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Original Article

Criteria for Determining the Transfer of Construction Risk Based on Risk Occurrence Probability

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Abstract *- This study explores risk transfer strategies in construction project management, aiming to establish evaluation criteria for effectively transferring known and unknown risks to third parties such as insurance companies or contractors. By cost-benefit analysis of historical insurance claims data and integrating the PERT network method, the study determines when risk transfer is economically beneficial, especially in large infrastructure projects facing natural disasters. The results show that risk transfer is optimal when the insurance compensation to risk probability ratio is less than the insurance premium or the probability of risk occurrence is within the calculated threshold. This study provides a judgment benchmark for risk transfer in the risk response program of construction management, which greatly helps project managers and project planners improve the efficiency of risk response.*

Keywords **-** *Cost-Benefit Analysis, PERT Network Method, Risk Management, Risk Probability, Risk Transfer.*

1. Introduction

Reference [5] shows that, in terms of risk cost estimation, existing research has pointed out that construction contractors generally lack awareness of risk costs when preparing their budgets and fail to implement standards in practice. Risk is the probability of negative or undesirable things, such as injury or loss, and it refers to uncertainty.

In business management, the definition of risk is the uncertainty of things that will have a negative impact on the achievement of a company's goals. Construction risk management refers to the systematic management activities of quality, schedule, cost, safety, etc., which include identifying various risks that may occur throughout the construction project in advance, analyzing their impact, formulating appropriate response methods, and effectively achieving project goals.

Risk is the probability of negative or undesirable things, such as injury or loss, and it refers to uncertainty. In business management, the definition of risk is the uncertainty of things that will have a negative impact on the achievement of a company's goals. Construction risk management refers to the systematic management activities of quality, schedule, cost, safety, etc., which include identifying various risks that may occur throughout the construction project in advance, analyzing their impact, formulating appropriate response methods, and effectively achieving project goals.

Reference [4] shows Risks can come from various sources, including all stages of the design, development, production or maintenance life cycle, such as uncertainty in the financial market, threats of project failure, as well as legal liabilities, credit risks, accidents, natural causes and disasters. Threats from hostile parties, deliberate attacks or uncertain causes and events.

Reference [19] show that construction projects are large in scale, with many participants, and the possibility of risks occurring among various stakeholders and complex processes is high. Accidents or problems can lead to delays in the project schedule and additional costs, so risk management is necessary to minimize accidents.

Safety accidents, quality defects, etc. can lead to fatal consequences, so a management system that can prevent such accidents is needed. Therefore, risk management is the key to ensuring the complexity, cost impact, safety and quality of the project.

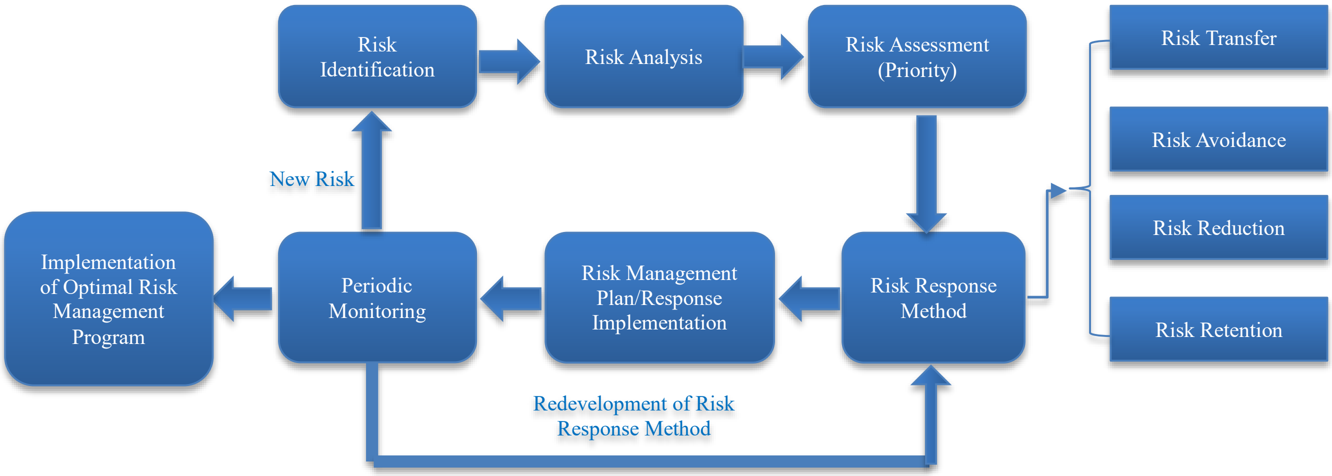

Fig. 1 Research procedure

Reference [6] shows that decision tree analysis methods demonstrate good applicability in predicting fatal accidents across different occupations in construction engineering, effectively enhancing the accuracy of safety risk prediction. And reference [12] shows that a construction dispute prediction model developed using decision tree technology can effectively identify potential disputes in advance in practical applications, thereby reducing dispute risks during project implementation. And reference [8] shows that a risk factor extraction method based on BIM technology can significantly enhance the quantitative capabilities of risk assessment models, making risk assessment results more accurate and reliable.

The Project Management Institute (PMI) defines project risk as an uncertain event that may lead to project losses. Project risk can affect the project schedule, budget, and quality, and is defined as a key threat to the successful implementation of project management. Many projects have failed in practice due to poor project risk control. Project stakeholders require project managers to implement more comprehensive project risk management to minimize project deviations, and the importance of project risk management has been valued in academia and practice.

Project risk management generally has four methods: risk identification, analysis, assessment, and response. Among them, risk response refers to the experts formulating specific strategies for identified project risks to reduce the losses or impacts caused by risks and ensure that the project is not affected by risks. Reference [12] shows the analysis of loss costs and risk provisions resulting from risk events in airport runway construction projects, highlighting the importance of refined risk management and funding reserve strategies for large infrastructure projects.

Reference [18] shows that establishing a NATM tunnel engineering risk database and risk classification system helps enhance the systematic and standardized identification of tunnel engineering risks, providing a reliable data foundation for future risk assessments.

In the risk management system, there is no unified standard for the judgment basis of risk response plans. The currently known judgment methods are all for project experts to discuss and judge the project together, which is very subjective and based on personal views, feelings, experience and values. Therefore, this article simplifies the risk judgment basis through cost analysis, so that anyone can participate in the analysis and evaluation process of the project. It also provides an effective judgment basis for the response plan. So far, this deficiency has been made up in the project management system.

In the risk management system, risk response plans are often divided into four risk response plans: risk transfer, reduction, avoidance, and retention. Risk transfer refers to the process of transferring potential project risks to third parties (insurance companies, underwriters, agents, etc.) through contracts or legal means. Reference [4] During the construction phase of the Zhuhai XiangHai Bridge Project, work was suspended due to a typhoon, and the completion date was uncertain. However, effective risk control was carried out during the project's design phase, so that the project was fully protected when work resumed, and the bridge was successfully opened to traffic. When undertaking such a large-scale bridge project, the comprehensiveness and thoroughness of project risk management are valued.

Reference [4] A section of a highway in Sichuan Province, China, was damaged by landslides caused by heavy rain, and the newly built highway collapsed. Since it was still under construction, there were no casualties, but the road under construction suffered certain losses, causing a major economic accident. Similarly, in the construction project, effective risk management was carried out during the design phase to avoid greater economic losses. At the same time, due to proper risk transfer, the insurance company subsequently paid insurance compensation to compensate for the losses caused by risk disasters of different facilities in the construction project.

Reference [12] Phase I of Metro Line 1 in Shenyang, Liaoning Province, China, is the first subway transportation line in Shenyang, with a total length of 22.141 kilometers and a project budget of approximately RMB 9.6 billion. There are many prosperous commercial streets and building communities where the subway line passes, which increases the complexity and the probability of risks occurring during subway construction. Therefore, project managers, construction team leaders and other experts conducted a detailed analysis of the rail transit project, which was divided into feasibility study, risk management, survey, design risk management, bidding contract signing risk management, and construction risk management. After this series of work, the Shenyang Metro Line 1 project, which was facing many difficulties at the time, was successfully opened to traffic.

Therefore, this article discusses and studies the judgment criteria for whether the project is applicable to risk transfer response plans.

When it comes to the facility risk area, past insurance company compensation contracts were analyzed, and data on insurance premiums and insurance compensation related to engineering management projects in the facility risk area were selected.

$$\frac{I_P}{x} = I \quad (1)$$

I_p: Insurance premium
I: Insurance compensation
x: Risk occurrence probability

2. Equation of Probability of Risk Occurrence (x), Insurance Premium (I_p), and Insurance Compensation (I)

Regarding the judgment benchmark of risk transfer, by collecting data on past risk claims (insurance premiums and insurance compensation), the ratio of insurance premiums to insurance compensation is used for comparative analysis. Compare insurance premiums and insurance compensation according to the ratio of the probability of risk occurrence to insurance premiums. According to the probability of risk occurring due to insurance in the project, calculate whether the cost of risk transfer is lower than the loss after the risk occurs, and determine whether the risk transfer plan is appropriate.

$$\frac{I_P}{x} > I \quad (2)$$

$$\frac{I_p}{x} < I \quad (3)$$

Combined with the cost-benefit analysis, if Equation (2) holds true, the ratio of the risk probability to the project premium is greater than the insurance compensation. This means that the expected compensation cost is lower than the premium paid, and risk transfer is a risk that is not suitable for the plan.

If Equation (3) holds true, the ratio of the risk probability to the project premium is less than the insurance compensation amount. This means that the expected compensation cost is higher than the premium paid, indicating that risk transfer is a risk that is suitable for the plan.

2.1. Insurance Companies Calculate Premiums

When estimating project risks, insurance companies use a fuzzy calculation method based on the bridge-tunnel ratio. Bridges and tunnels account for a high proportion of the project, and there is a high possibility of risk factors occurring. Therefore, the higher the bridge-tunnel ratio, the greater the probability of risk occurrence.

The traditional method of calculating insurance compensation is multiplying the expected insurance compensation by the probability of risk occurrence (China Insurance Group Co., Ltd., 2021).

When calculating insurance compensation, insurance companies usually use the size of the risk as the benchmark value. At the same time, according to all values in the construction process, premium calculation is implemented to obtain an ideal premium that meets the conditions of the project and the insurance company.

$$Expected\ Premium \times Risk\ Probability \quad (4)$$

The insurance company prices the general risk probability based on P_{normal}, and the actual risk probability of this event is expected to be P_{max}.

$$Insurance\ Premium = Expected\ insurance\ compensation \times P_{normal} \quad (5)$$

However, for the company's operations and profits, the insurance company changed the project risk occurrence probability P_{normal} to P_{max}.

$$Actual\ Insurance\ Premium = Expected\ insurance\ compensation \times P_{max} \quad (6)$$

According to Equation (1), the ratio of insurance premium to insurance compensation can be obtained by transformation. The result of this ratio is the probability of risk occurrence. However, insurance compensation is generally made within the most reasonable range. Therefore, the ratio of insurance premiums to insurance compensation can be used as the basis for calculating the minimum probability of risk occurrence.

$$\frac{I_P}{I} = \textit{Minimum probability of Risk Occurrence, } P_{min} \quad (7)$$

The maximum risk threshold can generally be understood as the maximum loss that may occur under certain conditions. In this article, the maximum threshold for risk occurrence is the insurance compensation ratio (the ratio of insurance compensation to insurance premium often represents the insurance compensation under ideal conditions.

$$\frac{I}{I_P} = \textit{The maximum risk threshold} \quad (8)$$

By interviewing several insurance brokers who visited insurance companies, learned about the relationship between premiums and insurance compensation calculations in construction management. Insurance companies use Equations (5) and (6) to calculate premiums. The amount that appears in the insurance company's internal risk claims is calculated based on the relationship between the probability of risk occurrence, premiums, and insurance compensation.

$$P_{max} \approx P_{normal} \times \textit{The maximum risk threshold} \quad (9)$$

Based on some construction management projects, distinguish different situations and calculate insurance premiums and insurance compensation based on the claim information of different facility risks in different projects in the past. This results in the maximum risk threshold under different conditions.

Insurance companies generally set the standard risk probability to 1% (Pnormal ≈ 0.01) in these cases, as seen in Table 1. "*Medium probability*" and apply Equation (9) accordingly.

2.2. The Calculation Equations for the Minimum Probability of Risk Occurrence (P_{min}) and the Maximum Probability of Risk Occurrence (P_{max})

Finally, it can be known that through the ratio of insurance premium and insurance compensation, two formulas for the minimum probability of risk occurrence, Equation (10) and the maximum probability of risk occurrence, Equation (11).

$$P_{min} = \frac{I_p}{I} \times 100\% \quad (10)$$

$$P_{max} \approx 0.01 \times \frac{I}{I_p} \times 100\% \quad (11)$$

2.3. Risk Occurrence Probability Range by Facility

Through interviews and surveys with insurance companies, this paper has sorted out the claims agreements for force majeure risks, such as emergencies, natural disasters, etc., that occurred in several major construction projects, such as bridge, railway, and highway construction.

Based on these survey results, each risk's minimum and maximum probabilities are calculated using the insurance premiums and paid data stipulated in the claims contract. Equations (10) and (11) are used for corresponding calculations.

This results in the probability range of force majeure risks, such as emergencies, natural disasters, etc., that may occur in bridge, railway, and highway construction projects.

2.3.1. The Range of Bridge Risk Probability

According to interviews with insurance companies and referring to accident claim contracts related to bridge construction, the probability range of risk occurrence for each facility in the bridge project was organized when faced with facility-specific risks due to facility-specific risk.

By calculating the risk area of each bridge facility, it is found that the risk probability range of the bridge is (3.64% to 27.44%).

Taking a bridge construction project as an example, when the compensation plan proposed by the insurance company calculates the range between 3.64% ~ 27.44%, it can be concluded that it is reasonable to purchase insurance for risk transfer. In addition, when experts use Monte Carlo simulation analysis to conclude that the probability of risk occurring in each facility in the project is between 3.64% ~ 27.44%, it can be concluded that it is reasonable to transfer risk by purchasing insurance. On the contrary, when this probability range is not met, it can be concluded that using insurance to transfer risk is not feasible.

Table 1. Standard risk probabilities through the ISO 31000 standard

	Probability of occurrence	Standard risk probability
Very high probability	70% ~ 100%	5%
High probability	50% ~ 70%	1% ~ 5%
Medium probability	30% ~ 50%	1%
Low probability	10% ~ 30%	0.1% ~ 1%
Very low probability	< 10%	< 0.1%

Table 2. Bridge construction insurance premiums, insurance compensation, and risk occurrence probability

No.	Risk Cause	Construction Area	Date	Insurance Premium (USD)	Insurance Compensation (USD)	Minimum Probability	Maximum Probability
1	Collapse	Hezhou City, Guangxi Province	2023.2.19	56,000.00	812,000.00	6.90%	14.50%
2	Collapse	Zhongshan City, Guangdong Province	2022.9.24	51,520.00	671,440.00	7.67%	13.03%
3	Collapse	China National Highway 108	2019.7.18	99,400.00	1,814,400.00	5.48%	18.25%
4	Collapse	Hangzhou City, Zhejiang Province	2017.7.6	12,600.00	280,000.00	4.50%	22.22%
5	Collapse	Zhengzhou City, Henan Province	2017.1.12	27,720.00	414,400.00	6.69%	14.95%
6	Collapse	Nantong City - Suzhou City, Jiangsu Province	2016.3.17	169,612.16	3,455,163.84	4.91%	20.37%
7	Construction accident	Chengdu City, Sichuan Province	2018.7.11	45,920.00	859,600.00	5.34%	18.72%
8	Natural disaster	Ganzi Tibetan Autonomous Prefecture, Sichuan Province	2024.8.3	116,266.40	2,954,534.40	3.94%	25.41%
9	Natural disaster	Ganzhou City, Jiangxi Province	2022.6.13	13,440.00	280,000.00	4.80%	20.83%
10	Natural disaster	Zhuhai City, Guangdong Province	2017.8.23	35,826.00	503,804.00	7.11%	14.06%
11	Natural disaster	Zhuhai City, Guangdong Province	2017.8.23	24,612.00	311,360.00	7.90%	12.65%
12	Natural disaster	Fuzhou City, Fujian Province	2007.8.18	75,600.00	1,680,000.00	4.50%	22.22%
13	Ship collision	Baltimore, Maryland, United States	2024.3.26	29,000,000.00	350,000,000.00	8.29%	12.07%
14	Ship collision	Guangzhou City, Guangdong Province	2024.2.22	51,016.00	1,400,000.00	3.64%	27.44%
15	Ship collision	Guangzhou City, Guangdong Province	2024.2.22	28,000.00	474,460.00	5.90%	16.95%
16	Ship collision	Zhushan City, Zhejiang Province	2008.12.5	89,096.00	1,742,636.00	5.11%	19.56%
17	Ship collision	Foshan City, Guangdong Province	2007.6.15	95,200.00	2,100,000.00	4.53%	22.06%
18	Ship collision	Foshan City, Guangdong Province	2004.12.6	18,200.00	282,520.00	6.44%	15.52%

2.3.2. The Range of RAILWAY Risk Probability

According to an interview with an insurance company, referring to accident claims contracts related to railroad construction, 24 different projects are listed in Table 3.

Summarized the probability of risk occurrence by rail project facilities when faced with facility-specific risks due to facility-specific risk accidents.

Calculating the risk area by railway facility category, the railway risk probability range is (2.28%~43.81%).

For railway construction projects, when the compensation plan proposed by the insurance company is calculated between 2.28% ~ 43.81%, it can be concluded that it is feasible to implement risk transfer by purchasing insurance. In addition, experts use Monte Carlo simulation analysis to conclude that when the probability of risk occurrence of each facility in the project is between 2.28% ~ 43.81%, insurance can also be purchased together to implement risk transfer. On the contrary, if it does not fall within this probability range, it will be concluded that risk transfer using insurance is inappropriate.

Table 3. Railway construction insurance premiums, insurance compensation, and risk occurrence probability

No.	Risk Cause	Construction Area	Date	Insurance Premium (USD)	Insurance Compensation (USD)	Minimum Probability	Maximum Probability
1	Collapse	Hangzhou City, Zhejiang Province	2018.9.25	22,400.00	411,040.00	5.45%	18.35%
2	Collapse	Taiyuan City, Shaanxi Province	2018.4.13	164,920.00	5,014,422.00	3.29%	30.41%
3	Construction accident	Hefei City, Anhui Province	2018.1.4	78,120.00	957,460.00	8.16%	12.26%
4	Construction accident	Chengdu City, Sichuan Province	2017.3.3	58,114.00	1,790,600.00	3.25%	30.81%
5	Construction accident	Xuzhou City, Jiangsu Province	2016.11.11	50,400.00	745,612.00	6.76%	14.79%
6	Delay accident	Zhengzhou City, Henan Province	2021.7.20	11,200.00	280,000.00	4.00%	25.00%
7	Delay accident	Hefei City, Anhui Province	2016.11.28	13,720.00	343,000.00	4.00%	25.00%
8	Natural disaster	Zhengzhou City, Henan Province	2021.7.20	56,000.00	1,400,000.00	4.00%	25.00%
9	Natural disaster	Zhengzhou City, Henan Province	2021.7.20	67,200.00	1,680,000.00	4.00%	25.00%
10	Natural disaster	Xuzhou City, Jiangsu Province	2020.1.8	30,800.00	980,000.00	3.14%	31.82%
11	Natural disaster	Hangzhou City, Zhejiang Province	2020.1.16	22,876.00	344,890.00	6.63%	15.08%
12	Natural disaster	Hangzhou City, Zhejiang Province	2019.9.24	22,554.00	448,700.00	5.03%	19.90%
13	Natural disaster	Sichuan Province	2019.8.11	22,876.00	381,836.00	5.99%	16.69%
14	Natural disaster	Zhengzhou City, Henan Province	2019.8.10	52,080.00	1,331,288.00	3.91%	25.56%
15	Natural disaster	Hangzhou City, Zhejiang Province	2019.3.7	46,200.00	1,796,970.00	2.57%	38.90%
16	Natural disaster	Hangzhou City, Zhejiang Province	2019.3.25	22,554.00	386,302.00	5.84%	17.13%
17	Natural disaster	Hangzhou City, Zhejiang Province	2019.11.7	34,496.00	1,113,000.00	3.10%	32.26%
18	Natural disaster	Hangzhou City, Zhejiang Province	2019.10.1	46,200.00	2,024,036.00	2.28%	43.81%
19	Natural disaster	Hangzhou City, Zhejiang Province	2019.1.17	48,790.00	2,047,738.00	2.38%	41.97%

20	Natural disaster	Taizhou City, Zhejiang Province	2018.8.16	15,484.00	558,180.00	2.78%	36.03%
21	Natural disaster	Ningbo City, Zhejiang Province	2018.12.15	66,360.00	741,580.00	8.95%	11.18%
22	Natural disaster	Hangzhou City, Zhejiang Province	2016.8.2	63,000.00	1,216,684.00	5.18%	19.31%
23	Natural disaster	Shenzhen City, Guangdong Province	2016.11.11	27,230.00	745,500.00	3.65%	27.37%
24	Natural disaster	Qingdao City, Shandong Province	2014.10.8	2,240.00	31,318.00	7.13%	14.02%

2.3.3. The Range of Road Risk Probability

According to interviews with insurance companies and referring to accident claim contracts related to road construction, the probability range of risk occurrence for each road project facility was organized when facing facility-specific risks due to facility-specific risk accidents in 23 different projects in Table 4.

Calculate the risk area by road facility category, and the road risk probability range is (3.30%~30.31%).

For highway construction projects, when the range calculated by the compensation plan proposed by the insurance company is between 3.30% ~ 30.31%, it can be concluded that it is feasible to implement risk transfer by purchasing insurance. In addition, experts use Monte Carlo simulation analysis to conclude that when the probability of risk occurrence of each facility in the project is between 3.30% ~ 30.31%, insurance can also be purchased together to implement risk transfer. On the contrary, if it does not fall within this probability range, it will be concluded that risk transfer using insurance is inappropriate.

Table 4. Road construction insurance premiums, insurance compensation, and risk occurrence probability

No.	Risk Cause	Construction Area	Date	Insurance Premium (USD)	Insurance Compensation (USD)	Minimum Probability	Maximum Probability
1	Collapse	Meizhou City, Guangdong Province	2024.5.1	112,420.00	1,765,260.00	6.37%	15.70%
2	Construction accident	Bijie City, Guizhou Province	2016.9.13	51,800.00	784,000.00	6.61%	15.14%
3	Delay accident	China 101 Highway	2023.11.8	43,232.00	544,796.00	7.94%	12.60%
4	Natural disaster	Lizhao City, Shandong Province	2022.6.26	12,600.00	3,640,000.00	3.46%	28.89%
5	Natural disaster	Guilin, Guangxi Province	2022.6.19	22,400.00	560,000.00	4.00%	25.00%
6	Natural disaster	Dazhou City, Sichuan Province	2022.11.10	5,880.00	71,400.00	8.24%	12.13%
7	Natural disaster	Sichuan Province	2022.11.09	661,934.00	12,014,996.00	5.51%	18.15%
8	Natural disaster	Wenchang City, Hainan Province	2021.7.21	7,000.00	126,000.00	5.56%	18.00%
9	Natural disaster	Dazhou City, Sichuan Province	2021.7.11	1,610.00	40,600.00	3.96%	25.28%
10	Natural disaster	Sichuan Province	2021.6.30	23,002.00	406,378.00	5.66%	17.67%
11	Natural disaster	Sichuan Province	2021.4.24	6,776.00	139,118.00	4.87%	20.54%
12	Natural disaster	Sichuan Province	2021.2.21	11,200.00	140,000.00	8.00%	12.50%
13	Natural	Sichuan Province	2020.8.18	18,200.00	504,000.00	3.61%	27.69%

	disaster						
14	Natural disaster	Sichuan Province	2020.8.17	700,700.00	12,677,882.00	5.53%	18.09%
15	Natural disaster	Sichuan Province	2020.7.20	328,398.00	9,954,000.00	3.30%	30.31%
16	Natural disaster	Jiuzhaigou City, Sichuan Province	2020.4.18	700,700.00	8,061,256.00	8.69%	11.50%
17	Natural disaster	Sichuan Province	2020.4.12	112,098.00	2,797,984.00	4.01%	24.96%
18	Natural disaster	Sichuan Province	2020.11.11	5,740.00	126,000.00	4.56%	21.95%
19	Natural disaster	Sichuan Province	2019.11.28	328,398.00	9,954,000.00	3.30%	30.31%
20	Natural disaster	Guangzhou City, Guangdong Province	2018.9.16	42,000.00	1,267,196.00	3.31%	30.17%
21	Natural disaster	Suining City, Sichuan Province	2018.7.11	15,078.00	336,000.00	4.49%	22.29%
22	Natural disaster	Zhuhai City, Guangdong Province	2017.8.23	21,000.00	592,130.00	3.55%	28.20%
23	Natural disaster	Putian City, Fujian Province	2016.8.5	22,400.00	572,488.00	3.91%	25.56%

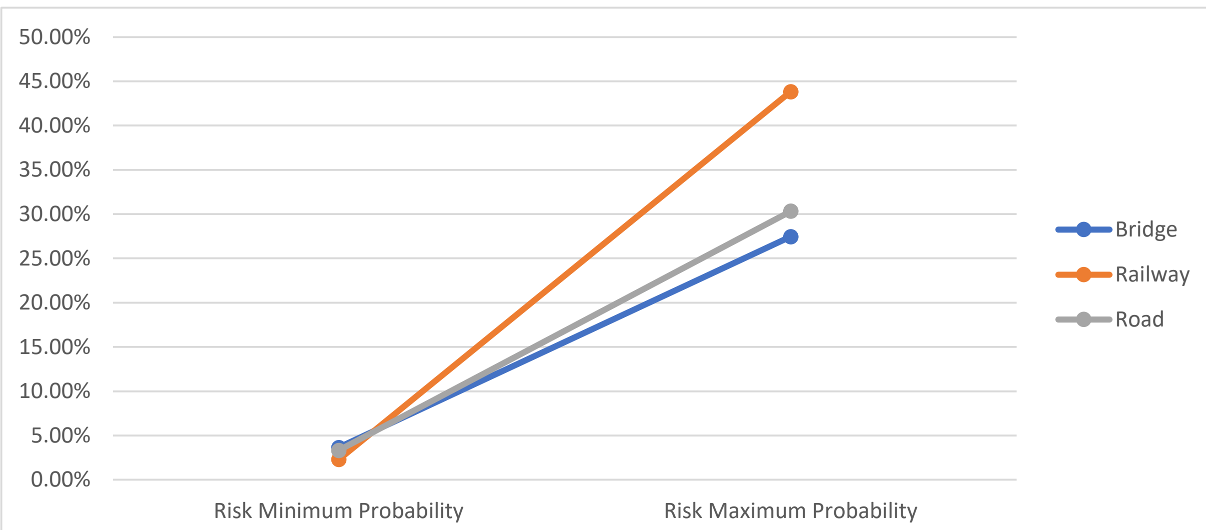

Fig. 2 Risk occurrence range by facility

2.4. Judging Criteria Based on the Range of Risk Probability

Table 5. Risk occurrence range by facility

	Risk Minimum Probability	**Risk Maximum Probability**
Bridge	3.64%	27.44%
Railway	2.28%	43.81%
Road	3.30%	30.31%

The probability of risks that may occur during the construction of key infrastructure, such as bridges, railways, and highways, was predicted through insurance company data. The probability of bridge construction risks is about 3.64% to 27.44%, which can provide the main basis for predicting and responding to risks such as natural disasters and technical accidents related to bridge construction. Risk events within this probability range show that risk transfer through insurance is an economical and effective means of response.

The risk occurrence probability range of the bridge is obtained through (Table 5) and the risk occurrence probability is substituted into Equation (3).

$$I_p < 3.64\% \times I \sim 27.44\% \times I \qquad (12)$$

$$I > 27.44\% \times I_P \qquad (13)$$

When the insurance premium is 1 million dollars, the expected insurance compensation is at least 3.6443 million dollars. It can be a suitable alternative to risk transfer. On the contrary, other alternatives should be considered, or an alternative combined with risk transfer should be selected.

Analysis of railway projects shows that the probability of risk occurrence ranges from 2.28% to 43.81%. Due to the long distance, complex construction environment and technical characteristics of railway projects, it is very likely to generate risks for different facilities. The probability judgment within this range can serve as an important basis for project managers to implement effective risk response and cost control through insurance. Considering the complex and long-term nature of railway projects, it is imperative to do a good job in risk assessment and corresponding insurance strategy formulation in the early stage.

The risk occurrence probability range of the railroad is obtained through (Table 5) and the risk occurrence probability is substituted into Equation (3).

$$I_p < 2.28\% \times I \sim 43.81\% \times I \tag{14}$$

$$I > 43.81\% \times I_P \tag{15}$$

When the insurance premium is 1 million dollars, the expected insurance compensation is at least 2.2826 million dollars. It can be a suitable alternative for risk transfer. On the contrary, other alternatives should be considered, or an alternative combined with risk transfer should be selected.

According to the results of the probability analysis of highway construction projects, the probability of natural disasters, collapse accidents and other risks at road construction sites is as high as 3.30% to 30.31%. This accurately reflects the project's geographical characteristics and meteorological environment characteristics, suggesting that insurance premium formulation and risk transfer strategies can be formulated based on these data. Therefore, starting from the road construction planning stage, we should actively use these risk probability prediction data to develop reasonable response methods to minimize economic losses.

The risk occurrence probability range of the road is obtained through (Table 5) and the risk occurrence probability is substituted into Equation (3).

$$I_p < 3.30\% \times I \sim 30.31\% \times I \tag{16}$$

$$I > 30.31\% \times I_P \tag{17}$$

When the insurance premium is 1 million dollars, the expected insurance compensation is at least 3.2992 million dollars. It may be suitable as an alternative to risk transfer. On the contrary, consider other alternatives or choose an alternative combined with risk transfer.

By analyzing historical insurance claim data, a comprehensive calculation method within insurance companies aligns with the interests of the insurance formula. Using historical insurance claim data effectively ensures the acquisition of risk probability data during construction management. Risk occurrence probabilities are typically calculated using Qualitative Methods, Semi-Quantitative Methods, and Quantitative Methods, but these require substantial data for computation, simulation, and subjective judgment. So, by citing historical insurance claim data, simplifying this stage can make it easier to obtain the probability of risks occurring, and even involve non-experts in project work, significantly reducing unnecessary termination and delays due to a lack of experts.

In the risk management of construction projects, experts generally judge the appropriate risk response methods based on the probability of risk occurrence. However, some construction projects may have unexpected risk factors or force majeure risks, and the probability of these risks is often difficult to express in clear numbers. In view of this, this study analyzes the past data of insurance companies and uses the data of project insurance claims to analyze and calculate the probability range of unexpected risk factors or force majeure risks that may occur in construction projects. According to the research, the key elements in the criteria for evaluating risk response methods are as follows.

First, from the perspective of effectiveness, whether the probability of occurrence or the impact of the target risk can be significantly reduced. In other words, whether the goals of reducing accident rates, reducing loss amounts, and improving quality or safety levels are achieved within the expected range.

Secondly, in terms of feasibility, see whether the organization can truly implement the corresponding response methods under existing resources, technology, capabilities, and time constraints. At the same time, consider whether the internal management environment or external policies and market environment pose a major obstacle to the implementation of the plan.

Third, in terms of economy, the focus is on the balance between costs and benefits, such as direct costs, indirect costs, potential profits or opportunity costs. Net Present Value (NPV) has a positive (+) value or can ensure a reasonable Return On Investment (ROI), so whether the organization can accept it is also a core judgment criterion.

Fourth, in terms of flexibility and adaptability, the core is whether the response plan can be quickly adjusted, repeatedly improved or upgraded according to changes in the environment or internal conditions. In addition, it is also evaluated whether it can expand to meet the potential risk needs of various scales or scopes.

Fifth, strategic alignment is to observe how consistent the organization's overall strategic goals, core competitiveness, long-term development direction and corresponding response plans are. In addition, whether or not it can consider the company's short-term tactical needs and long-term strategic development has also become a major assessment factor.

Sixth, in terms of risk preference and regulatory compliance, determine whether the plan is within the risk preference range of the organization or project, and whether it complies with external regulations, standards, and industry guidelines. In addition, full consideration of the needs of stakeholders and social responsibilities, whether it complies with the trend of sustainable development, has become a key judgment indicator. Seventh, in terms of measurability and monitorability, the risk response method must have feasible monitoring indicators and evaluation systems, whether it can be continuously improved, and whether clear Key Performance Indicators (KPI) or Key Risk Indicators (KRIs) are set.

Therefore, the method proposed in this study is based on the calculation relationship between insurance premiums and insurance compensation in previous insurance claims contracts as the basis for judging risk transfer in risk response methods. In the risk management system, the economy, that is, the cost-benefit balance, comprises direct costs, indirect costs, potential benefits or opportunity costs. In addition, in terms of feasibility, ensure that the response plan is implemented under the constraints of existing resources, technology, capabilities and time; at the same time, in terms of flexibility and adaptability, it can also be adjusted, repeatedly improved and upgraded in time when the environment or internal conditions change.

Insurance companies mainly consider a variety of interest factors to calculate insurance premiums and calculate insurance compensation according to ideal standards when applying for insurance premiums. Therefore, taking the insurance contract data related to construction project management as a reference, the risk occurrence probability obtained through the calculation process proposed in Equations (10) and (11) intuitively gives the probability range of unexpected risk factors or force majeure risks that may occur in construction projects. This can provide project managers and experts with a simpler judgment standard and contribute to the establishment of an effective risk response method.

3. Using the PERT Network Method to Assess the Expected Value of the Probability of a Risk Occurring

3.1. PERT Network Method

In the PERT Network Method, the time required for each task exists in three forms: optimistic time (O), pessimistic time (P), and most likely time (M). In this study, the concept of time is converted into probability, optimistic probability (O), pessimistic probability (P), and most likely probability (M). The optimistic probability assumes that the probability of risk occurring in all intervals is close to or lower than the minimum value. The pessimistic probability assumes that the probability of risk occurring in all intervals is close to or higher than the maximum value. The most likely probability assumes that the risk is minimized in each interval (the middle degree between the minimum and the maximum).

Expected Probability of Risk Occurring (E_r):

$$E_r = \frac{O + 4M + P}{6} \tag{18}$$

Variance of risk occurring (σ^2):

$$\sigma^2 = \left(\frac{P - O}{6}\right)^2 \tag{19}$$

Expected Value represents the average level or best estimate of the probability of risk occurrence. In project management, it can be regarded as the weighted average of the probability or potential impact of a specific risk event. The larger the expected value, the greater the probability of the risk occurring, or the greater the impact on the project, and the more attention and resources are invested accordingly.

Variance represents the degree of uncertainty of risk and is an indicator of the fluctuation range of the probability or impact of project activities or risk events. The larger the variance, the more uncertain the estimate of the risk event, and the farther the actual result may differ from the expected value. Project managers will consider a higher safety margin and formulate corresponding emergency plans or buffer measures.

Therefore, the expected value probability and variance obtained through PERT analysis indicate the relative level of the possibility of risk occurrence, so that the project team can prioritize the allocation of limited resources and methods to deal with risks with greater probability or greater impact. This can be used as a criterion for judging rapid and effective risk response plans.

Variance representing risk uncertainty helps to judge the stability of the estimation results. If the dispersion is large, it means that there is uncertainty in the understanding or input parameters of the risk event, and the actual results are likely to be far from the forecast, which requires increased monitoring and adjustment efforts.

In summary, these indicators help project managers grasp risks more accurately and develop more specific risk response methods based on the risk probabilities of different facilities obtained from past data analysis. This can improve the overall control and probability of success of the project.

3.2. Risk Estimation Using the PERT Network Method

In the PERT technique, the minimum and maximum probabilities of risk occurrence are used instead of the existing optimistic and pessimistic probabilities because the objective probability obtained through actual observation data can provide more reliable results than the subjective judgment of optimism or pessimism on the actual characteristics of construction project risks. In construction risk management, the specific values of the minimum and maximum probabilities of project risks obtained through actual data experience have the advantage of being more realistic and objectively based.

In building a risk management system, there is significant uncertainty due to various force majeure factors (natural disasters, accidents during construction, etc.). However, the PERT method provides project managers with a more scientific and flexible planning and control tool by considering the uncertainty in project occurrence probabilities. This weighted approach allows project planning to reflect fluctuations and uncertainties in the engineering process more accurately, outperforming traditional probabilistic estimation methods. Since each task includes variance, the PERT method can statistically analyze the project's probability of occurrence, calculate the expected and standard deviation of the project's risk occurrence probability. This provides a strong scientific basis for developing corresponding risk response strategies.

This paper calculates the ratio of actual premium to insurance compensation through the analysis of insurance data, and objectively calculates the minimum and maximum probability of risk occurrence based on this. Using insurance data of actual risk cases in the construction environment improves reality and is an approach to make up for the subjectivity and ambiguity of the existing optimistic and pessimistic probabilities.

Therefore, when using the PERT technique, this paper uses the minimum and maximum probabilities obtained from actual experience data instead of simply using the abstract concepts of optimism and pessimism as the expected probability value of the project, aiming to achieve more accurate predictions and the formulation of effective risk transfer strategies. It can provide project managers with clearer and more reliable judgment criteria and improve the efficiency of risk management of complex and dynamic construction projects.

Combined with the predicted probability values and variances of the risk probability ranges of bridges, railways and roads in Tables 2, 3 and 4, the PERT Network Method is used to calculate the results in Table 6. Calculated according to Equations (12) and (13).

Table 6. Optimistic, most probable and pessimistic probabilities of risks for bridges, railways and roads

	Optimistic probability (O) (minimum probability of occurrence)	Most probable probability (M) (intermediate probability of occurrence)	Pessimistic probability (P) (maximum probability of occurrence)
Bridge	3.64%	12.07%	27.44%
Railway	2.28%	14.77%	43.81%
Road	3.30%	13.28%	30.31%

3.2.1. Risk Estimation of the Bridge

According to Table 6, the predicted probability of bridge risk occurrence:

$$E_r = \frac{0 + 4M + P}{6} = \frac{3.64\% + (4 \times 12.07\%) + 27.44\%}{6} = 13.23\% \quad (20)$$

According to Table 6, the risk of bridges varies.

$$\sigma^2 = \left(\frac{P - O}{6}\right)^2 = \left(\frac{27.44\% - 3.64\%}{6}\right)^2 = 0.016\% \quad (21)$$

This study uses the PERT Network Method to analyze the possible risks in the bridge construction process, and the expected value is 13.23% and the variance is 0.016%. Based on the results of the analysis, the risk transfer response method is explained as follows:

3.2.2. Risk Estimation of railway

According to Table 6, the predicted probability of railway risk occurrence:

$$E_r = \frac{0 + 4M + P}{6} = \frac{2.28\% + (4 \times 14.77\%) + 43.81\%}{6} = 17.53\% \quad (22)$$

According to Table 6, the risk of the railway varied.

$$\sigma^2 = \left(\frac{P - O}{6}\right)^2$$

$$= \left(\frac{43.81\% - 2.28\%}{6}\right)^2$$

$$= 0.048\% \quad (23)$$

In railway construction management, when selecting transfer strategies for different facility risks, comprehensive assessments are made of multiple factors, including the probability of risk occurrence, the scale of losses, the risk tolerance of project participants, and the cost of transfer. If the PERT analysis method is used to obtain a risk prediction value of 17.53% for each facility, with a dispersion of 0.048%, this can be used as the core quantitative basis for the selection of risk transfer strategies. The judgment criteria for risk transfer can be derived by comprehensively considering the following factors.

3.2.3. Risk Estimation of The Road

According to Table 6, the predicted probability of road risk occurrence:

$$E_r = \frac{0 + 4M + P}{6} = \frac{3.30\% + (4 \times 13.28\%) + 30.31\%}{6}$$
$$= 14.46\% \quad (24)$$

According to Table 6, the variance of the road risk occurs.

$$\sigma^2 = \left(\frac{P - O}{6}\right)^2$$

$$= \left(\frac{30.31\% - 3.30\%}{6}\right)^2$$

$$= 0.020\% \quad (25)$$

The expected value of 14.46% has a low probability of occurrence, but if the risk occurs, it will cause great losses to the project, so it is preferred to transfer the risk to professional institutions or third parties through insurance or contract terms.

The variance of 0.020% indicates that the probability of risk occurrence is concentrated, and the characteristics of risk events are obvious. This allows insurance companies or partners to assess risks more accurately, and these risks are suitable for effective management through transfer.

When the expected value is 14.46% and the variance is 0.020%, the probability of risk occurrence is low, but the distribution is stable, which is suitable for transfer through insurance and contract terms. The final solution combines cost-effectiveness with risk priority to ensure that the transfer method will not incur excessive additional costs while effectively reducing the burden on enterprises.

3.3. The Probability of Risk Occurrence is Predicted through Expected Value and Variance

This study combines the PERT Network Method and insurance data to predict the probability of risk occurrence in major infrastructure construction projects such as bridges, roads and railways, and evaluates the applicability of risk transfer strategies based on this. The results of the study provide a range of probabilities of risk occurrence in different types of projects, which is helpful for formulating effective risk management plans.

The application deeply explores the risk management of construction projects such as bridges, railways, and roads, and combines insurance data to quantify the expected probability and dispersion of risk occurrence in different types of facilities. The main conclusions of the study are as follows.

First, through the PERT Network Method, the predicted probability of bridge engineering risk occurrence is 13.23%, and the variance is 0.016%. This value indicates that the overall risk level faced by bridge construction projects is relatively low, and the risk prediction is relatively stable and reliable. It is suitable to adopt risk transfer methods such as insurance to effectively reduce potential losses.

Second, the expected probability of road engineering risk occurrence is slightly higher, at 14.46%, with a variance of 0.020%. A higher expected probability means that the possibility of facing risks during road construction is slightly higher than that of bridges, and an increase in dispersion indicates an increase in risk uncertainty. Project management should pay more attention to risk monitoring and dynamic adjustment, and advocate the combination of risk transfer and reduction methods.

Third, the expected probability of railway project risk occurrence is the highest, reaching 17.53%, with a dispersion of 0.048%, which is significantly higher than that of bridge and road projects. This reflects that railway projects are generally complex in construction, and the geological conditions and construction technology risks are relatively high. Project management should especially strengthen risk management investment, and it is recommended to combine insurance with the risk transfer and reduction methods of the contract to effectively deal with the financial and progress situation after the risk occurs.

The calculation results based on the PERT Network Method show that facilities such as bridges, roads, and railways face different degrees of risk during construction. Among them, the expected probability of railway construction risk occurrence is about 17.53%, and the expected probability of bridge and road risk occurrence is relatively low, at 13.23%

and 14.46% respectively. This result shows that among the three major types of infrastructure construction, the risk management needs of railway projects are the most prominent. Complex structural design, mountains and the external environment have a greater impact, and more stringent risk control measures are needed in the early stages of construction.

From the perspective of risk distribution, the dispersion of different types of facilities reflects the uncertainty of risk. This indicates that the risk dispersion of bridges and roads is small (0.016% for bridges and 0.020% for roads), and the probability of risk occurrence is relatively stable, which is suitable for standardized risk response methods such as regular inspection, structural monitoring and preventive maintenance. The dispersion of railways is large (0.048% for railways), which means that the risk is greatly affected by the external environment and may fluctuate greatly due to geological conditions, construction methods or unpredictable external factors. Therefore, in the risk management of bridge and road projects, a more dynamic monitoring mechanism, such as real-time data analysis, intelligent sensor monitoring, etc., is adopted, and the flexibility of risk response is higher.

Overall, the PERT Network Method effectively quantifies the probability and uncertainty characteristics of various types of infrastructure risks. Through the prediction value and variance analysis, the risk response methods suitable for different projects are clarified. Based on the results of the analysis, project managers make scientific and reasonable risk decisions in the early planning and design stages of the project to ensure the smooth implementation of the project.

Table 7. Estimated probability and variance of risks in bridges, railways and roads

	Expected probability of occurrence (E_r)	Variance of occurrence (σ^2)
Bridge	13.23%	0.016%
Railway	17.53%	0.048%
Road	14.46%	0.020%

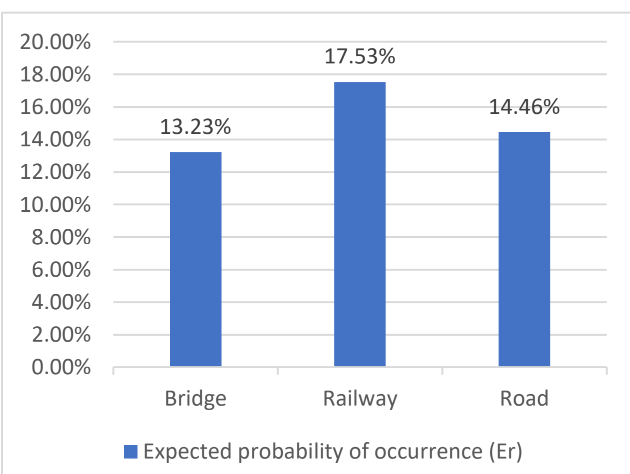

Fig. 3 Estimated probability of risks in bridges, railways and roads

4. Conclusion

This study proposes a risk transfer method based on insurance data as a risk assessment and response strategy for different facilities in construction project management. To this end, past insurance data was analyzed to quantitatively evaluate the relationship between the risk probability of each facility and the insurance premium and insurance compensation. Based on this, an evaluation model for objectively judging the appropriateness of the risk transfer strategy was proposed. In addition, combined with the PERT technique, the risk probability and dispersion were obtained, and the risk judgment standard for each facility was formulated.

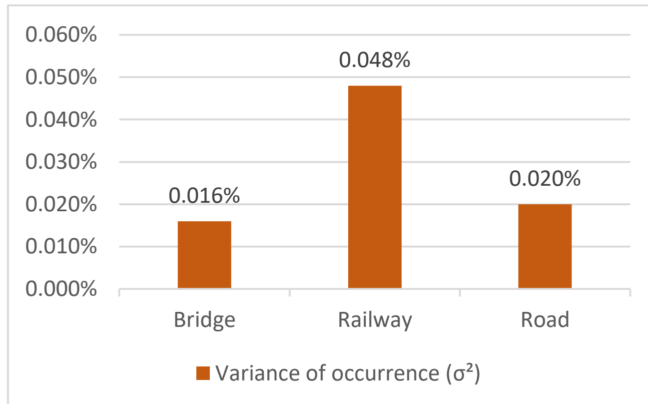

Fig. 4 Variance of risks in bridges, railways and roads

1. Through insurance data analysis, the minimum and maximum probability of risk occurrence of each bridge, highway, railway and other facilities were quantitatively calculated. This can become an objective basis for deciding whether to apply the risk transfer strategy.
2. With the clear distinction of the risk probability of each facility type, an effective risk management plan that meets the characteristics of each facility can be formulated. For example, considering the complexity of the construction environment, construction period, etc., the strategy of using insurance to transfer risks may be more important for railway projects.
3. A methodology is proposed to effectively derive the minimum and maximum probability of risk for each facility using the ratio of insurance premiums to insurance compensation.
4. Combining the calculated minimum and maximum probabilities with the PERT method, the probability of risk occurrence and dispersion is obtained. When the probability of risk occurrence is high or the dispersion is large, risk transfer is an effective response measure. On the contrary, if the probability of risk occurrence and dispersion are low, it can be confirmed that risk avoidance or holding strategies are more appropriate.
5. Emphasize whether the risk transfer strategy is adopted, and fully consider the cost rationality, the third-party performance ability, and the clarity of management responsibilities after the transfer.

The expected results of this study are as follows.

1. The analysis of insurance premiums and insurance compensation ratios supports faster and more effective judgment of risk transfer and improves the efficiency of risk transfer decision-making.
2. Combine expert experience and objective insurance data to improve the accuracy and practicality of decision-making and enhance the effectiveness of construction risk management.
3. Use each facility's risk probability inference method to formulate a realistic response plan and use it repeatedly.
4. Improve the objectivity and efficiency of decision-making throughout the construction project by applying the risk transfer method and PERT method of application analysis.
5. Promote information sharing and collaboration among stakeholders, strengthen project governance, and clarify the risk compensation mechanism.

To enhance the applicability and reliability of the proposed risk transfer strategy based on insurance data, future studies should pursue the following directions:

First, multi-national and multi-institutional data collection must be prioritized to validate the generalizability of the proposed model. The risk environment of construction projects differs significantly across regions due to regulatory, climatic, economic, and social factors. Therefore, expanding the data scope beyond a single insurance company and integrating datasets from different countries will allow for more robust and region-specific calibration of risk probability and transfer models.

Second, to improve the accuracy and multidimensionality of risk assessment, future research should introduce hybrid evaluation methods, incorporating both quantitative (e.g., insurance metrics, historical risk frequency) and qualitative (e.g., expert interviews, stakeholder perception) dimensions. Techniques such as the Analytic Hierarchy Process (AHP) and fuzzy logic-based modeling can help to represent expert knowledge under uncertainty and capture intangible risk attributes.

Third, from a practical standpoint, it is essential to develop a standardized decision-support tool or software module that integrates insurance-based risk probability estimation with project schedule planning (via the PERT technique). This tool should be able to dynamically calculate risk dispersion, recommend appropriate risk response strategies, and simulate the cost-effectiveness of each response (transfer, avoid, retain).

However, this study has some limitations. The data used are based on data collected by an insurance company, which may limit the generalizability of the research results. The environmental, policy, economic conditions, social, and cultural differences that affect risk factors vary from region to region, so it is necessary to conduct additional research using data from multiple countries and institutions in the future. In addition, this study mainly evaluates quantitative data such as premiums and insurance compensation, but qualitative factors are not considered sufficiently. In future research, it is necessary to establish a more comprehensive risk management model through multi-dimensional evaluations such as expert interviews, AHP, and fuzzy logic.

Despite these limitations, this study proposes the practicality of using insurance data to formulate risk assessment and response strategies for construction projects, which is expected to contribute to the establishment of objective judgment criteria for risk transfer. In future research, it is necessary to conduct empirical verification in multiple environments, develop more sophisticated risk assessment models, and continuously develop risk management systems for construction projects.

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