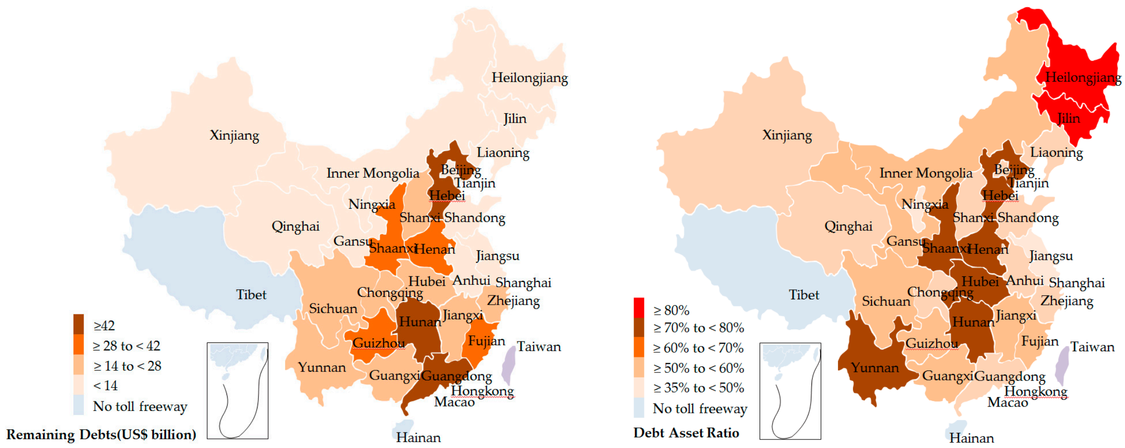
Abstract: With a proactive loan policy to raise construction funds, a large number of toll freeways have been built in Mainland China in the past three decades. However, it brought about a long-term heavy debt burden for most provincial governments. To ensure financial sustainability of toll freeways, an accurate and appropriate debt risk evaluation has become necessary. This research aims to explore debt risk factors and calculate the overall debt risk levels of toll freeways using the grey approach. Debt risk factors were identified as belonging to five categories—debt scale, debt structure, debt management, external environment, and solvency—and three new debt risk factors were added for specific concern of toll freeways—toll revenue, free cash flow, and earnings before interest, tax, depreciation, and amortization (EBITDA) margin. Debt risk levels of toll freeways in 29 provinces in Mainland China were evaluated by the proposed method and classified into three groups–low debt risk, medium debt risk, and high debt risk according to grey possibility degree ranges. Calculation results show that six provinces have low debt risk, 10 provinces have medium debt risk, and 13 provinces have high debt risk. Additionally, some specific policies to reduce toll freeway debt risk were provided based on the evaluation findings.

Keywords: toll freeways; debt risk evaluation; grey approach; grey possibility degree

1. Introduction

Toll freeways in Mainland China have attracted widespread attention, especially the financial issue [1]. Due to the support of the Chinese government, toll freeway networks in Mainland China had a rapid expansion, boosting economic development greatly in the past three decades. A toll freeway network scale of almost 133,000 kilometers had been built by the end of 2017, ranking first in the world. As a large public infrastructure, the construction of freeways needs a large amount of capital invested by the government; however, local government finance usually cannot afford such huge expenditures. To solve the problem of insufficient financial funds, the Chinese government has adopted a proactive loan policy, which allows provincial governments to obtain loans from banks to raise funds for the construction of toll freeways, and the permitted debt ratio of total construction investment for a single freeway project can be a maximum of 65%. The proactive loan policy relieves financial pressure effectively in the short-term but brings about a long-term heavy debt burden for most provincial governments. Actually, as much as 63% of the total freeway investment relies on short- and long-term loans from banks, and the total debt of toll freeways in Mainland China that needs to be repaid is more than US$ 700 billion so far.

Statistics from the Ministry of Transport (MOT) in China shown in Figure 1 reveal that, except for Tibet and Hainan (two provinces that have no toll freeways), all the other provinces have an average debt–asset ratio of 63.2% and an average remaining debt of US$20.8 billion in toll freeway; even more seriously, Jilin province has a debt–asset ratio as high as 83.7% and Hunan province has a remaining debt as much as US$ 43.6 billion [2], which indicates that toll freeways in Mainland China are facing a high debt risk. In order to prevent a debt crisis and adopt effective measures to ensure the sustainable development of toll freeways in China, debt risk factors and risk levels should be identified.



(**a**) (**b**)

Figure 1. Debt scale of toll freeways in each province in Mainland China. (**a**) Remaining debts, (**b**) debt–asset ratio.

There are two kinds of research streams concentrating on the financial issue of toll freeways in Mainland China. The first stream studies feasible pricing strategies to increase toll revenue, such as the system dynamics-based concession pricing model [3], the logit-based pricing model [4], and the congestion pricing model [5], etc. The second stream focuses on promoting Public–Private Partnership (PPP) project and Build–Operate–Transfer (BOT) projects, etc., to diversify funding sources, attract social capital, and reduce financial burden [6–8]. However, they failed to identify debt risk factors and determine the debt risk level. Comprehensive debt risk evaluation and comparison of toll freeways in Mainland China from the perspective of provincial governments have not been completely investigated.

To fill this gap, we will discuss risk factors influencing the debt of toll freeways and investigate the debt risk level of toll freeways of each provincial government in Mainland China using the grey approach. As a charging infrastructure mainly invested in by government, its debt risk can be affected by numerous potential factors, such as revenue streams [9], debt capacity [10], total liabilities [11], and so on, which make the debt risk evaluation a multi-criteria decision making (MCDM) problem with uncertainty and complexity [12]. In addition, the grey approach is an effective method, which is widely used in performance and risk evaluation with uncertain information. For better identification of risk factors and evaluation of debt risk level, this research extends the approach from three aspects, namely, (i) selecting risk factors through literature review, (ii) determining the criteria weight, and (iii) applying the grey approach to evaluate risk levels of toll freeways of each provincial government.

This research makes the following two contributions. Firstly, we precisely and comprehensively identify risk factors affecting the debt risk of toll freeways in Mainland China. Secondly, we propose a framework to evaluate and compare the debt risk level of toll freeways from the perspective of provincial governments using the grey approach.

The remainder of this paper is organized as follows. Section 2 reviews debt risk factors of highways and the application of the grey approach. Section 3 determines the evaluation criteria and introduces a methodology in detail used in this research. In Section 4, the proposed approach is applied in the debt risk evaluation problem of toll freeways in Mainland China. Section 5 presents the calculation results. Section 6 analyzes and discusses the results. Section 7 provides some important policy implications, and the conclusions are drawn in Section 8.

2. Literature Review

2.1. Debt Risk Factors of Highways

Identification of appropriate risk factors is important and necessary to carry out debt risk evaluation for highways. From the literature analysis, different debt risk factors of highways have been identified through wide-ranging literature resources, which can be classified into four categories, i.e., debt scale risk, debt structure risk, debt management risk, and external environment risk, shown in Table 1.

Table 1. Risk factor list based on literature review.

Categories	Risk Factors	Literature
Debt scale risk	Debt–asset ratio	[13–17]
	Remaining debts	[18–20]
	Repayment of principal and interest	[9,21–23]
	Cost of financing	[24]
Debt structure risk	Commercial loan ratio	[25,26]
	Proportion of short-term loans	[26,27]
Debt management risk	Debt management system	[28]
	Leadership and management skills	[28,29]
	Debt managers' skill	[28,29]
External environment risk	Policy	[28,30–32]
	Interest-rate fluctuation	[25,30,31]
	Exchange-rate fluctuation	[27,30]
	Inflation rate	[25,28,33]
	Investment from the government finance	[32,34]
	Political interference	[28,35]

To our knowledge, the literature mentioned above shows that researchers have concentrated on the debt risk factors from the perspective of a single highway project instead of the entire highway system. In addition, compared to regular highways, toll freeways have the ability to generate cash flows by the toll charging of vehicles or vehicle users, which is an important capital source for debt repayment. Another limitation of the risk factors listed above is that it is rare to consider solvency risk. In view of this, this research will conduct an in-depth debt risk analysis and establish a more comprehensive debt risk factor system. Only in this way can debt risk of toll freeways be assessed and compared accurately.

2.2. Application of the Grey Approach

The Grey approach is an effective method that can be used to evaluate the performance of alternatives and assist decision-making based on grey relationship analysis in an uncertain and inconsistent environment [36]. It has been widely used as an effective mathematical analysis of systems with uncertain information in recent years. For example, Baskaran et al. adopted the grey approach to evaluate Indian textile suppliers' sustainability and identify the best supplier based on subjective criteria [37]. Chithambaranathan et al. employed a grey-based hybrid framework for evaluating the environmental performance of service supply chains [38]. Zhang et al. solved the investment allocation problem of the whole network for the objective of energy saving using a grey theory-based energy-saving potential evaluation [39]. Wu et al. analyzed barriers to offshore wind power development using a grey-based approach [40].

Despite the wide range of applications of the grey approach, it is rare in literature to assess the debt risk level of toll freeways in Mainland China under uncertain conditions. This research chooses the grey approach as an effective method to make debt risk evaluations of toll freeways considering the following several advantages over other techniques: (i) It has a general applicability in dealing with the fuzziness situation flexibly with no strict requirements for sample size [41]; (ii) it does not need the sample to obey any statistical distribution [42]; and (iii) it can handle both quantitative and qualitative data with efficient and simple calculation [43]. Furthermore, since the impact of the criteria on debt risk of toll freeways is uncertain and a part of the evaluation criteria are qualitative, the grey approach is a suitable method to solve the problem in this research.

3. Materials and Methods

3.1. Data Collection

Since Tibet and Hainan Provinces have no toll freeways, debt risk of toll freeways in the other 29 provinces was evaluated, and their data were collected. Data adopted in this research were collected from official statistics and expert knowledge.

(i) Data on quantitative risk factors were extracted from the China Toll Freeway Statistical Yearbook published by MOT in China every year, in which data of toll freeways in each province such as toll revenue, operating cost, maintenance cost, repayment of principal and interest, taxes and dues, remaining debts, total investment, etc., are revealed. The statistical data from 2017 was used in this research.

(ii) A committee of 20 experts was formed including 7 professors from universities, who have a long-term and in-depth study of toll freeways in Mainland China, 7 officials working for MOT, who have rich experience in toll freeway management, and 6 chief financial officers from toll freeway enterprises, who have been engaged in the financial management of toll freeways for a long time. Experts were invited to judge the scores of occurrence probabilities (OPs), magnitudes of impacts (MIs), and integrated risk impacts (IRIs) for each risk factor and assess the evaluation criteria weights. The data of qualitative criteria are determined by linguistic variables.

3.2. Risk Factor Identification

Identification of appropriate risk factors is an important step to carry out debt risk evaluation and risk control [44]. To improve the risk factor system, three solvency risk factors including (i) toll revenue, (ii) free cash flow, and (iii) earnings before interest, tax, depreciation, and amortization (EBITDA) margin were newly added into the risk factors listed in Table 1.

Toll revenue is the amount of money that toll freeways actually receive from different types of vehicles during a specific period. It is the top line or gross income figure from which costs are subtracted to determine net income. Toll revenue is calculated by multiplying the toll rates of different types of vehicles by their driving mileage [45–48].

Free cash flow is the cash toll freeways generate after cash outflows to support operations and maintain its capital asset. It is a measure of profitability that excludes the non-cash expenses of the income statement and includes spending on equipment and assets as well as changes in working capital [49–52].

Free cash flow is calculated by Equation (1) as in Reference [53].

$$FCF = TR - OC - MC - I - TD \tag{1}$$

where *FCF* is free cash flow; *TR* is toll revenue; *OC* is operating cost; *MC* is maintenance cost; *I* is interest; *TD* is taxes and dues.

EBITDA margin is an assessment of operating profitability of toll freeways as a percentage of their total revenue. It is equal to earnings before interest, tax, depreciation and, amortization divided by total revenue. Because EBITDA excludes interest, depreciation, amortization, and taxes, EBITDA margin can provide a clear view of toll freeways' operating profitability [54–57].

EBITDA margin is calculated by Equation (2) as in Reference [58].

$$EBITDA\ margin = \frac{TR - OC - MC}{TR} \quad (2)$$

3.3. Risk Factor Ranking and Criteria Determination

Mean score ranking analysis was used to calculate the relative importance between risk factors described as OPs, Mis, [59] and IRIs. IRI is defined as $IRI = \sqrt{OP \times MI}$ [60]. To obtain the values of OPs and MIs, a group of 20 experts were invited to give scores to OPs and MIs of each risk factor with a 5-point system (1 = very low, 2 = low, 3 = moderate, 4 = good, and 5 = very good). Scores of OPs, Mis, and IRIs were collected and their mean scores for each debt risk factor were calculated. Risk factors were ranked by IRI values in descending order, as shown in Table 2.

Table 2. Calculation results of debt risk factors.

Risk Factors	OP	MI	IRI	Normalized Values of IRI	Ranking
Debt–asset ratio #	5.33	5.16	5.26	0.99	1
Remaining debts #	5.15	4.86	5.21	0.98	2
Free cash flow *,#	4.97	4.62	5.17	0.96	3
Toll revenue *,#	4.82	4.65	5.09	0.94	4
Investment from the government finance #	5.01	4.54	4.94	0.92	5
Proportion of short-term loans #	4.67	4.23	4.85	0.91	6
Repayment of principal and interest #	4.53	4.36	4.79	0.89	7
Commercial loan ratio #	4.31	4.14	4.65	0.86	8
EBITDA margin *,#	3.95	3.58	4.43	0.82	9
Debt management system @	3.79	3.62	4.37	0.81	10
Policy @	3.63	3.43	4.26	0.79	11
Debt managers' skill @	3.32	3.15	4.17	0.77	12
Interest rate #	3.83	3.46	3.95	0.73	13
Exchange-rate fluctuation @	3.63	2.96	3.78	0.68	14
Inflation-rate fluctuation @	3.36	3.19	3.57	0.52	15
Leadership and management skills @	3.23	2.87	3.14	0.48	16
Cost of financing #	3.06	2.75	3.05	0.42	17
Political interference @	2.84	2.56	2.76	0.32	19

Note: * refers to newly added risk factors; # refers to quantitative risk factors; @ refers to qualitative risk factors.

To determine the evaluation criteria, normalized corresponding IRIs were calculated using Equation (3)

$$Y_i = \frac{IRI_i - IRI_{min}}{IRI_{max} - IRI_{min}} \quad (3)$$

where Y_i is the normalized corresponding IRI value of ith debt risk factor; IRI_i is the mean score of ith debt risk factor's IRI; IRI_{max} and IRI_{min} are the maximum and minimum of IRI of each risk factor, respectively.

Critical risk factors were selected if their normalized values of IRI ≥0.5. As a result, 15 critical risk factors were chosen as evaluation criteria, as shown in Table 2.

3.4. The Grey Approach

This section describes the grey approach used to evaluate toll freeway debt risk based on risk criteria in detail. This method is appropriate to solve the evaluation problem in an uncertain environment.

It assumes that $S = \{S_1, S_2, \cdots, S_m\}$ is a discrete set of m alternatives. $A = \{A_1, A_2, \cdots, A_n\}$ is a set of n criteria of alternatives, which are additively independent. $\Theta w = \{\Theta w_1, \Theta w_2, \cdots, \Theta w_n\}$ is the vector of criteria weights. This research considers the criteria weights and qualitative criteria ratings value as linguistic variables [61]. Table 3 shows the linguistic criteria weights Θw and the qualitative criteria ratings value ΘG in grey numbers [62].

Table 3. The scale of criteria weights and qualitative criteria ratings value.

Scale	Θw	ΘG
Very low (VL)	[0.0,0.1]	[0,1]
Low (L)	[0.1,0.3]	[1,3]
Medium low (ML)	[0.3,0.4]	[3,4]
Medium (M)	[0.4,0.5]	[4,5]
Medium high (MH)	[0.5,0.6]	[5,6]
High (H)	[0.6,0.9]	[6,9]
Very High (VH)	[0.9,1.0]	[9,10]

The procedure of the grey approach is summarized in detail as follows.

Step 1: Form a committee of decision makers

Form a committee of decision makers who are experts with good expertise and experience in the research field. The decision group is invited to assess the criteria weights.

Step 2: Identify criteria weights

It assumes that the decision group has K decision makers, then the weight of criteria A_j can be calculated using

$$\Theta w_j = \frac{1}{K}\left[\Theta w_j^1 + \Theta w_j^2 + \cdots + \Theta w_j^K\right] \tag{4}$$

where $\Theta w_j, j = 1, 2, \cdots, n$ is the weight of criteria A_j; Θw_j^K is the weight of criteria A_j assessed by K^{th} decision maker, which can be described by grey number $\Theta w_j^K = [\underline{w}_j^K, \overline{w}_j^K]$.

Step 3: Establish the decision matrix

The decision matrix can be formulated as

$$D = \begin{bmatrix} \Theta G_{11} & \Theta G_{12} & \cdots & \Theta G_{1n} \\ \Theta G_{21} & \Theta G_{22} & \cdots & \Theta G_{2n} \\ \vdots & \vdots & \Theta G_{ij} & \vdots \\ \Theta G_{m1} & \Theta G_{m2} & \cdots & \Theta G_{mn} \end{bmatrix} \tag{5}$$

where ΘG_{ij} $(i = 1, 2, \cdots, m; j = 1, 2, \cdots, n)$ is the value of alternative S_i against criteria A_j. ΘG_{ij} can be either a linguistic variable based on grey number or a constant variable.

Step 4: Normalize the decision matrix

Normalization depends on either minimization (cost) or maximization (benefit) of criteria considered in this study.

For maximization (benefit) criteria, denote

$$\Theta G_{ij}^* = \frac{G_{ij}}{G_j^{\max}} \tag{6}$$

where $G_j^{\max} = \max\{G_{ij}\}, i = 1, 2, \cdots, m; j = 1, 2, \cdots, n$.

For minimization (cost) criteria, denote

$$\Theta G_{ij}^* = \frac{G_j^{\min}}{G_{ij}} \tag{7}$$

where $G_j^{\min} = \min\{G_{ij}\}, i = 1, 2, \cdots, m; j = 1, 2, \cdots, n$.

Then the normalized decision matrix can be expressed as

$$D^* = \begin{bmatrix} \Theta G_{11}^* & \Theta G_{12}^* & \cdots & \Theta G_{1n}^* \\ \Theta G_{21}^* & \Theta G_{22}^* & \cdots & \Theta G_{2n}^* \\ \vdots & \vdots & \Theta G_{ij}^* & \vdots \\ \Theta G_{m1}^* & \Theta G_{m2}^* & \cdots & \Theta G_{mn}^* \end{bmatrix} \quad (8)$$

The normalization method mentioned above is to preserve the property that the ranges of the normalized ΘG_{ij}^* belong to [0,1].

Step 5: Establish the weighted normalized grey decision matrix

The weighted normalized grey decision matrix is calculated by multiplying the normalized decision matrix by the criteria weight vector, $V = D^* \times \Theta w$. Considering the different weights of each criterion, the weighted normalized grey decision matrix can be established as

$$V = \begin{bmatrix} \Theta G_{11}^* & \Theta G_{12}^* & \cdots & \Theta G_{1n}^* \\ \Theta G_{21}^* & \Theta G_{22}^* & \cdots & \Theta G_{2n}^* \\ \vdots & \vdots & \Theta G_{ij}^* & \vdots \\ \Theta G_{m1}^* & \Theta G_{m2}^* & \cdots & \Theta G_{mn}^* \end{bmatrix} \times [\Theta w_1, \Theta w_2, \cdots, \Theta w_n] = \begin{bmatrix} \Theta V_{11} & \Theta V_{12} & \cdots & \Theta V_{1n} \\ \Theta V_{21} & \Theta V_{22} & \cdots & \Theta V_{2n} \\ \vdots & \vdots & \Theta V_{ij} & \vdots \\ \Theta V_{m1} & \Theta V_{m2} & \cdots & \Theta V_{mn} \end{bmatrix} \quad (9)$$

where $\Theta V_{ij} = \Theta G_{ij}^* \times \Theta w_j$.

Step 6: Set the ideal referential alternative

For m possible alternatives $S = \{S_1, S_2, \cdots, S_m\}$, the ideal referential alternative is defined as $S^{\max} = \left\{\Theta G_1^{\max}, \Theta G_2^{\max}, \cdots, \Theta G_n^{\max}\right\}$, which can be calculated as

$$S^{\max} = \{[\max_{1\le i\le m} \underline{V}_{i1}, \max_{1\le i\le m} \overline{V}_{i1}], [\max_{1\le i\le m} \underline{V}_{i2}, \max_{1\le i\le m} \overline{V}_{i2}], \cdots, [\max_{1\le i\le m} \underline{V}_{in}, \max_{1\le i\le m} \overline{V}_{in}]\}. \quad (10)$$

Step 7: Calculate the grey possibility degree value

The grey possibility degree value between alternatives $S = \{S_1, S_2, \cdots, S_m\}$ and the ideal referential alternative $S^{\max}$ can be calculated as

$$P\{S_i \le S^{\max}\} = \frac{1}{n}\sum_{j=1}^{n} P\left\{\Theta V_{ij} \le \Theta G_j^{\max}\right\} \quad (11)$$

$$P\{\Theta V_{ij} \le \Theta G_j^{\max}\} = \frac{\max[0, L^* - \max(0, \Theta\overline{V}_{ij} - \Theta \underline{G}_j^{\max})]}{L^*} \quad (12)$$

where $L^* = L(\Theta V_{ij}) + L(\Theta G_j^{\max})$, $L(\Theta V_{ij}) = \Theta\overline{V}_{ij} - \underline{V}_{ij}$, $L(\Theta G_j^{\max}) = \Theta\overline{G}_j^{\max} - \Theta\underline{G}_j^{\max}$.

Step 8: Rank the order of alternatives

When $P\{S_i \le S^{\max}\}$ is smaller, the ranking order of S_i is better. Otherwise the ranking order is worse.

4. Application of the Grey Approach

In this section, we apply the proposed grey approach to assess the toll freeway debt risk level of each province in Mainland China.

Since the Tibet and Hainan Provinces have no toll freeways, we take the other 29 provinces in Mainland China as alternatives S_i (i = 1, 2, $\cdots$, 29) against 15 evaluation criteria A_j (j = 1, 2, $\cdots$, 15) in this research, shown in Table 4. Criteria A_6, A_7, A_8, A_{12}, A_{13}, A_{14}, and A_{15} were maximization (benefit) criteria, with the greater values being better. Criteria A_1, A_2, A_3, A_4, A_5, A_9, A_{10}, and A_{11} were minimization (cost) criteria, with the smaller values being better. The detailed evaluation procedure is as follows.

Table 4. Criteria weights of toll freeway debt risk evaluation.

Categories	Risk Factors (A_j)	Unit	Θw_j
Debt scale risk	Debt–asset ratio (A_1)	%	[0.657,0.843]
	Remaining debts (A_2)	Billion USD	[0.714,0.900]
	Repayment of principal and interest (A_3)	Billion USD	[0.571,0.757]
Debt structure risk	Commercial loan ratio (A_4)	%	[0.486,0.643]
	Proportion of short-term loans (A_5)	%	[0.614,0.771]
Debt management risk	Debt management system (A_6)	-	[0.729,0.943]
	Debt managers' skill (A_7)	-	[0.451,0.625]
External environment risk	Policy (A_8)	-	[0.512,0.722]
	Interest-rate fluctuation (A_9)	-	[0.476,0.682]
	Exchange-rate fluctuation (A_{10})	-	[0.381,0.538]
	Inflation rate (A_{11})	%	[0.474,0.637]
	Investment from the government finance (A_{12})	Billion USD	[0.684,0.857]
Solvency risk	Free cash flow (A_{13})	Billion USD	[0.437,0.618]
	Toll revenue (A_{14})	Billion USD	[0.547,0.738]
	EBITDA margin (A_{15})	%	[0.671,0.816]

Step 1: Form a committee of decision makers

A committee of 20 experts was informed as presented in Section 3.1. The values of criteria weights were evaluated by the 20 experts.

Step 2: Identify criteria weights

Table 4 summarizes the results of criteria weights Θw_j calculated by Equation (4) according to the judgment of 20 experts.

Step 3: Establish the decision matrix

The decision matrix was established using Equation (5). The value of ΘG_{ij} is presented in Appendix A, Table A1.

Step 4: Normalize the decision matrix

For maximization (benefit) criteria, ΘG_{ij} ($i = 1, 2, \cdots, 29$; $j = 6, 7, 8, 12, 13, 14, 15$) are normalized by Equation (6), and for minimization (cost) criteria, ΘG_{ij} ($i = 1, 2, \cdots, 29$; $j = 1, 2, 3, 4, 5, 9, 10, 11$) are normalized by Equation (7). According to Equation (8), the normalized decision matrix is presented in Appendix A, Table A2.

Step 5: Establish the weighted normalized grey decision matrix

The weighted normalized grey decision matrix is the product of normalized decision matrix and criteria weights vector $V = D^* \times \Theta w$. According to Equation (9), the weighted normalized grey decision matrix is shown in Appendix A, Table A3.

Step 6: Identify the ideal referential alternative

Using Equation (10), the ideal referential alternative can be obtained as Equation (13).

$$S^{\max} = \{[0.66,0.84],[0.71,0.90],[0.57,0.76],[0.49,0.64],[0.59,0.77],[0.67,0.94],[0.42,0.63],[0.51,0.72],[0.48,0.68],[0.38,0.54],[0.47,0.64],[0.68,0.86],[0.44,0.62],[0.44,0.74],[0.57,0.82]\} \quad (13)$$

Step 7: Calculate the grey possibility degree value

According to Equations (11) and (12), the grey possibility degree values between the 29 alternatives S_i (i = 1, 2, $\cdots$, 29) and the ideal referential alternative $S^{\max}$ are calculated and shown as follows.

$$\begin{array}{c} P\{S_1 \le S^{\max}\} = 0.241, P\{S_2 \le S^{\max}\} = 0.567, P\{S_3 \le S^{\max}\} = 0.674, P\{S_4 \le S^{\max}\} = 0.686, \\ P\{S_5 \le S^{\max}\} = 0.523, P\{S_6 \le S^{\max}\} = 0.511, P\{S_7 \le S^{\max}\} = 0.643, P\{S_8 \le S^{\max}\} = 0.552, \\ P\{S_9 \le S^{\max}\} = 0.546, P\{S_{10} \le S^{\max}\} = 0.579, P\{S_{11} \le S^{\max}\} = 0.618, P\{S_{12} \le S^{\max}\} = 0.605, \\ P\{S_{13} \le S^{\max}\} = 0.493, P\{S_{14} \le S^{\max}\} = 0.391, P\{S_{15} \le S^{\max}\} = 0.489, P\{S_{16} \le S^{\max}\} = 0.424, \\ P\{S_{17} \le S^{\max}\} = 0.343, P\{S_{18} \le S^{\max}\} = 0.273, P\{S_{19} \le S^{\max}\} = 0.253, P\{S_{20} \le S^{\max}\} = 0.364, \\ P\{S_{21} \le S^{\max}\} = 0.632, P\{S_{22} \le S^{\max}\} = 0.324, P\{S_{23} \le S^{\max}\} = 0.360, P\{S_{24} \le S^{\max}\} = 0.458, \\ P\{S_{25} \le S^{\max}\} = 0.232, P\{S_{26} \le S^{\max}\} = 0.258, P\{S_{27} \le S^{\max}\} = 0.375, P\{S_{28} \le S^{\max}\} = 0.588, \\ P\{S_{29} \le S^{\max}\} = 0.289 \end{array} \tag{14}$$

Step 8: Rank the order of alternatives

Rank the order of 29 alternatives based on grey possibility degree value. The results are shown as follows.

$$\begin{array}{c} S_{25} > S_1 > S_{19} > S_{26} > S_{18} > S_{29} > S_{22} > S_{17} > S_{23} > S_{20} > S_{27} > S_{14} > S_{16} > S_{24} > S_{15} > S_{13} > S_6 > \\ S_5 > S_9 > S_8 > S_2 > S_{10} > S_{28} > S_{12} > S_{11} > S_{21} > S_7 > S_3 > S_4 \end{array} \tag{15}$$

5. Results

In this section, we analyze the grey possibility degree values of the 29 provinces. In order to compare debt risk levels of toll freeways, we classify the 29 provinces into three groups, i.e., "low debt risk", "medium debt risk", and "high debt risk" based on their grey possibility degree values, shown in Table 5. The first group had a grey possibility degree value ranging between >0.2 and ≤0.3, while the grey possibility degree values of the second group ranged between >0.3 and ≤0.5 and the third group ranged between >0.5 and ≤0.7, respectively. If grey possibility degree values are in the first group, the provinces fall in the category of low debt risk, which means that these provinces adhere to norms in most of the 15 criteria. If the possibility degree values belong to the second category, these provinces are medium debt risk and have to improve some aspects of the criteria. If provinces are in the category of high debt risk, they have to improve most of the criteria. The grouping can identify the important aspects, which need more attention by provincial governments to reduce debt risk levels of toll freeways.

The analysis indicates that only 6 provinces fell in the category of low debt risk, 10 provinces belonged to the category of medium debt risk and 13 provinces were in the category of high debt risk. Interestingly, there was no significant correlation between debt risk level of toll freeways and GDP level for provincial governments.

For the whole Mainland China, the grey possibility degree values over the past 15 years were calculated using the proposed grey approach. From Figure 2, we know that the grey possibility value has had a continuous increase in the past 15 years, namely, the debt risk of toll freeways in Mainland China is getting higher and higher, especially since 2010. So, we can conclude that toll freeway debt has become a great challenge and caused a high probability of debt crisis for the Chinese government.

Table 5. Grey possibility degree values of 29 provinces.

Grey Possibility Degree Range	Category	Provinces	Grey Possibility Degree Value	Ranking of GDP
$0.2 \le P\{S_i \le S^{max}\} \le 0.3$	Low debt risk	Ningxia (S_{25})	0.232	29
		Guangdong (S_1)	0.241	1
		Anhui (S_{19})	0.253	13
		Qinghai (S_{26})	0.258	30
		Shandong (S_{18})	0.273	3
		Shanghai (S_{29})	0.289	11
$0.3 < P\{S_i \le S^{max}\} \le 0.5$	Medium debt risk	Gansu (S_{22})	0.324	27
		Xinjiang (S_{17})	0.343	26
		Jilin (S_{23})	0.360	23
		Zhejiang (S_{20})	0.364	4
		Tianjin (S_{27})	0.375	19
		Jiangsu (S_{14})	0.391	2
		Liaoning (S_{16})	0.424	14
		Chongqing (S_{24})	0.458	18
		Sichuan (S_{15})	0.489	6
		Guangxi (S_{13})	0.493	17
$0.5 < P\{S_i \le S^{max}\} \le 0.7$	High debt risk	Inner Mongolia (S_6)	0.511	22
		Heilongjiang (S_5)	0.523	21
		Jiangxi (S_9)	0.546	16
		Guizhou (S_8)	0.552	25
		Hunan (S_2)	0.567	9
		Shanxi (S_{10})	0.579	24
		Beijing (S_{28})	0.588	12
		Fujian (S_{12})	0.605	10
		Hubei (S_{11})	0.618	7
		Yunnan (S_{21})	0.632	20
		Shaanxi (S_7)	0.643	15
		Henan (S_3)	0.674	5
		Hebei (S_4)	0.686	8

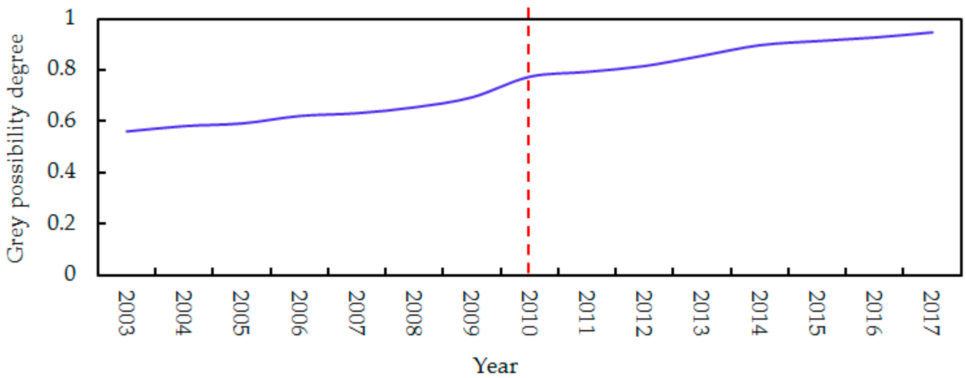


Figure 2. Grey possibility values in Mainland China over the past 15 years.

6. Discussion

This research explores risk factors affecting the debt risk of toll freeways and evaluates debt risk levels of toll freeways in each province in Mainland China to determine their debt risk state. We discuss our key findings as follows.

1. From the IRI ranking results in Table 2, debt–asset ratio, remaining debts, investment from the government finance, proportion of short-term loans, repayment of principal and interest, commercial loan ratio, debt management system, policy, debt managers' skill, interest rate, exchange-rate fluctuation, and inflation-rate fluctuation are determined as key risk factors affecting toll freeways debt. These factors were also identified as financial risk factors of highway projects by previous studies [9,13,18,26,28,30]. However, from the existing literature, we newly added solvency risk factors to improve the risk factor system, namely, free cash flow, toll revenue, and EBITDA margin. These factors can significantly measure the profitability and solvency of toll freeways [45,49,54].

2. It was found that there was no significant correlation between debt risk level of toll freeways and GDP level of provincial governments, which is in line with several previous studies [63,64]. Additionally, the whole of Mainland China had an increasing debt risk of toll freeways in the past 15 years. To our knowledge, it is because the construction of toll freeways in the whole of Mainland China has been in a rapid development period since 2010, with an average of more than 7 km new toll freeways built per year, which brought about a large scale of debt by bank loans.

7. Policy Implications

Based on risk factors and the calculation results, specific policies need to be considered to reduce debt risk. Policies are provided from debt scale, debt structure, debt management, external environment, and solvency aspects.

7.1. Debt Scale Aspect

Debt scale risk mainly comes from debt–asset ratio and remaining debts. For this concern, provincial governments should: (i) Encourage more private capital and foreign capital to invest in toll freeways, for example, governments should launch more PPP projects for newly built toll freeways, which is an effective way to save capital investment for provincial governments [65]; (ii) make a blueprint of reasonable expansion of the toll freeway network and create a level playing field for private and foreign capital investment in toll freeways [66]; (iii) for the provinces with much higher debt risks in toll freeways, like Hubei, Yunnan, Shaanxi, Henan, and Hebei, policies such as debt restructuring, debt-to-equity swap, mergers, and asset sale can also be considered to reduce the present remaining debts.

7.2. Debt Structure Aspect

Debt structure risks mainly include unreasonable commercial loan ratio and proportion of short-term loans, which usually have a higher interest rate. As a response, (i) diverse financing sources should be considered, for example, absorbing investments from creditors like insurance funds, industry foundation, etc.; (ii) transferring equity interest of toll freeways in operation is also feasible, with which construction cost can be recovered in advance, and high capital premium can even be realized.

7.3. Debt Management Aspect

Debt management system and debt managers' skill affect the level of debt management. (i) Governments should introduce a stiff loan approval system to prevent non-performing loans, and establish a scientific debt risk assessment and early warning system; (ii) managers with high debt management skills should be preferred, and training to improve debt management skills for financial staff should be conducted.

7.4. External Environment Aspect

External political and economic risk factors should be paid attention to. It is advisable to (i) be detailed with the policy change in determining concession period, and toll pricing revised by the central government; (ii) make reasonable and diverse charging strategies to increase incomes; and (iii) establish a close corporation with various types of social capital to ensure financing sources.

7.5. Solvency Aspect

Good operating performance can improve solvency. Provincial governments should ensure maximum revenue and minimum cost during the construction and operation periods of toll freeways: (i) Policies to improve service quality should be implemented to attract more users, such as reducing charge queuing time, improving pavement service performance, increasing driving safety level, and providing free, diverse real-time traffic information. Furthermore, setting competitive toll rates is another effective policy to attract more users; (ii) policies to improve management efficiency and reduce operating costs should also be adopted to increase free cash flow, including promoting the application of electronic toll collection (ETC) systems, maintenance work outsourcing, and automation equipment.

8. Conclusions

Toll freeways play an important role in promoting economic development and increasing mobility, but the debt problem has become a significant challenge for most of the provincial governments in Mainland China nowadays, which may be inclined to trigger potential debt crisis greatly. Debt risk analysis is necessary for provincial governments to ensure financial sustainability of toll freeways and it is important to identify risk factors and assess the overall debt risk level. In view of this, this research established a debt risk identification and evaluation framework of toll freeways using the grey approach based on 15 evaluation criteria. Debt risk evaluation was conducted to determine and compare debt risk levels of toll freeways in 29 provinces in Mainland China, which were classified into three categories: low debt risk, medium debt risk, and high debt risk, based on grey possibility degree values. The results show that for 29 provincial governments, 20.7% of them have low debt risk, 34.5% of them have medium debt risk, and 44.8% of provinces have high debt risk; for the whole Mainland China, the debt risk of toll freeways has been getting higher and higher in the past 15 years, especially since 2010. Accordingly, some important policy implications were proposed based on the evaluation findings. As part of highway infrastructure, debt risk evaluation and analysis of toll freeways are critical issues and attract attention from researchers. However, few studies have yet evaluated toll freeway debt risk in Mainland China from the perspective of provincial government. This research intends to contribute to the literature.

However, there are two limitations to this research. Firstly, although the number of experts involved in this research is sufficient to make judgments, more experts can be invited to improve the accuracy of the results. Secondly, other uncertainties, such as the availability of data and characterization of dynamic data should also be considered. These limitations should be taken into consideration in future work.

Author Contributions: X.M. designed the research methods and wrote the manuscript; J.G. collected and analyzed the data; X.Z. edited and revised the manuscript.

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Appendix A

Table A1. Values of 15 evaluation criteria.

Provinces	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}
Guangdong (S_1)	55.74	43.53	5.37	73.58	47.94	[1.24,3.56]	[2.66,4.54]	[2.01,3.89]	5.58	[2.47,3.27]	[3.57,5.43]	3.64	1.82	9.60	6.06
Hunan (S_2)	78.39	43.61	2.48	83.47	63.42	[0.66,1.83]	[2.21,3.97]	[1.56,3.32]	5.56	[1.73,2.29]	[1.57,2.01]	1.78	−0.16	2.29	4.23
Henan (S_3)	73.14	34.03	6.27	76.54	62.93	[1.03,3.29]	[4.49,5.63]	[3.84,4.98]	6.01	[2.75,3.65]	[2.37,3.04]	1.94	0.73	3.46	6.71
Hebei (S_4)	74.67	43.50	8.90	78.56	61.22	[0.17,1.47]	[2.66,4.54]	[2.01,3.89]	6.02	[1.85,2.45]	[2.45,3.15]	2.34	−0.45	3.58	4.57
Heilongjiang (S_5)	52.55	13.58	2.20	69.37	41.19	[5.05,7.63]	[1.28,2.11]	[0.63,1.46]	5.58	[4.07,5.39]	[3.15,4.04]	3.67	1.09	4.61	9.98
Inner Mongolia (S_6)	60.93	24.81	2.18	80.43	52.45	[3.38,4.78]	[4.56,6.16]	[5.27,6.83]	5.65	[2.18,2.89]	[1.77,2.26]	3.12	0.38	2.58	5.31
Shaanxi (S_7)	79.38	42.64	5.37	74.78	62.27	[0.31,1.65]	[2.66,5.56]	[1.07,3.97]	5.65	[2.01,2.67]	[1.89,2.42]	1.68	−0.49	2.76	4.97
Guizhou (S_8)	64.02	36.77	2.46	84.51	56.06	[1.36,2.45]	[3.15,5.35]	[1.56,3.76]	5.78	[4.52,5.99]	[2.09,3.46]	2.43	−0.77	1.59	1.13
Jiangxi (S_9)	67.42	20.00	2.25	83.99	57.98	[1.29,3.63]	[2.13,3.06]	[0.54,1.47]	5.69	[2.06,2.72]	[0.42,1.83]	2.35	0.39	2.08	5.04
Shanxi (S_{10})	57.74	23.56	2.50	76.22	49.66	[1.95,2.46]	[3.14,4.78]	[1.55,3.19]	6.05	[0.19,1.58]	[1.36,1.75]	1.56	−0.32	1.99	2.92
Hubei (S_{11})	75.39	28.69	3.77	79.51	64.84	[4.08,5.66]	[6.15,7.52]	[4.56,5.93]	5.95	[2.47,3.27]	[3.61,5.07]	1.89	−0.17	2.36	6.08
Fujian (S_{12})	68.14	35.96	3.30	78.94	58.66	[1.01,2.27]	[4.23,6.35]	[2.64,4.71]	5.84	[2.01,2.67]	[0.21,1.55]	2.02	−0.26	1.76	4.92
Guangxi (S_{13})	65.63	17.42	1.60	86.63	57.44	[0.06,1.07]	[2.16,3.31]	[0.51,1.72]	5.76	[2.51,3.32]	[1.15,3.47]	1.67	0.30	1.68	6.13
Jiangsu (S_{14})	47.02	14.22	6.65	62.07	47.44	[1.08,2.37]	[2.81,5.52]	[1.22,3.91]	5.72	[4.23,5.61]	[4.27,5.48]	3.54	1.55	6.24	10.31
Sichuan (S_{15})	51.39	12.21	1.40	67.83	44.25	[2.63,3.79]	[2.31,3.46]	[0.72,1.87]	5.82	[3.04,4.03]	[0.54,1.98]	2.11	0.97	2.25	7.49
Liaoning (S_{16})	57.80	13.21	1.21	76.3	43.71	[0.41,1.52]	[1.74,3.48]	[1.91,3.82]	6.02	[3.29,4.36]	[1.03,1.32]	2.27	0.33	1.51	0.83
Xinjiang (S_{17})	58.23	8.49	0.94	76.86	46.08	[1.06,2.08]	[3.11,4.51]	[3.42,4.95]	5.92	[2.47,3.27]	[2.81,4.04]	1.68	−0.09	1.19	0.64
Shandong (S_{18})	82.08	12.57	0.78	88.35	68.59	[3.43,5.54]	[0.37,1.34]	[0.41,1.47]	5.86	[5.71,7.57]	[1.52,2.67]	1.32	−0.33	0.76	13.94
Anhui (S_{19})	66.52	12.40	0.06	87.81	53.21	[0.47,1.59]	[1.41,2.42]	[1.55,2.66]	5.79	[1.07,1.42]	[2.86,3.67]	2.14	0.50	4.18	2.61
Zhejiang (S_{20})	56.54	23.77	3.56	74.63	44.62	[1.79,2.99]	[2.28,2.84]	[2.51,3.12]	5.75	[3.29,4.36]	[3.72,4.75]	2.35	1.55	5.41	8.07
Yunnan (S_{21})	72.09	26.01	4.01	95.16	62.53	[1.24,3.56]	[4.58,5.92]	[5.03,6.51]	5.82	[1.19,1.58]	[1.22,1.56]	2.03	−0.26	1.78	2.94
Gansu (S_{22})	65.19	14.12	0.89	86.05	56.06	[0.66,1.83]	[1.16,2.72]	[1.27,2.99]	5.68	[3.17,4.29]	[0.52,1.95]	1.95	0.01	2.22	0.94
Jilin (S_{23})	83.73	13.57	0.99	91.52	72.01	[1.03,3.29]	[0.58,1.35]	[0.64,1.48]	5.92	[2.06,2.72]	[1.51,2.65]	1.34	−0.28	0.74	5.03
Chongqing (S_{24})	58.48	15.37	1.34	77.19	50.29	[0.17,1.47]	[1.37,1.84]	[1.51,2.02]	5.63	[1.77,2.34]	[1.98,3.25]	1.08	0.16	1.43	4.38
Ningxia (S_{25})	37.91	1.80	0.13	50.04	32.68	[5.05,7.63]	[2.64,3.92]	[2.86,4.29]	5.87	[1.33,2.44]	[2.43,4.55]	1.24	0.11	0.63	0.81
Qinghai (S_{26})	54.43	3.03	0.14	71.85	43.81	[3.38,4.78]	[2.94,5.41]	[3.23,5.94]	5.86	[2.29,3.38]	[2.31,4.38]	0.95	0.02	0.44	0.77
Tianjin (S_{27})	71.12	9.44	1.01	93.88	56.16	[0.31,1.65]	[1.69,2.67]	[1.86,2.93]	5.91	[1.52,2.02]	[1.52,2.67]	1.42	−0.11	0.76	3.73
Beijing (S_{28})	59.82	8.54	2.74	78.96	56.45	[1.36,2.45]	[0.28,1.66]	[0.31,1.82]	6.03	[1.89,2.51]	[1.71,2.91]	2.06	0.12	1.04	4.66
Shanghai (S_{29})	39.67	3.55	1.05	52.36	41.12	[1.29,3.63]	[2.61,4.33]	[2.87,4.72]	5.97	[3.12,4.14]	[2.52,4.67]	1.52	0.20	0.76	7.62

Table A2. Normalized decision value.

S_i	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}
S_1	0.68	0.04	0.01	0.68	0.68	[0.25,0.47]	[0.43,0.60]	[0.38,0.57]	1.00	[0.28,0.43]	[0.06,0.24]	0.99	1.00	1.00	0.43
S_2	0.48	0.04	0.02	0.60	0.52	[0.13,0.24]	[0.36,0.53]	[0.31,0.49]	1.00	[0.11,0.62]	[0.13,0.66]	0.49	0.09	0.24	0.30
S_3	0.52	0.05	0.01	0.65	0.52	[0.21,0.43]	[0.63,0.75]	[0.61,0.73]	0.93	[0.17,0.39]	[0.09,0.43]	0.53	0.40	0.36	0.48
S_4	0.51	0.04	0.01	0.64	0.53	[0.03,0.19]	[0.43,0.60]	[0.38,0.57]	0.92	[0.10,0.58]	[0.09,0.42]	0.64	0.25	0.37	0.33
S_5	0.72	0.13	0.03	0.72	0.79	[0.96,1.00]	[0.21,0.28]	[0.12,0.21]	1.00	[0.05,0.26]	[0.07,0.33]	1.00	0.60	0.48	0.72
S_6	0.62	0.07	0.03	0.62	0.62	[0.62,0.68]	[0.74,0.82]	[0.92,1.00]	0.98	[0.09,0.49]	[0.12,0.58]	0.85	0.21	0.27	0.38
S_7	0.48	0.04	0.01	0.67	0.52	[0.06,0.22]	[0.43,0.74]	[0.21,0.58]	0.98	[0.09,0.53]	[0.11,0.55]	0.46	0.27	0.29	0.36
S_8	0.59	0.05	0.02	0.59	0.58	[0.27,0.32]	[0.51,0.71]	[0.32,0.55]	0.96	[0.04,0.24]	[0.10,0.38]	0.66	0.42	0.17	0.08
S_9	0.56	0.09	0.03	0.60	0.56	[0.26,0.48]	[0.35,0.41]	[0.10,0.22]	0.98	[0.09,0.52]	[0.50,0.72]	0.64	0.21	0.22	0.36
S_{10}	0.66	0.08	0.02	0.66	0.66	[0.32,0.39]	[0.51,0.64]	[0.29,0.47]	0.92	[0.81,0.92]	[0.15,0.75]	0.43	0.18	0.21	0.21
S_{11}	0.50	0.06	0.02	0.63	0.50	[0.74,0.81]	[0.93,1.00]	[0.77,0.87]	0.93	[0.08,0.43]	[0.06,0.26]	0.51	0.09	0.25	0.44
S_{12}	0.56	0.05	0.02	0.63	0.56	[0.21,0.32]	[0.69,0.84]	[0.50,0.69]	0.95	[0.09,0.53]	[0.85,1.00]	0.55	0.14	0.18	0.35
S_{13}	0.58	0.10	0.04	0.58	0.57	[0.01,0.14]	[0.35,0.44]	[0.10,0.25]	0.97	[0.08,0.43]	[0.18,0.38]	0.46	0.16	0.18	0.44
S_{14}	0.81	0.13	0.01	0.81	0.69	[0.21,0.31]	[0.46,0.73]	[0.23,0.57]	0.97	[0.04,0.25]	[0.05,0.24]	0.96	0.85	0.65	0.74
S_{15}	0.74	0.15	0.04	0.74	0.74	[0.42,0.53]	[0.38,0.46]	[0.14,0.27]	0.96	[0.06,0.35]	[0.39,0.67]	0.57	0.53	0.23	0.54
S_{16}	0.66	0.14	0.05	0.66	0.75	[0.08,0.21]	[0.28,0.46]	[0.36,0.56]	0.92	[0.06,0.33]	[0.20,1.00]	0.62	0.18	0.16	0.06
S_{17}	0.65	0.21	0.06	0.65	0.71	[0.21,0.27]	[0.51,0.62]	[0.65,0.72]	0.94	[0.08,0.43]	[0.07,0.33]	0.46	0.05	0.12	0.05
S_{18}	0.46	0.14	0.08	0.57	0.48	[0.68,0.73]	[0.06,0.18]	[0.08,0.22]	0.95	[0.03,0.19]	[0.14,0.49]	0.36	0.18	0.08	1.00
S_{19}	0.57	0.15	1.00	0.57	0.61	[0.09,0.21]	[0.23,0.32]	[0.29,0.39]	0.96	[0.18,1.00]	[0.07,0.36]	0.58	0.27	0.44	0.19
S_{20}	0.67	0.08	0.02	0.67	0.73	[0.35,0.39]	[0.37,0.48]	[0.38,0.46]	0.97	[0.06,0.33]	[0.06,0.28]	0.64	0.85	0.56	0.58
S_{21}	0.53	0.07	0.01	0.53	0.52	[0.25,0.47]	[0.74,0.79]	[0.83,0.95]	0.96	[0.16,0.90]	[0.17,0.85]	0.55	0.14	0.19	0.21
S_{22}	0.58	0.13	0.07	0.58	0.58	[0.13,0.24]	[0.19,0.36]	[0.24,0.44]	0.98	[0.06,0.33]	[0.40,0.68]	0.53	0.01	0.23	0.07
S_{23}	0.45	0.13	0.06	0.55	0.45	[0.22,0.43]	[0.09,0.18]	[0.12,0.22]	0.94	[0.09,0.52]	[0.14,0.50]	0.37	0.15	0.08	0.36
S_{24}	0.65	0.12	0.04	0.65	0.65	[0.03,0.19]	[0.12,0.24]	[0.29,0.35]	0.99	[0.11,0.61]	[0.11,0.41]	0.29	0.09	0.15	0.31
S_{25}	1.00	1.00	0.46	1.00	1.00	[0.95,1.00]	[0.43,0.52]	[0.54,0.63]	0.95	[0.14,0.58]	[0.09,0.29]	0.34	0.06	0.07	0.06
S_{26}	0.70	0.59	0.43	0.70	0.75	[0.63,0.67]	[0.48,0.72]	[0.61,0.87]	0.95	[0.08,0.42]	[0.09,0.30]	0.26	0.01	0.05	0.06
S_{27}	0.53	0.19	0.06	0.53	0.58	[0.06,0.22]	[0.27,0.36]	[0.35,0.43]	0.94	[0.13,0.70]	[0.14,0.49]	0.39	0.06	0.08	0.27
S_{28}	0.63	0.21	0.02	0.63	0.58	[0.27,0.32]	[0.05,0.22]	[0.06,0.27]	0.92	[0.10,0.57]	[0.12,0.45]	0.56	0.07	0.11	0.33
S_{29}	0.96	0.51	0.06	0.96	0.79	[0.26,0.48]	[0.42,0.58]	[0.54,0.69]	0.93	[0.06,0.34]	[0.08,0.28]	0.41	0.11	0.08	0.55

Table A3. Grey weighted normalized decision value.

S_i	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}
S_1	[0.35,0.49]	[0.02,0.03]	[0.00,0.01]	[0.47,0.58]	[0.26,0.37]	[0.15,0.36]	[0.19,0.38]	[0.28,0.54]	[0.44,0.62]	[0.15,0.32]	[0.04,0.20]	[0.57,0.75]	[0.66,0.84]	[0.71,0.92]	[0.21,0.28]
S_2	[0.25,0.35]	[0.02,0.03]	[0.00,0.01]	[0.41,0.51]	[0.20,0.28]	[0.08,0.19]	[0.16,0.33]	[0.23,0.46]	[0.44,0.62]	[0.06,0.46]	[0.09,0.54]	[0.28,0.37]	[0.06,0.08]	[0.17,0.22]	[0.15,0.19]
S_3	[0.27,0.38]	[0.02,0.03]	[0.00,0.01]	[0.44,0.56]	[0.20,0.28]	[0.13,0.33]	[0.28,0.47]	[0.44,0.69]	[0.41,0.57]	[0.09,0.29]	[0.06,0.35]	[0.30,0.41]	[0.26,0.34]	[0.26,0.32]	[0.23,0.31]
S_4	[0.26,0.37]	[0.02,0.03]	[0.00,0.01]	[0.44,0.55]	[0.20,0.29]	[0.02,0.15]	[0.19,0.38]	[0.28,0.54]	[0.40,0.57]	[0.05,0.43]	[0.06,0.34]	[0.37,0.48]	[0.16,0.21]	[0.26,0.33]	[0.16,0.21]
S_5	[0.37,0.52]	[0.06,0.09]	[0.01,0.02]	[0.49,0.62]	[0.30,0.43]	[0.59,0.77]	[0.09,0.18]	[0.09,0.2]	[0.44,0.62]	[0.03,0.19]	[0.05,0.27]	[0.57,0.76]	[0.39,0.51]	[0.34,0.43]	[0.35,0.46]
S_6	[0.32,0.45]	[0.03,0.05]	[0.01,0.02]	[0.42,0.53]	[0.24,0.33]	[0.38,0.52]	[0.33,0.51]	[0.67,0.94]	[0.43,0.61]	[0.05,0.36]	[0.08,0.47]	[0.49,0.64]	[0.14,0.18]	[0.19,0.24]	[0.18,0.24]
S_7	[0.25,0.35]	[0.02,0.03]	[0.00,0.01]	[0.46,0.57]	[0.20,0.28]	[0.04,0.17]	[0.19,0.46]	[0.15,0.55]	[0.43,0.61]	[0.05,0.39]	[0.07,0.45]	[0.26,0.35]	[0.18,0.23]	[0.21,0.26]	[0.17,0.23]
S_8	[0.30,0.43]	[0.02,0.03]	[0.00,0.01]	[0.40,0.51]	[0.22,0.31]	[0.17,0.25]	[0.23,0.44]	[0.23,0.52]	[0.42,0.59]	[0.02,0.18]	[0.07,0.31]	[0.38,0.50]	[0.28,0.35]	[0.12,0.15]	[0.04,0.05]
S_9	[0.29,0.40]	[0.04,0.06]	[0.01,0.02]	[0.41,0.51]	[0.21,0.30]	[0.16,0.37]	[0.16,0.26]	[0.07,0.21]	[0.43,0.61]	[0.05,0.38]	[0.34,0.59]	[0.37,0.48]	[0.14,0.18]	[0.16,0.24]	[0.17,0.23]
S_{10}	[0.34,0.48]	[0.04,0.05]	[0.00,0.01]	[0.45,0.57]	[0.25,0.36]	[0.21,0.30]	[0.23,0.40]	[0.21,0.44]	[0.40,0.57]	[0.44,0.68]	[0.10,0.61]	[0.25,0.33]	[0.12,0.15]	[0.15,0.19]	[0.10,0.14]
S_{11}	[0.26,0.36]	[0.03,0.04]	[0.00,0.01]	[0.43,0.54]	[0.19,0.27]	[0.45,0.62]	[0.42,0.63]	[0.56,0.82]	[0.41,0.57]	[0.04,0.32]	[0.04,0.21]	[0.29,0.39]	[0.06,0.08]	[0.18,0.23]	[0.21,0.28]
S_{12}	[0.29,0.40]	[0.02,0.03]	[0.00,0.01]	[0.43,0.54]	[0.21,0.30]	[0.13,0.25]	[0.31,0.53]	[0.36,0.65]	[0.42,0.59]	[0.05,0.39]	[0.57,0.82]	[0.31,0.42]	[0.09,0.12]	[0.13,0.16]	[0.17,0.23]
S_{13}	[0.30,0.42]	[0.05,0.07]	[0.02,0.03]	[0.41,0.50]	[0.22,0.31]	[0.01,0.11]	[0.16,0.28]	[0.07,0.24]	[0.42,0.60]	[0.04,0.32]	[0.12,0.31]	[0.26,0.35]	[0.11,0.13]	[0.13,0.16]	[0.21,0.28]
S_{14}	[0.41,0.58]	[0.06,0.09]	[0.00,0.01]	[0.55,0.69]	[0.26,0.37]	[0.13,0.24]	[0.21,0.46]	[0.17,0.54]	[0.42,0.60]	[0.02,0.18]	[0.03,0.20]	[0.55,0.73]	[0.56,0.72]	[0.46,0.59]	[0.36,0.48]
S_{15}	[0.38,0.53]	[0.07,0.10]	[0.02,0.03]	[0.51,0.63]	[0.28,0.40]	[0.26,0.41]	[0.17,0.29]	[0.10,0.25]	[0.42,0.59]	[0.03,0.26]	[0.26,0.55]	[0.33,0.43]	[0.35,0.45]	[0.16,0.21]	[0.26,0.35]
S_{16}	[0.34,0.48]	[0.07,0.10]	[0.02,0.03]	[0.45,0.57]	[0.29,0.40]	[0.05,0.16]	[0.13,0.29]	[0.26,0.53]	[0.40,0.57]	[0.03,0.24]	[0.13,0.82]	[0.35,0.47]	[0.12,0.15]	[0.11,0.14]	[0.03,0.04]
S_{17}	[0.33,0.47]	[0.10,0.14]	[0.03,0.04]	[0.44,0.56]	[0.27,0.38]	[0.13,0.21]	[0.23,0.39]	[0.47,0.68]	[0.41,0.58]	[0.04,0.32]	[0.05,0.27]	[0.26,0.35]	[0.03,0.04]	[0.09,0.11]	[0.02,0.03]
S_{18}	[0.24,0.33]	[0.07,0.10]	[0.04,0.05]	[0.39,0.49]	[0.18,0.26]	[0.42,0.56]	[0.03,0.11]	[0.06,0.21]	[0.42,0.59]	[0.02,0.14]	[0.09,0.40]	[0.21,0.27]	[0.12,0.15]	[0.06,0.07]	[0.49,0.64]
S_{19}	[0.29,0.41]	[0.07,0.10]	[0.47,0.64]	[0.39,0.49]	[0.23,0.33]	[0.06,0.16]	[0.11,0.20]	[0.21,0.37]	[0.42,0.59]	[0.10,0.74]	[0.05,0.29]	[0.33,0.44]	[0.18,0.23]	[0.31,0.46]	[0.09,0.12]
S_{20}	[0.34,0.48]	[0.04,0.05]	[0.01,0.03]	[0.46,0.57]	[0.28,0.39]	[0.21,0.30]	[0.17,0.30]	[0.28,0.43]	[0.42,0.60]	[0.03,0.24]	[0.04,0.23]	[0.37,0.48]	[0.56,0.72]	[0.41,0.55]	[0.28,0.37]
S_{21}	[0.27,0.38]	[0.03,0.05]	[0.02,0.03]	[0.36,0.45]	[0.20,0.28]	[0.15,0.36]	[0.33,0.49]	[0.61,0.90]	[0.42,0.59]	[0.09,0.66]	[0.11,0.69]	[0.31,0.42]	[0.09,0.12]	[0.14,0.17]	[0.10,0.14]
S_{22}	[0.30,0.42]	[0.06,0.09]	[0.03,0.04]	[0.41,0.50]	[0.22,0.31]	[0.08,0.19]	[0.09,0.23]	[0.17,0.41]	[0.43,0.61]	[0.03,0.24]	[0.27,0.55]	[0.30,0.41]	[0.01,0.01]	[0.16,0.21]	[0.03,0.05]
S_{23}	[0.23,0.32]	[0.06,0.09]	[0.03,0.04]	[0.38,0.47]	[0.17,0.24]	[0.14,0.33]	[0.04,0.11]	[0.09,0.21]	[0.41,0.58]	[0.05,0.38]	[0.09,0.41]	[0.21,0.28]	[0.1,0.13]	[0.06,0.07]	[0.17,0.23]
S_{24}	[0.33,0.47]	[0.06,0.08]	[0.02,0.03]	[0.44,0.56]	[0.25,0.35]	[0.02,0.15]	[0.05,0.15]	[0.21,0.33]	[0.43,0.61]	[0.06,0.45]	[0.07,0.33]	[0.17,0.22]	[0.06,0.08]	[0.11,0.14]	[0.15,0.20]
S_{25}	[0.51,0.72]	[0.48,0.68]	[0.22,0.29]	[0.68,0.86]	[0.38,0.54]	[0.58,0.77]	[0.19,0.33]	[0.39,0.59]	[0.42,0.59]	[0.08,0.43]	[0.06,0.24]	[0.19,0.26]	[0.04,0.05]	[0.05,0.06]	[0.03,0.04]
S_{26}	[0.36,0.51]	[0.28,0.40]	[0.21,0.27]	[0.48,0.60]	[0.29,0.40]	[0.39,0.52]	[0.22,0.45]	[0.44,0.82]	[0.42,0.59]	[0.04,0.31]	[0.06,0.24]	[0.15,0.21]	[0.01,0.01]	[0.04,0.05]	[0.03,0.04]
S_{27}	[0.27,0.38]	[0.09,0.13]	[0.03,0.04]	[0.36,0.45]	[0.22,0.31]	[0.04,0.17]	[0.12,0.23]	[0.26,0.41]	[0.41,0.58]	[0.07,0.52]	[0.09,0.40]	[0.22,0.30]	[0.04,0.05]	[0.06,0.07]	[0.13,0.17]
S_{28}	[0.32,0.45]	[0.1,0.14]	[0.01,0.08]	[0.43,0.54]	[0.22,0.31]	[0.17,0.25]	[0.02,0.14]	[0.04,0.25]	[0.40,0.57]	[0.05,0.42]	[0.08,0.37]	[0.32,0.42]	[0.05,0.06]	[0.08,0.13]	[0.16,0.21]
S_{29}	[0.49,0.69]	[0.24,0.35]	[0.03,0.07]	[0.66,0.82]	[0.30,0.43]	[0.16,0.37]	[0.19,0.36]	[0.39,0.65]	[0.41,0.57]	[0.03,0.25]	[0.05,0.23]	[0.23,0.31]	[0.07,0.09]	[0.06,0.07]	[0.27,0.35]

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