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Research Article

The Portfolio Balanced Risk Index Model and Analysis of Examples of Large-Scale Infrastructure Project

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This paper focuses on a three-dimensional portfolio balanced risk index model for large-scale infrastructure project risk evaluation as a hot topic of current research. Taking subjectivity utility and complex evaluation motivation into consideration, a method of combinational equilibrium evaluation is built using the index form to reflect whole loss changes of risk. For risk index evaluation and measurement issues, this paper first constructs a risk evaluation index system and three risk coefficients of single factor by questionnaire survey and fuzzy evaluation. Then we calculate the risk index of single factor, which arrives at the classification and combination risk index through AHP method. Finally, we verify the index validity by analysis of examples. With this research we expand the evaluation dimension and provide a new analytical tool for risk monitoring and warning.

1. Introduction

In the near future, major infrastructure project investment will prove to be a pivotal means of improving people's livelihood and promoting a healthy and sustainable development of China's national economy. How to scientifically and reasonably carry on the dynamic evaluation will influence the control, solution, and even the success of the project. Project risk refers to the deviation between the final result and expected subject or the loss due to the existence of uncertain factors. In the joint action of internal and external environment change and multiple subject game, major infrastructure project risk is a complex and evolved dynamic making project risk evaluation more difficult. Project risk measurement methods in the existing literature include variance, standard deviation, the product of probability and loss [1], and average value of personal injury and property losses [2].

Among them, using dynamic, comparative, integrative, and average characteristics, a project risk index is a more intuitive approach reflecting the project risk in numerical form on the basis of unified dimension [3–6]; for example, coast corrosion risk index can be divided into stable, low, medium, and high level according to corrosion rate led by coastal vulnerability and development degree (Guido Benassai, et al., 2015). In order to better conduct evaluation of risk parameters, based on existing fuzzy mathematical models, like fuzzy differential equations, integrodifferential equations, group decision-making [7], interval number [8], and so forth, this paper builds a portfolio balance index model (PBIM) for project risk to reflect the multidimensional combination value losses by combined dynamic equilibrium index and provides analysis tools for early warning and monitoring. The innovation points can be listed as follows: first, it changes the common practice of the individual project subject evaluation and lets all item subjects participate in the project risk evaluation; second, psychological utility factors are added in the project risk severity evaluation, which breaks through the two-dimensional evaluation method of probability multiplying the objective loss; third, group intuitionistic fuzzy evaluation and statistical analysis are used to determine the risk parameters, which can reflect all the will and preferences of the project.

Research ideas and methods of this article are as follows: (1) to filter main risk indicators through typical case analysis, questionnaire investigation, and statistical analysis, (2) to construct risk evaluation index system and design index weight by analytic hierarchy process, (3) to build a project risk portfolio balance evaluation model and add main psychological effect factors based on traditional two-dimensional evaluation, which can make up the limitations of the evaluation of project risk material loss and at the same time make the project risk assessment have subjective and objective characteristics, and (4) to do questionnaire survey in fuzzy evaluation of project risk parameters. The average data reflects a collection of plural value preference, which can effectively make up disadvantages of single subject evaluation and make project risk assessment into a group of decision-making behaviors. A project risk index can not only make value loss explicit and comparable, but can also provide evidence to analyze and offer reasons for project changes and risk strategy.

2. The Theoretical Basis of Major Infrastructure Project Portfolio Balance Risk Index Model Construction

The risk portfolio balance index model of major infrastructure projects must be based on multidimensional value impact and evaluation of complex decision-making motivation analysis, because they jointly determine game design ideas of model parameters and a combined calculation method of risk index.

2.1. The Subjective and Objective Value of Project Risk Impact Analysis. General project risk evaluation only considers the probability of occurrence and the objective severity; however, project risk bears the characteristics of subjectivity and objectivity. Risk is the result of subjective evaluation wherein even the same project risk has different implications for different subject [9]. As a result, subject factors must be considered in risk assessment. The aim of rational behavior subject is to pursue comprehensive utility maximization [10] instead of simple profit maximization.

Project risk evaluation should not only consider objective value losses, but also measure the damage to the subject itself and others' well-being and satisfaction [11]. Therefore, a three-dimensional evaluation method used in project risk assessment (probability + objective severity + subjective utility loss) is a more scientific approach than the usual two-dimensional evaluation method (probability + objective severity). Objective loss refers to material loss caused by problems to project value such as a decrease of project quality, construction schedule delay, safety performance degradation, profit reduction, and rising costs. Subjective utility cost refers to all types of emotional damage and the subjective judgment value decline led by the risk to project subject. Emotional damage includes psychological fear, anxiety, frustration, discontent, injustice, and impatience.

2.2. The Complex Psychological Motivation Analysis of Evaluation Subject. Behavioral economics describes associated subjects of major infrastructure projects as "complex economic men." They have many preferences including risk aversion, altruism, and fairness preference. When evaluating project risk, they not only consider their own risk losses, but also take the risk of other associated subjects into account. They not only consider the material loss brought on by the risk, but also consider psychology utility loss. A project subject is based on a complex collection of preferences when making risk assessment decisions [12, 13]. In order to validate the above viewpoint, the questionnaire shown in Table 1 investigates the complex evaluation motivation of a project subject.

Issuing 100 questionnaires to related subjects of major infrastructure project in a mobile Internet platform, we had 96 valid questionnaires returned, indicating that 96% of respondents would both consider the social, environmental, and ecological value loss, while only 4% of respondents reported they would only consider the economic loss. Of respondents, 89% stated they would also consider personal emotion, risk capacity, and psychological disutility, and only 11% of the respondents would merely consider material loss. Of respondents, 82% said they would consider the interest and feelings of other related subjects, while only 18% reported they would consider only their own interest loss and subjective feeling. 98% of respondents indicated they would both consider other related subjects' behavior strategy reactions, and only 2% of the respondents would only consider their own behavior strategy. The survey suggests that most related subjects would consider economic, social, environmental, and ecological value loss, nonmaterial psychological utility cost, and behavior strategy reactions of correlation subjects. Therefore, building a framework, which contains factors such as risk probability, objective severity, and psychological utility loss makes the interactive equilibrium evaluation a more reasonable and scientific approach.

3. Construction of a Project Risk Portfolio Balance Evaluation Index System of a Major Infrastructure Project

The construction of an evaluation index system is the key to calculating a project risk index and to screen and sort risk factors within the whole life cycle of a major infrastructure project based on many case studies and questionnaires. The objective is to use the principles of importance, representativeness, and conciseness and to select appropriate main risk factors in order to form a project risk evaluation index system according to the nature of the classification.

(1) Questionnaire and Statistical Analysis of Project Risk Factors Screening. First, the main risk factors based on many case studies throughout the life cycle of major infrastructure projects are listed [14]. Then, the project risk factors list is sent to the related subjects for their additional inclusions or modifications in order to determine the main project risk factors which are established after 2-3 rounds of feedback and changes. Finally, respondents would score the occurrence probability and severity of risk factors by five-mark scoring. For the occurrence probability of risk factors, five-mark scoring ranges are as follows: 1 = *extremely unlikely*, 2 = *slim chance*, 3 = *certain possibility*, 4 = *high possibility*, and 5 = *most*

Table 1: Subject risk evaluation motivation questionnaire of major infrastructure projects.

Answer choices	Survey questions
□ Only consider the former □ Consider all factors	(1) Whether you only consider the economic loss or you consider the social, environmental and ecological value loss when evaluating project risk?
□ Only consider the former □ Consider all factors	(2) Whether you only consider the material loss or you consider the personal emotion, risk capacity and psychological disutility when evaluating project risk?
□ Only consider the former □ Consider both	(3) Whether you consider only your own interest loss and subjective feeling or both the interest loss and feelings of other related subjects when evaluating project risk?
□ Only consider the former □ Consider both	(4) If you do the project risk evaluation, do you prefer to consider your own behavior strategy, or consider other related subject behavior strategy reactions caused by your own evaluation behavior?

likely. For the severity of the risk factors, five-mark scoring ranges as follows: 1 = *mild*, 2 = *milder,* 3 = *generally serious*, 4 = *serious*, and 5 = *very serious*. Using SPSS17.0 software to statistically analyze 96 questionnaires, the mean, median, mode, and standard deviation [15] of all the risk factors' probability and severity evaluation are as shown in Table 2.

(2) The Importance Sequence of Project Risk Factors. According to the results shown in Table 2, we are required to rank the importance of the project risk factors based on the product size of probability and severity average. Results are shown in Table 3.

(3) The Choice and Grouping of Major Project Risk Factors. According to the sequence of risk factors shown in Table 3, we selected the top 50% of risk factors to construct a major infrastructure project risk evaluation index system, shown in Table 4. Owing to the uniqueness of each major infrastructure project, the indicators in Table 4 can be properly adjusted to a specific project risk assessment.

4. Construction of a Combinational Balanced Risk Index Model

The construction idea of a portfolio balanced risk index model is based on clear index connotation and principle. This includes calculating individual risk index through the base model and then calculating the project classification and balanced risk index by using the method of weighted portfolio addition [16].

4.1. Construction Principles of a Combinational Balanced Risk Index

4.1.1. Portfolio Addition Principle. The construction principle of portfolio balanced risk index is as follows: the project overall risk index is composed of six secondary indexes including (1) management risk index, (2) technology risk index, (3) economic risk index, (4) social risk index, (5) legal risk index, and (6) natural risk index; in addition, a secondary index is made up of several three-level indexes. In the process of portfolio addition, expert evaluation method is used to analyze the importance level of the index in order to determine the weight of each index so as to reach the weighted synthesis step by step.

4.1.2. Balance Reflects Risk Value Preference Principle of Multiple Subjects. The portfolio balanced risk index is a comprehensive reflection of the value of multivariate subjects' preferences and interests. Through the questionnaire survey of probability of project risk factors, objective severity and subjective opinions and preferences of all projects can be reflected in the project risk parameters.

4.1.3. Dynamic Comparable Principle. The portfolio balanced risk index reflects the size of the project risk and comparability between different periods of project risk. For example, if the projects' risks index in *t3* is 0.3 and in *t2* is 0.2, then the project risk in *t2* is smaller than *t3*.

4.2. The Basic Model of Portfolio Balanced Risk Index. The portfolio balanced risk index is the function of three variables: risk probability, objective severity, and subject negative feelings as shown in (1). The project risk coefficient value is in the range of 0~1; the greater the value, the greater the project risk is [17, 18].

$$\mathrm{RI}_i = f\left(P_i, V_i, F_i\right) = P_i' \times V_i' \times F_i'. \quad (1)$$

Index definition: RI_i is single factor risk index; P_i' is probability coefficient; V_i' is objective gravity coefficient; F_i' is subjective feeling coefficient; $P_i' = \overline{P}_i/5$ (probability coefficient is equal to probability scoring mean of all the main projects concerning risk i and the ratio of the maximum possible value); $V_i' = \overline{V}_i/5$ (objective gravity coefficient is equal to objective gravity mean of all the main projects concerning risk i and the ratio of the maximum possible value); $F_i' = \overline{F}_i/3$ (subjective feeling coefficient is equal to

Table 2: Survey results of main risk factors through the whole life cycle of a major infrastructure project.

Stages	Sequence number	Risk factors	Occurrence probability				Severity			
			Mean	Median	Mode	Standard deviation	Mean	Median	Mode	S.D
	1	Incorrect project orientation	3.188	3.0	3.0	0.734	4.083	4.0	4.0	0.767
	2	Incorrect market demand forecasting	3.958	4.0	3.0	0.824	3.646	4.0	4.0	0.911
	3	Thoughtless about inflation impact	3.083	3.0	3.0	0.739	3.195	3.0	3.0	0.798
	4	Incorrect estimation about project investment	3.25	3.0	3.0	0.526	3.229	3.0	3.0	0.515
	6	Incorrect estimation aboutInvestment return	3.167	3.0	3.0	0.559	3.125	3.0	3.0	0.64
Decision stage	6	Thoughtless about financing difficulty	3.25	3.0	3.0	0.526	3.083	3.0	3.0	0.739
	7	Government policy changes	3.417	3.0	3.0	0.767	3.5	3.0	3.0	0.744
	8	Lack of external experts consultation	3.167	3.0	3.0	0.695	3.229	3.0	3.0	0.515
	9	Thoughtless about project impact	3.167	3.0	3.0	0.559	3.125	3.0	3.0	0.64
	10	Wrong decision-making process or method	3.688	3.0	3.0	0.829	3.396	3.0	3.0	0.792
	11	Inability or inexperience of design team	3.167	3.0	3.0	0.559	3.125	3.0	3.0	0.64
	12	Lack of field investigation and not adjusting measures to local conditions	3.25	3.0	3.0	0.526	3.229	3.0	3.0	0.515
Design stage	13	Insufficient communication between designer and owner	3.167	3.0	3.0	0.559	3.021	3.0	3.0	0.699
	14	Lack of innovation and applicability of design plan	3.646	3.0	3.0	0.812	3.833	4.0	3.0	0.834
	15	Lack of designers' full participation	3.02	3.0	3.0	0.699	3.229	3.0	3.0	0.515
	16	Instability of safety equipment performance	3.166	3.0	3.0	0.695	3.124	3.0	3.0	0.64
	17	Financing difficulty or rising costs	3.25	3.0	3.0	0.526	3.229	3.0	3.0	0.515
	18	Improved environmental protection requirements on construction site	3.164	3.0	3.0	0.559	3.123	3.0	3.0	0.64
	19	Materials and equipment supply not in time	3.25	3.0	3.0	0.526	3.229	3.0	3.0	0.515
	20	Lack of experienced construction personnel	3.25	3.0	3.0	0.526	3.146	3.0	3.0	0.772
	21	Inability or irresponsibility of contractors	3.333	3.0	3.0	0.519	3.271	3.0	3.0	0.536
	22	Inability or irresponsibility of supervisors	3.25	3.0	3.0	0.526	3.229	3.0	3.0	0.515
Construction stage	23	Nontimely funding	3.833	4.0	3.0	0.883	3.896	4.0	4.0	0.831
	24	Material price increase	3.375	3.0	3.0	0.489	3.292	3.0	3.0	0.504
	26	Lack of scientific construction process and method	3.771	4.0	4.0	0.857	3.833	4.0	3.0	0.808
	26	Legal disputes of related subject	3.374	3.0	3.0	0.489	3.291	3.0	3.0	0.504
	27	Worsening social order of project area	3.333	3.0	3.0	0.519	3.271	3.0	3.0	0.536
	28	Opposition and obstruction to project construction	3.125	3.0	3.0	0.703	3.958	4.0	3.0	0.824
	29	Lack of good communication and cooperation among subjects	3.917	4.0	3.0	0.821	3.75	4.0	3.0	0.863
	30	Bad weather or major natural disasters	2.958	3.0	3.0	0.713	3.875	4.0	3.0	0.841
	31	Trial operation effect can not meet the design requirements	3.083	3.0	3.0	0.739	3.125	3.0	3.0	0.64
	32	Instability of equipment performance	3.25	3.0	3.0	0.526	3.229	3.0	3.0	0.515
	33	Speedy technology and equipment renewal	3.373	3.0	3.0	0.489	3.290	3.0	3.0	0.504
	34	Technology and equipment maintenance is not timely	3.333	3.0	3.0	0.519	3.271	3.0	3.0	0.536
Operation stage	36	Rising operating costs	3.083	3.0	3.0	0.739	3.188	3.0	3.0	0.798
	36	Sudden events	2.979	3.0	3.0	0.699	3.292	3.0	3.0	0.504
	36	Major natural disasters	2.958	3.0	3.0	0.713	3.917	4.0	3.0	0.846
	37	Lack of a clear accountability system	3.371	3.0	3.0	0.489	3.289	3.0	3.0	0.504
	38	Lack of operation management or experiences	3.333	3.0	3.0	0.519	3.271	3.0	3.0	0.536

Table 3: Main risk factors sequence through the whole life cycle of a major infrastructure project.

Importance sequence	Project risk factors	Probability average	Severity average	Probability average × Severity average
1	Incorrect project orientation	3.833	3.896	14.93
4	Incorrect market demand forecasting	3.958	3.646	14.43
34	Thoughtless about inflation impact	3.083	3.195	9.85
20	Incorrect estimation about project investment	3.25	3.229	10.49
29	Incorrect estimation about return on investment (ROI)	3.167	3.125	9.90
28	Thoughtless about financing difficulty	3.25	3.083	10.02
9	Incorrect estimation about investment return	3.417	3.5	11.96
26	Thoughtless about financing difficulty	3.167	3.229	10.23
30	Government policy changes	3.167	3.125	9.90
7	Lack of external experts consultation	3.688	3.396	12.52
31	Thoughtless about project impact	3.167	3.125	9.90
21	Lack of field investigation and not adjusting measures to local conditions	3.25	3.229	10.49
39	Insufficient communication between designer and owner	3.167	3.021	9.57
5	Lack of innovation and applicability of design plan	3.646	3.833	13.98
37	Lack of designers' full participation	3.02	3.229	9.75
32	Instability of safety equipment performance	3.166	3.124	9.89
22	Financing difficulty or rising costs	3.25	3.229	10.49
33	Improved environmental protection requirements on construction site	3.164	3.123	9.87
23	Materials and equipment supply not on time	3.25	3.229	10.49
27	Lack of experienced construction personnel	3.25	3.146	10.22
16	Inability or irresponsibility of contractors	3.333	3.271	10.9
24	Inability or irresponsibility of supervisors	3.25	3.229	10.49
6	Nontimely funding	3.188	4.083	13.02
12	Material price increase	3.375	3.292	11.11
3	Lack scientific construction process and method	3.771	3.833	14.45
13	Legal disputes of related subject	3.374	3.291	11.10
17	Worsening social order of project area	3.333	3.271	10.90
8	Opposition and obstruction to project construction	3.125	3.958	12.37
2	Lack good communication and cooperation among subjects	3.917	3.75	14.69
11	Bad weather or major natural disasters	2.958	3.875	11.46
38	Trial operation effect can not meet the design requirements	3.083	3.125	9.63
25	Instability of equipment performance	3.25	3.229	10.49
14	Speedy technology and equipment renewal	3.373	3.290	11.09
18	Technology and equipment maintenance is not timely	3.333	3.271	10.90
35	Rising operating costs	3.083	3.188	9.83
36	Sudden events	2.979	3.292	9.81
10	Major natural disasters	2.958	3.917	11.59
15	Lack of a clear accountability system	3.371	3.289	11.07
19	Lack of operation management or experiences	3.333	3.271	10.90

Table 4: Portfolio balanced risk index system of a major infrastructure project.

The target layer	The primary Risk	The secondary risk
The combinational balanced risk	Technical risk (TR)	Lack scientific construction process and method (TR_1)
		Poor creativity and applicability of design plan (TR_2)
		Speedy technology and equipment (TR_3)
		Inability or irresponsibility of contractors (TR_4)
		Technology and equipment maintenance is not timely (TR_5)
	Economic risk (ER)	Nontimely funding (ER_1)
		Material price increase (ER_2)
		Incorrect market demand forecasting (ER_3)
		Financing difficulty or rising costs (ER_4)
	Social risk (SR)	Opposition and obstruction to project construction (SR1)
		Government policy changes (SR_2)
		Worsening social order of project area (SR_3)
	Natural risk (NR)	Major natural disasters (NR_1)
		Bad weather (NR_2)
	Management risk (MR)	Lack good communication and cooperation among subjects (MR_1)
		Incorrect project orientation (MR_2)
		Wrong decision-making procedure or method (MR_3)
		Lack of a clear accountability system (MR_4)
	Legal risk (LR)	Contract inadequacy (LR_1)
		Low contracture capability of cooperative enterprise (LR_2)

subjective feeling mean of all the main projects concerning risk i and the ratio of the intermediate value; if the subject of subjective evaluation is over the median 3, the psychological effect is amplified or the project risk is narrowed and vice versa).

The source data of $\overline{P}_i$, $\overline{V}_i$, $\overline{F}_i$ are scoring risk probability, objective severity, and subjective feeling on a related project by five-mark scoring to obtain the scores $\{P_i\}$, $\{V_i\}$, $\{F_i\}$, and then use SPSS software to calculate the mean $\overline{P}_i$, $\overline{V}_i$, $\overline{F}_i$.

The fuzzy evaluation principle is as follows: for risk probability, five-mark scoring ranges from 1 = *extremely unlikely*, 2 = *slim chance*, 3 = *certain possibility*, 4 = *high possibility*, and 5 = *most likely*; for objective severity, five-mark scoring ranges from 1 = *the influence of the objective value of the project can be ignored*, 2 = *slightly*, 3 = *generally serious*, 4 = *serious*, and 5 = *very serious;* for subjective feelings, five-mark scoring ranges from 1 = *psychological negative impact is very small and completely tolerable*, 2 = *psychological negative influence is small and tolerable*, 3 = *appropriate psychological negative influence which can be withstood*, 4 = *psychological negative impact is larger and can barely be afforded*, and 5 = *psychological negative effect is very serious and hard to bear* [19, 20].

4.3. The Calculation of Risk Classification. Risk classification index is calculated by weighted average method of each single index; the formula is in

$$\mathrm{CRI} = \sum_{i=1}^{m} \mathrm{RI}_i \times w_i, \quad (2)$$

where CRI is portfolio balanced project risk index; RI_i is single factor portfolio balanced project risk index; w_i are single factor weights.

4.4. The Calculation of Portfolio Risk Index. The portfolio risk index is calculated by weighted average method of natural, social, legal, economic, management, and technology classification. The calculation formula is in

$$\mathrm{PRI} = \sum_{l=1}^{n} w_l \cdot \sum_{i=1}^{m} \mathrm{RI}_i \times w_i. \quad (3)$$

4.5. Establishment of a Project Risk Index Weight. Based on AHP method, this includes forming a discriminant matrix first by the importance of the comparison between two indicators at the same level and then calculating the index weight. The specific process is as follows.

4.5.1. To Build a Project Risk Hierarchical Structure. The project risk hierarchical structure of risk evaluation index system is shown in Figure 1.

4.5.2. To Build the Discriminant Matrix and Assignment. The importance scales and their meaning are shown in Table 5.

The discriminant matrix, after soliciting opinions from experts, is shown in Table 6.

4.5.3. The Calculation and Test of Weight. Using the sum method to calculate the weight and to get the arithmetic mean

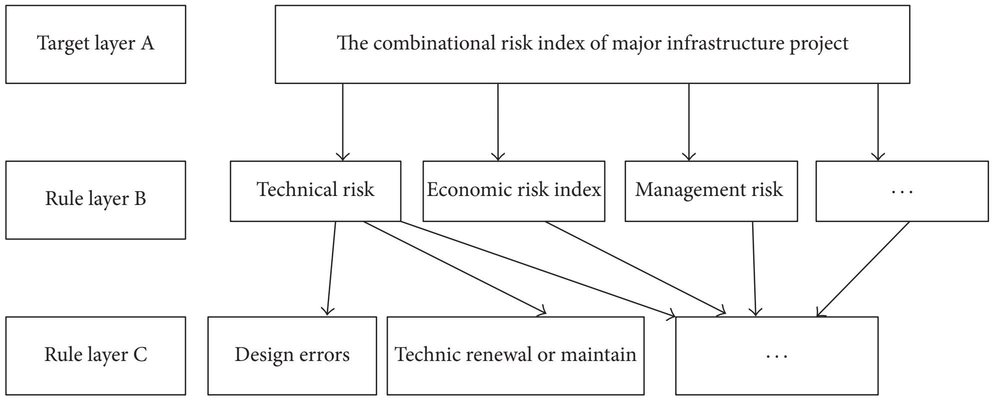

FIGURE 1: The hierarchy of project risk index.

TABLE 5: The Importance scale.

Importance scale	Meaning
1	Comparison between two factors, the former is equally as important as the latter
3	Comparison between two factors, the former is slightly more important than the latter
5	Comparison between two factors, the former is obviously more important than the latter
7	Comparison between two factors, the former is strongly more important than the latter
9	Comparison between two factors, the former is extremely more important than the latter
2, 4, 6, 8	Median value of above judgment
Inverse	If the importance percentage of factor I and factor j is a_{ij}, then the importance percentage of factor j and factor I is $1/a_{ij}$

TABLE 6: The discriminant matrix.

A	B_1	B_2	B_3	B_4	B_5	B_6
B_1	1	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}
B_2	a_{21}	1	a_{23}	a_{24}	a_{25}	a_{26}
B_3	a_{31}	a_{32}	1	a_{34}	a_{35}	a_{36}
B_4	a_{41}	a_{42}	a_{43}	1	a_{45}	a_{46}
B_5	a_{51}	a_{52}	a_{53}	a_{54}	1	a_{56}
B_6	a_{61}	a_{62}	a_{63}	a_{64}	a_{65}	1

of the column vectors as the final weight is shown in (4). In addition, to limit the deviation of discriminant matrix in a certain range, we needed to undertake a consistency check with CR; when CR < 0.1, the consistency of discriminant matrix is acceptable

$$W_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n} a_{kl}}. \tag{4}$$

5. Example Analyses

The Hong Kong-Zhuhai-Macau Bridge (HZMB) is an oversized bridge-tunnel project linking Hong Kong, Zhuhai, and Macau, with a total length of 49.968 kilometers and a total investment of 72.9 billion Yuan. It is a world-class sea-crossing passageway of national strategic significance. With project construction projected to be 7 years, construction began in December 2009 and will be completed in 2017. It will be the world's longest six-lane driving immersed tunnel and in distance the world's longest sea-crossing bridge-tunnel road. Next we will evaluate and analyze the HZMB using a combinational balanced risk index model.

5.1. The Main Project Risk Identification in Construction Phase. In addition to the common features every large project generally shares such as large scale, tight construction period, high level of difficulty, and heightened risk, the HZMB also contends with the characteristics of high social attention, coconstruction, and coadministration by three distinct governments and complicated navigation environment constraints such as white dolphin conservation. On the basis of investigation and access to second-hand data, it is concluded that the HZMB construction stages of the main project risks are as follows.

5.1.1. Technical Risk

(1) Risk of Being Poorly Designed. The sea areas of the HZMB are the world's most important trade channel with extensive air- and waterways. The design height of the bridge cannot be too low because of the normal passage of tonnage ships. At the same time, the height of the bridge deck and bridge

tower cannot be too high or it will affect the normal takeoff and landing of planes.

(2) Technology Innovation Risk. The HZMB project is the construction of the world's longest immersed deep-water tunnel, requiring numerous technological innovations. For example, the connection between the bridge and the tunnel requires an artificial island to be constructed using a grouping of giant round steel cylinders fixed directly onto the seabed and then filled with earth in order to form the man-made island. For Chinese engineers this is a first endeavor at creating this type of structure and, therefore, it includes high levels of uncertainty.

5.1.2. Economic Risk

(1) Risk of Nontimely Funding. With an investment of over 70 billion Yuan, the financing of this project has been the subject of much debate including issues such as who will invest and how to allocate investment proportion from the decision-making stage to the time when the bridge officially started. The principal financing risk is whether all involved parties can provide project construction funds at the appropriate time.

(2) Risk of Rising Costs. On one hand, inflation causes a rise in the price of materials; even if it specifies the value adjusting formula in the contract terms, it is hard to fully compensate the loss caused by the rising cost of raw materials in the future. On the other hand, the frequent changes of complicated construction conditions will cause the rise of cost control risk.

5.1.3. Social Risk

(1) Risk of Regional System Differences. The HZMB belongs to the coconstruction and coadministration of three distinct governments and involves the policy of "one country, two systems." The interest orientation of all governments, laws and regulations, administrative systems, management procedures, and technical standard requirements vary thereby creating innumerable challenges and difficulties in coordination efforts.

(2) Public-Against-Project Risks. The project has a significant impact on local natural ecological environment and the lives of the public making it easy to trigger social dissatisfaction and opposition if mishandled.

5.1.4. Natural Risk

(1) Typhoon Risk. Typhoons are common in the Lingdingyang Bay and pass through the South China Sea every year with more than 200 days a year reporting a wind speed of 6 magnitude. Consequently, the wind action will naturally move the steel with the same frequency which can produce resonance and cause destructive effects on the bridge.

(2) Earthquake Risk. Construction of the HZMB faces a serious challenge in the form of an earthquake. It is difficult to predict earthquake risk because of complex seabed structure. An earthquake would cause horizontal and vertical deformation and destruction of the tunnel and differences in movement and rotation in the tunnel socket joints, after which the project would be a total loss.

(3) Chloride Salt Corrosion Risk. Experiments show that the reinforced concrete will rust under the action of chlorine salt corrosion and eventually result in cracking and peeling of the concrete. How to ensure a service life of 120 years for the bridge is uncertain.

5.1.5. Management Risk

(1) Schedule Control Risk. The main body construction began in December 2009 and was projected to be completed by the end of 2016. However, whether the project can be completed smoothly has become a great challenge due to hydrological and meteorological factors as well as less effective working days.

(2) Quality Management Risk. The construction project is difficult with many operation points, long duration, synchronous operation, and crossover operation processes. The complicated meteorology in Lingdingyang Bay can easily lead to negligence in the quality of management.

(3) Safety Management Risk. The construction environment is very poor due to many factors including a large tidal range, quick water flow, various flow directions, high waves, deep scour, thick, soft ground, and frequent typhoons that endanger the safety of the workers and the construction creating an environment where injuries and property losses are probable.

5.1.6. Legal Risk. The nature of the project attracts an international financial clique desiring to invest in the form of BOT. However, in view of the different legal systems of Mainland China, Hong Kong, and Macao, this may involve some legal conflict and blind areas. If legal blind areas are used by financial clique and some funds are reserved in the contract, the bridge construction may fall into endless legal disputes.

5.2. The Construction of Project Risk Evaluation Index System in Construction Stage. Based on the above project risks, to construct a project risk evaluation index system according to the AHP method, as shown in Table 7, some appropriate adjustments of indexes are made in line with the project.

5.3. Calculation of Portfolio Balanced Risk Index in Initial Construction Stage

5.3.1. Probability and Severity Investigation of Project Risk Factors. Invite 30 related subjects from the project construction unit, as well as investors and government departments in order to score the probability, severity, objectivity, and subjectivity of single risk factor in the HZMB construction stage, and then calculate the average by SPSS17.0.

Table 7: Risk evaluation index system in construction stage.

Primary index	Secondary index	Third-grade index
The CTR of the HZMB in construction stage	Technical risk (R_1)	Risk of being poorly designed (R_{11})
		Innovation risk (R_{12})
	Economic risk (R_2)	Risk of nontimely funding (R_{21})
		The risk of rising costs (R_{22})
	Social risk (R_3)	The risk of regional system differences (R_{31})
		The public against risks (R_{32})
	Nature risk (R_4)	Typhoon risk (R_{41})
		Earthquake risk (R_{42})
		Chloride salt corrosion risk (R_{43})
	Management risk (R_5)	Schedule control risk (R_{51})
		Quality management risk (R_{52})
		Safety management risk (R_{53})
	Legal risk (R_6)	Legal conflict or blind area risk (R_{61})

Table 8: Three-dimensional evaluation data of single risk factor in the HZMB initial construction stage.

Stage	Sequence	Risk factors	Average value of probability	Average value of object severity	Average value of subject feeling
Initial construction stage	1	Risk of being poorly designed (R_{11})	2.17	3.65	3.42
	2	Innovation risk (R_{12})	2.52	3.48	3.07
	3	Risk of nontimely funding (R_{21})	2.08	4.16	3.66
	4	The risk of rising costs (R_{22})	3.21	3.23	2.77
	5	The risk of regional system differences (R_{31})	2.78	2.35	2.47
	6	The public against risks (R_{32})	1.56	3.72	3.98
	7	Typhoon risk (R_{41})	3.45	4.03	3.86
	8	Earthquake risk (R_{42})	1.06	4.75	4.67
	9	Chloride salt corrosion risk (R_{43})	2.72	3.25	3.09
	10	Schedule control risk (R_{51})	2.91	2.76	2.92
	11	Quality management risk (R_{52})	1.85	4.49	4.33
	12	Safety management risk (R_{53})	2.04	4.16	4.08
	13	Legal conflict or blind area risk (R_{61})	2.11	3.53	3.16

5.3.2. Calculation of Single Risk Factor Parameter. Calculate, respectively, probability, objective severity, and subjective feeling coefficient of a single factor according to the survey results in Table 8 and the equation in Section 4.2, as shown in Table 9.

5.3.3. Calculation of Classification and Portfolio Risk Index. Use weighted addition to obtain project risk classification index according to single risk factor index shown in Table 10 and obtain portfolio risk index in the same way; then calculate index weight by AHP method; the final results are shown in Table 10.

5.4. The Calculation of Risk Index in Medium-Term Construction Stage. Calculate the classification and portfolio risk index of the HZMB in medium-term according to the above-mentioned method to reorganize investigation and collect basic data, as shown in Table 11.

5.5. Comparative Analysis of Project Risk Index in Early- and Mid-Construction. The portfolio balanced project risk index in early 2010 and middle 2012 is obtained through the above-mentioned calculation, as shown in Table 12. It is clear that the portfolio balanced project risk index fall is very obvious, and technology risk index and management risk index decrease dramatically, which is in accord with our intuitive understanding.

The combinational balanced risk index of this project in 2010 was 0.38, showing if all kinds of risk factors were not well controlled or changed; about 38% expected value will

Table 9: Single risk factor parameter and coefficient of the HZMB in initial construction stage.

Stages	Sequence	Risk factor	Probability coefficient	Objective severity coefficient	Subjective feeling coefficient	Single risk factor parameter
Initial construction stage	1	Risk of being poorly designed (R_{11})	0.43	0.73	1.14	0.36
	2	Innovation risk (R_{12})	0.50	0.70	1.02	0.36
	3	Risk of nontimely funding(R_{21})	0.42	0.83	1.22	0.43
	4	The risk of rising costs (R_{22})	0.64	0.65	0.92	0.38
	5	The risk of regional system differences (R_{31})	0.56	0.47	0.82	0.22
	6	The public against risks (R_{32})	0.31	0.74	1.33	0.31
	7	Typhoon risk (R_{41})	0.69	0.81	1.29	0.72
	8	Earthquake risk (R_{42})	0.21	0.95	1.56	0.31
	9	Chloride salt corrosion risk (R_{43})	0.54	0.65	1.03	0.36
	10	Schedule control risk (R_{51})	0.58	0.55	0.97	0.31
	11	Quality management risk (R_{52})	0.37	0.90	1.44	0.48
	12	Safety management risk (R_{53})	0.41	0.83	1.36	0.46
	13	Legal conflict or blind area risk (R_{61})	0.42	0.71	1.05	0.31

Table 10: The classification and portfolio risk index of the HZMB in initial construction stage.

Primary index	Secondary index			Third-grade index		
	Risk name	Index	Weight	Risk name	Index	Weight
Portfolio risk index of the HZMB in initial construction stage PRI = 0.38	Technical risk	0.36	0.212	Risk of being poorly designed (R_{11})	0.36	0.667
				Innovation risk (R_{12})	0.36	0.333
	Economic risk	0.41	0.137	Risk of nontimely funding (R_{21})	0.43	0.667
				The risk of rising costs (R_{22})	0.38	0.333
	Social risk	0.27	0.162	The risk of regional system differences (R_{31})	0.22	0.50
				The public against risks (R_{32})	0.31	0.50
	Nature risk	0.48	0.116	Typhoon risk (R_{41})	0.72	0.387
				Earthquake risk (R_{42})	0.31	0.412
				Chloride salt corrosion risk (R_{43})	0.36	0.201
	Management risk	0.44	0.265	Schedule control risk (R_{51})	0.31	0.227
				Quality management risk (R_{52})	0.48	0.538
				Safety management risk (R_{53})	0.46	0.235
	Legal risk	0.31	0.108	Legal conflict or blind area risk (R_{61})	0.31	1.00

be lost after their interaction. The combinational balanced risk index in 2012 was 0.15, showing only about 15% projects could not achieve expected value. The main reason for these dramatic declines is that related subjects accumulate substantial knowledge and experience and significantly improve the knowledge level and behavior ability during the construction process. In addition, after a running-in period, the cooperation relationship between subjects is effectively improved. Moreover, the subjects actively explore and innovate in areas such as technology research and development, plan design, government cooperation mechanism, and international BOT financing and formulate a series of effective countermeasures such as (1) largely eliminating and weakening the force between the seismic energy by using polymer rubber materials; (2) developing high-performance concrete to resist the erosion from chlorine salt on concrete in sea water; (3) devising a creative installation method to ensure that the crane tower height is less than 120 meters; (4) establishing a coordination team led by the National Development and Reform Commission to eliminate organizational difficulties

Table 11: Classification and portfolio risk index of the HZMB in medium-term construction stage.

Primary index	Secondary index			Third-grade index		
	Risk name	Index	Weight	Risk name	Index	Weight
Portfolio risk index of the HZMB in medium-term construction stage PRI = 0.15	Technical risk	0.17	0.212	Risk of being poorly designed (R_{11})	0.18	0.667
				Innovation risk (R_{12})	0.14	0.333
	Economic risk	0.30	0.137	Risk of nontimely funding (R_{21})	0.28	0.667
				The risk of rising costs (R_{22})	0.35	0.333
	Social risk	0.15	0.162	The risk of regional system differences (R_{31})	0.12	0.50
				The public against risks (R_{32})	0.18	0.50
	Nature risk	0.32	0.116	Typhoon risk (R_{41})	0.48	0.387
				Earthquake risk (R_{42})	0.25	0.412
				Chloride salt corrosion risk (R_{43})	0.14	0.201
	Management risk	0.20	0.265	Schedule control risk (R_{51})	0.29	0.227
				Quality management risk (R_{52})	0.18	0.538
				Safety management risk (R_{53})	0.16	0.235
	Legal risk	0.18	0.108	Legal conflict or blind area risk (R_{61})	0.18	1.00

Table 12: The portfolio balanced risk comparison of the HZMB in initial and medium-term construction stage.

T	PR						
	Technical risk index	Economic risk index	Social risk index	Nature risk index	Management risk index	Law risk index	Portfolio risk index
2010	0.36	0.41	0.27	0.48	0.44	0.31	0.38
2012	0.17	0.30	0.15	0.32	0.20	0.18	0.15

arising from three governments and the risks brought on by varying legal demands and management systems; and (5) inviting lawyers familiar with international BOT legal business to study the contract details, risk control, and so on.

5.6. Early Warning Analysis of Project Risk Index. In order to dynamically monitor and analyze early warning project risks, we can set the risk index threshold through the investigation of the risk bearing capacity and the degree of acceptance of the risk by the subjects, combined with the risk loss, and divide different levels of risk early warning intervals and set up corresponding risk countermeasures [21] as shown in Table 13, in order to ensure the appropriate measures be initiated according to the level of risk.

This study shows that the portfolio balanced risk index of the HZMB reaches above the orange line in initial construction stage, while it drops below the orange line and enters a relative safety area in the median-term construction.

6. Conclusion and Discussion

In this article, a combination of behavioral science, questionnaire method, statistical analysis, and fuzzy evaluation is used to construct a portfolio balanced index model in order to dynamically evaluate the risk factors of major infrastructure projects and to measure the combined loss of project risk to project subjects. PBIM is an effective and powerful tool for risk evaluation and monitoring of major infrastructure projects. Our conclusions are as follows.

(1) From the perspective of project entity utility, the risk of major infrastructure projects is not only related to the probability of occurrence of project risks, loss of objective value caused by risks, but also to the risk bearing capacity, emotional factors, and psychological utility of the project subjects. These factors need to be systematically balanced, considered, and measured in combination so as to fully evaluate the overall value loss of the project risk.

(2) A project risk index constructed on the basis of portfolio balanced evaluation has strong inclusiveness. This is accomplished through questionnaires and scenario investigation of the multiproject related subjects, the selection of project risk index and the design of relevant parameters reflecting the collective value preference of multiproject subjects, multiple psychological utility, and behavioral strategy interaction factors, and eliminating the limitations of a single subject closed evaluation of project risk.

Table 13: Early warning level of project risk index.

Portfolio balanced risk index	Qualitative description of the project risk severity	Early warning level and coping strategy
Above 0.40	The risk is very serious and the overall value may result in significant loss	Red warning interval, first-grade powerful measures are taken to control and resolve risk
[0.30, 0.40]	The risk is comparatively serious and the overall value may result in great loss	Orange warning interval, secondary measures are taken to control and resolve risk
[0.20, 0.30]	The risk is generally serious and the overall value may result in great loss	Yellow warning interval, three-grade measures are taken to control and resolve risks
[0.10, 0.20]	The risk is comparatively mild and the chance that the overall value deviating from the expected goal is minimal	A relatively safe interval, analyze the cause of risks and verify risk control measures
Below 0.1	The risk is comparatively mild and the chance of the overall value deviating from the expected goal is very minimal	Safe interval, analyze the cause of risks

(3) The combined equilibrium risk index is simple and intuitive for reflecting the size of the project risk, which can directly compare the risks of different projects and the same project in different periods, not only to determine the relevance of the main project feasibility and the size of the potential risk in order to provide an effective analysis tool, but also, according to the Early Warning Interval of Project risk index, to help the project in relation to the main control and resolving of risk.

(4) The main body of the major infrastructure project has complex risk evaluation decision motive; this includes avoidance of their own risk for self-interest motive needs, but also an interactive fairness and altruism motive, whereby the motivation to evaluate project risk is a complex preference set. This preference set affects the evaluation decision of the subject. For this reason, the preference set of the multiple project subjects can be displayed by means of group survey.

It should be noted that we principally used fuzzy mathematics and the questionnaire method to evaluate the risk factors of major infrastructure projects, and these methods have certain imprecision and subjectivity. However, this procedure is consistent with the characteristics of major infrastructure project risk and behavior decision-making and is also a scientific approach. In the next study, we will shorten the observation time for specific projects, extract more comprehensive data, and conduct a more detailed study of the evolution of a project risk index.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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