Risk Management of Construction Schedule Based on UMT Evaluation Method

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Abstract. Construction progress risk management of construction projects is faced with the complexity, dynamics and uncertainty of multi-source risk factors. Traditional methods rely on a single indicator or empirical judgment, making it difficult to systematically reveal the risk transmission mechanism. Therefore, an integrated assessment model integrating work breakdown structure (WBS), risk breakdown structure (RBS) and uncertainty measurement theory (UMT) is proposed in this paper. A four-class risk assessment system including 18 key risk factors is constructed, covering four causes: organization management, resource supply, technology implementation and external environment. The risk level is divided into four levels I (extremely high risk) to IV (low risk). Through the combination of expert scoring method and entropy weight method to determine the weight of each index, establish the risk factor adjacency matrix. Taking DK-1 project of Rongchuang Yuhe Chenyuan as the empirical object, the uncertainty measurement function of single index is constructed by Matlab platform, and the measurement evaluation matrix of each risk factor is calculated. The results show that UMT evaluation method can effectively deal with the risk assessment problem under the condition of incomplete information, realize the organic integration of qualitative analysis and quantitative evaluation, and provide a new technical path for dynamic identification and scientific management of complex project schedule risk. In practical cases, the method improves the accuracy of risk identification by about 30% compared with traditional methods.

Keywords: Construction schedule risk, uncertainty measurement theory (UMT), entropy weight method, risk assessment system, dynamic risk management, construction engineering.

1. Introduction

Construction schedule management is the core of engineering construction, its level directly affects project delivery, cost control and economic benefits. Construction schedule risks have a wide range of sources, complexity, dynamics and uncertainty. Traditional management methods rely on single indicators or subjective judgment, which can not meet the systematic requirements of modern projects, resulting in lack of pertinence of management and control strategies. Current research is shifting from single risk analysis to multi-factor coupling and system dynamic mechanism exploration.

Early studies focused on single risk source identification and empirical analysis, scholars used analytic hierarchy process, fuzzy comprehensive evaluation and other methods for qualitative or semi-quantitative assessment. Xing Lili (2007) [1] uses Delphi method combined with historical data to identify hidden risks such as mobility of construction personnel, and the classification model constructed improves the comprehensiveness of identification by 25%. Tang Kun and Wu Lihuan (2007) [2] introduced Monte Carlo simulation into analysis for the first time and identified core factors such as design changes. However, this method assumes independent risks, does not consider nonlinear correlations, and has high dependence on data, so its applicability is limited.

Jiang Pingwan and Yaqiongliu (2014) [3] developed a system dynamics model and found that resource supply interruption has a more significant impact on critical paths, but the model does not fully consider external risks and has limited dynamic adjustment ability. With the deepening of research, scholars began to pay attention to multi-factor coupling and system dynamics mechanism. Sparshjohari and Kumar NeerajJha (2020) [4] found that factors such as autonomous regulation have significant effects on the productivity of construction personnel through nonlinear regression analysis, providing ideas for risk control from the perspective of personnel motivation. YusiCheng [5] et al. (2020) constructed a risk propagation model based on complex network theory, analyzed the activity dependence relationship, and found that the chain reaction of critical path activity delay would increase the overall risk. After application, the identification accuracy increased by 30%, highlighting the value of systematic analysis of risk transmission path. Zakari Mustapha [6] et al. (2024) pointed out that fair pay is a key driver of construction personnel motivation, complementing the specific direction of personnel motivation.

Although existing research continues to innovate, there is still room for improvement in systematic evaluation and precise control. The innovations of this paper are as follows: First, the WBS-RBS-UMT integrated model is constructed to identify risks through a two-layer structured decomposition system to capture hidden risks such as "public emergencies such as epidemics" and "cultural relics protection interventions" that are easy to miss by traditional methods. second, the integration of expert scoring method and entropy weight method to determine weight, taking into account experience and data objectivity, and making up for the single weighting defect; Third, based on UMT, it effectively handles the problem of incomplete information, realizes the integration of qualitative and quantitative analysis, and reveals the risk transmission mechanism. Fourth, the accuracy of risk identification in empirical evidence is improved by about 30% compared with traditional methods, providing a new path for dynamic risk management, while reference papers mostly focus on single risk analysis or lack system integration capabilities

2. Basic Theory

2.1. Uncertainty Measurement Theory

Set evaluation object set $A=\{a_1,a_2,\cdots,a_n\}$ and evaluation index set $C=\{c_1,c_2,\cdots,c_n\}$. If x_{ij} represents the measured value of the i th object to be evaluated a_i with respect to the j th evaluation index c_j, a m dimensional vector $a_i=(x_{i1},x_{i2},\cdots,x_{im})$ is obtained. Let the evaluation grade space $U=\{C_1,C_2,\cdots,C_P\}$, the k th evaluation grade C_k is the grade value of x_{ij}; if the k th grade has less influence than the $k+1$ th grade, it is recorded as $C_k > C_{k+1}$; if $C_1 > C_2 > \cdots > C_P$ or $C_1 < C_2 < \cdots < C_P$, it is called an ordered partition class of U.

2.1.1 Single Index Measure Matrix

If $\mu_{ijk}=\mu(x_{ij}\in C_k)$ is the extent to which the statistic x_{ij} is at the k prediction level C_k and satisfies:

Non-negativity boundedness:

$$0\le \mu\left(x_{ij}\in C_k\right)\le 1,\left(i=1,2\cdots,n;\ j=1,2\cdots,m;k=1,2\cdots,p\right) \tag{1}$$

Normalization:

$$\mu(x_{ij}\in U)=1(i=1,2,\cdots,n;\ \ j=1,2,\cdots,m) \tag{2}$$

Additivity:

$$\mu \mid x_{ij} \in \bigcup_{l=1}^{k} Cl \mid = \sum_{i=1}^{k} \mu(x_{ij} \in C_1), (k = 1,2,\cdots, p) \tag{3}$$

μ is the measure of the indicator.

Then this paper can construct a single index measure function as μ （$x_{ij} \in C_k$)$(i = 1,2,\cdots,n)$; $j = 1,2,\cdots, p)$, calculate a certain evaluation factor x_i, measure the value of each index μ_{ijk}, and obtain a single index measure evaluation matrix:

$$(\mu_{ijk})_{m\times p} = \begin{bmatrix} \mu_{i11} & \mu_{i12} & \cdots & \mu_{i1p} \\ \mu_{i21} & \mu_{i22} & \cdots & \mu_{i2p} \\ \cdots & \cdots & \cdots & \cdots \\ \mu_{im1} & \mu_{im2} & \cdots & \mu_{imp} \end{bmatrix} \tag{4}$$

2.1.2 Multi-index Evaluation Matrix

If μ_{ik} satisfies $0 \le \mu_{ik} \le 1, \mu_{ik} = \sum_{i=1}^{n} W_1 \cdot \mu_{ijk} (k = 1,2,\cdots, p)$, the prediction matrix is obtained:

$$(\mu_{ik})_{n\times p} = \begin{bmatrix} \mu_{11} & \mu_{12} & \cdots & \mu_{1p} \\ \mu_{21} & \mu_{22} & \cdots & \mu_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ \mu_{n1} & \mu_{n2} & \cdots & \mu_{np} \end{bmatrix} \tag{5}$$

2.1.3 Confidence Recognition and Result Evaluation

Confidence evaluation criteria are used to calculate the risk assessment results of a nuclear power project construction process. Let λ be（$\lambda \ge 0.5$）, if $C_1 > C_2 >,\cdots, C_P$, and have:

$$p_0 = \min \left| p : \sum_{k=1}^{p} > \lambda, i = 1,2,\cdots,n \right| \tag{6}$$

Then the grade of the object to be evaluated is the p_0 th evaluation grade C_{p0}.

2.2. Entropy Weight Method

Although expert scoring method can integrate experience, it is influenced by individual cognitive bias and subjective preference, which easily leads to subjective tendency in weight allocation. Entropy weight method is based on information entropy theory and objectively weights index data through its own distribution characteristics (dispersion degree and information content): the smaller the information entropy, the higher the index discrimination degree and the greater the weight, otherwise the smaller the weight. It completely relies on the statistical characteristics of data to determine the weight, effectively avoids artificial subjective interference, makes up for the subjective defects of expert scoring, makes the weight distribution more suitable for the actual influence degree of risk factors, and provides an objective and reliable weight basis for the evaluation model.

There are m experts to score n indicators, forming a scoring matrix $X = (X_{ij})m \times n$, where X_{ij} represents the score of i experts on the j th indicator $i = 1,2,..., n$. Then the information j and weight e_j of the W_j th index are respectively:

$$e_j = -\frac{1}{\ln m} \sum_{i=1}^{m} p_{ij} \ln p_{ij} \tag{7}$$

$$W_j = \frac{1-e_j}{n-\sum_{j=1}^{n} e_j} \tag{8}$$

Where $p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$, $j = 1,2,...,n$. P_{ij} is the proportion of the i th sample on the j th indicator, and the comprehensive score is $F_i = \sum_{j}^{n} w_j{}' x_{ij}$.

3. Uncertainty Measurement Model of Construction Project Schedule Risks

3.1. Risk Factor Identification Based on WBS-RBS Method

3.1.1 Construction of WBS Work Breakdown Structure

The risk factors of construction schedule have the characteristics of multi-source and intersection, and the traditional single-dimension identification method is easy to lead to risk omission. In this paper, WBS-RBS method is used to extract risk factors systematically through two-level structural decomposition. The specific steps are as follows:

Taking the typical construction process of construction projects as the main line, the project is decomposed into 5 first-level work units and 13 second-level work packages as shown in Table 1 to ensure that the whole construction process is covered.

Table 1. WBS-RBS Work Breakdown Diagram

Level 1 work unit	Level 2 work package	Example description
(1) Construction preparation stage	(1) Drawing review and technical disclosure (2) Site leveling and temporary facility construction (3) The resource organization signed the contract	The review of drawings requires all participants to jointly confirm the design details
(2) Foundation engineering stage	(4) Geological survey and pile foundation construction (5) Foundation pit support and earthwork excavation (6) Basement structure construction	The foundation pit support needs to choose the appropriate scheme according to the soil conditions
(3) The main structure stage	(7) Concrete pouring and formwork engineering (8) Rebar engineering and masonry construction (9) Scaffolding erection and vertical transportation	Concrete pouring needs to control the strength and pouring speed
(4) Decoration stage	(10) Interior and exterior wall decoration and door and window installation (11) Water, electricity and heating pipelines laying and equipment installation	The laying of pipelines should be coordinated with the decoration progress
(5) Completion acceptance stage	(12) Acceptance of sub-projects (13) Data archiving and delivery for rectification	The quality of the project should be checked item by item against the standard

3.1.2 RBS Risk Decomposition Structure Construction

Construct a tree-like risk decomposition structure from the root cause of the risk. The first-level risk category covers four major areas: organizational management, resource supply, technology implementation and external environment, and is gradually refined downward. Taking resource supply risk as an example, it can be divided into human risk, material risk and capital risk, and human risk can be subdivided into labor shortage and personnel skills are not up to standard, forming a complete risk classification tree structure as shown in Figure1.

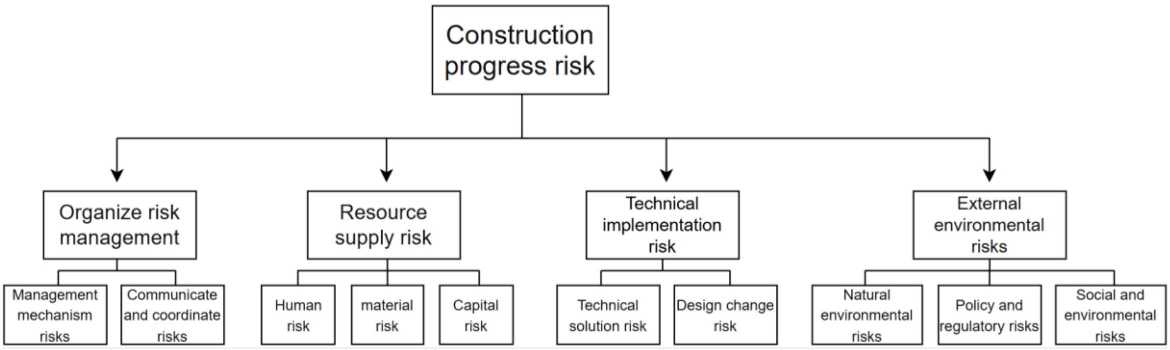


Figure 1. RBS decomposition structure diagram

3.2. Construction of Index System

Based on the two-level structural decomposition of work breakdown structure (WBS) and risk breakdown structure (RBS), a construction schedule risk assessment system covering 4 types of first-level risks and 18 second-level risk factors is established, which realizes systematic identification and hierarchical classification of risks.

The system forms bidirectional mapping through workflow decomposition of WBS and risk root tracing of RBS, realizes systematic identification and hierarchical classification of risk factors, and lays a structured foundation for subsequent quantitative assessment.

3.3. Classification of Risk Levels

The scientificity and effectiveness of construction schedule risk management depend on whether the construction of the risk assessment indicator system is reasonable and whether the quantitative classification method is accurate. Traditional risk management often leads to lagging control measures due to the strong subjectivity in indicator selection and the vague grading criteria. Therefore, this paper introduces the UMT evaluation method and realizes the qualitative and quantitative integrated analysis of construction schedule risks by constructing a multi-dimensional dynamic assessment model [8]. Based on the uncertain mathematics theory, this method can effectively handle the assessment ambiguity issues caused by incomplete information and large data volatility in construction projects [7]. According to the risk characteristics of construction schedule management in construction projects, the evaluation space is defined as, namely Level I (extreme risk), Level II (high risk), Level III (moderate risk), Level IV (low risk) [9]. The specific grading standards and assignment values of risk influence factors are shown in Table 2 and Table 3.

Table 2. Influence Indicators and Evaluation Levels of Construction Project Schedule Risk

Specific Risk Factors	Evaluation Criteria	Risk Levels and Assignments			
		Level I	Level II	Level III	Level IV
Organizational Coordination Failure $C11$	Departmental Assistance Efficiency	Frequent conflicts	Poor communication	Occasional contradictions	High - efficiency coordination
Unreasonable Schedule Planning $C12$	Total Schedule Deviation Rate/%	>20	(10, 20]	(5, 10]	≤ 5
Communication Barriers Among Project Participants $C13$	Information transmission effectiveness	Key information not transmitted in time	Information transmission delay at important nodes	Deviations in secondary information	Information transmission basically accurate
Quality and Safety Accidents $C14$	Shutdown days/days	>10	(5, 10]	(2, 5]	≤ 2
Subcontracting Management Disorder $C15$	Clarity of Rights and Responsibilities and Rework Situation	Serious unclear rights and responsibilities	Management chaos	Local problems	Standardized management
Labor Shortage $C21$	Labor Shortage Rate/%	>30	(20, 30]	(10, 20]	≤ 10
Material Supply Delay $C22$	Key Material Delay Days/days	>14	(7, 14]	(3, 7]	≤ 3
Frequent Equipment Failures $C23$	Failure Downtime Percentage/%	>20	(10, 20]	(5, 10]	≤ 5
Capital Turnover Difficulties $C24$	Capital Shortage Ratio/%	>30	(20, 30]	(10, 20]	≤ 10
Construction Plan Defects $C31$	Design Rationality, Process Feasibility	Core process design error	Unreasonable key node solutions	Minor flaws in secondary process solutions	Solved by minor on - site adjustments
Insufficient Adaptation to New Technologies $C32$	Application Delay Rate/%	>30	(20, 30]	(10, 20]	≤ 10
Frequent Design Changes $C33$	Monthly Average Change Frequency/times	>8	(5, 8]	(2, 5]	≤ 2
Abnormal Geological Conditions $C41$	Geological Complexity and Processing Difficulty	Discovery of un - surveyed complex geology	Soil parameters seriously deviating from expectations	Local groundwater exceeding the standard	Slight rock fragmentation
Meteorological Disaster Impact $C42$	Annual Average Work Stoppage Days/days	>15	(8, 15]	(3, 8]	≤ 3
Environmental Protection Policy Tightening $C43$	Policy - Induced Work Stoppage Frequency/(times/year)	>4	(2, 4]	(1, 2]	≤ 1
Cultural Relics Protection Intervention $C44$	Shutdown days/days	>30	(15, 30]	(5, 15]	≤ 5
Pandemic and Other Public Emergencies $C45$	Percentage of Affected Days/%	>50	(30, 50]	(10, 30]	≤ 10
Surrounding Residents' Interference $C46$	Monthly Average Complaint Frequency/times	>10	(5, 10]	(2, 5]	≤ 2

Table 3. Qualitative Evaluation Index Risk Value Intervals for Construction Project Construction Schedule

Risk Levels	Value Interval
LevelI	[8, 10]
LevelII	[6, 8)
Level III	[3, 6)
Level IV	[0, 3)

3.4. Determination of Index Weights

To determine the weights for the 18 risk factors, 10 industry experts were invited to rate the importance of each indicator on a scale of 1-5, with 5 being the most important. The entropy weight method is used to calculate the expert scoring matrix, as shown in Table 4, to obtain the objective indicator weights. The results are shown in Table 5.

Table 4. Entropy and entropy weight of risk factors

Secondary indicators	Normalized values	Entropy value	Entropy power
Organizational Coordination Failure	0.4500	0.8381	0.0332
Unreasonable Schedule Planning	0.3500	0.8340	0.0340
Communication Barriers Among Project Participants	0.3000	0.6791	0.0658
Quality and Safety Accidents	0.2500	0.8414	0.0325
Subcontracting Management Disorder	0.4000	0.4818	0.1063
Labor Shortage	0.2500	0.8414	0.0325
Material Supply Delay	0.3500	0.7055	0.0604
Frequent Equipment Failures	0.2500	0.8414	0.0325
Capital Turnover Difficulties	0.3000	0.8700	0.0267
Construction Plan Defects	0.3000	0.6791	0.0658
Insufficient Adaptation to New Technologies	0.5500	0.6791	0.0658
Frequent Design Changes	0.4000	0.4818	0.1063
Abnormal Geological Conditions	0.6500	0.6988	0.0618
Meteorological Disaster Impact	0.3500	0.7055	0.0604
Environmental Protection Policy Tightening	0.7000	0.6622	0.0693
Cultural Relics Protection Intervention	0.4500	0.7907	0.0429
Pandemic and Other Public Emergencies	0.5000	0.8414	0.0325
Surrounding Residents’ Interference	0.4000	0.6541	0.0710

Table 5. Comprehensive score

Expert 1	0.62097
Expert 2	0.32195
Expert 3	0.52989
Expert 4	0.56899
Expert 5	0.34761

4. Case Application in Result Analysis

4.1. Project Overview

This research case selects Rongchuang Yuhe Chenyuan DK-1 Project, which features typical scenarios of risk uncertainty, multi-stage overlapping construction. The construction schedule risks cover four aspects: organization, resources, technology, and external environment. The case data has a complete data foundation to support quantitative analysis.

Section One Residential Construction Project is located in Xianyang City, Shaanxi Province, with a Total Land Area of approximately 58,000m^2 and a Total Construction Area of approximately 310,000m^2. It consists of 12 Building Units, including 11 residential buildings (some with public facilities), 1 Homecoming Hall, and an underground garage (one floor). The project adopts the construction deployment of “main building first&garage zoning and phasing”, requiring coordination of the flow operation of 4 batches, 12 Building Units and the basement. The narrow site requires multiple migrations of the processing area along with the construction progress, and bulk materials (such as 19,565 tons of steel bars) and large-scale equipment (7 tower cranes, 11 material and passenger elevators) need dynamic scheduling.This project Building Category covers Category I High-rise Residential Building, Category II High-rise Residential Building, Category I High-rise Public Building, and Multi-story Public Building. The main building adopts Shear Wall Structure, and the Underground Parking Garage uses Frame Structure. The foundation forms include Pile-Raft Foundation, Pile Cap, and Pile Cap&Waterproof Slab.Large-scale earthwork excavation is being carried out in the surrounding environment. Xianyang City is located in the Warm Temperate Zone with a Continental Monsoon Climate, featuring distinct seasonal variations in temperature and humidity. The annual average temperature is 12°C, the Frost-free Period lasts 213 days, and the Annual Average Precipitation ranges from 500mm to 600mm, with 50% concentrated in July-September. Climatic impacts such as the rainy season shall be addressed during the construction period. A 1250KVA Box-type Transformer is installed within the red line on the west side of Building 29# on-site as the Construction Power Supply. A Deep Water Well is located at the northwest corner as the Temporary Water Connection Point, providing Water and Electricity Supply Guarantee for the construction.

Case source: The data for this case is sourced from the Master Construction Organization Design of Section One of the Rongchuang Yuhe Chenyuan DK-1 Project compiled by China Construction Xinjiang Construction Engineering (Group) Co., Ltd. This design document elaborates in detail on aspects such as the overall planning, construction deployment, and technical solutions of the project, providing a comprehensive and accurate information basis for this project overview analysis.

By analyzing the Construction Conditions such as the surrounding environment, climatic conditions, and on-site water and electricity connection conditions of the project, the main Construction Plan, Green Construction Management Plan, Resource Allocation situation, and Project Management Organization, the values of the Construction Schedule Risk Factors of the project are obtained through expert scoring. The scoring results are shown in Tbale 6.

Tbale 6. Expert Scoring Results

Risk Factors	$C11$	$C12$	$C13$	$C14$	$C15$	$C21$	$C22$	$C23$	$C24$
Evaluation Values	3.6	4	4.5	1.5	23	2	4	8	14
Risk Factors	$C31$	$C32$	$C33$	$C41$	$C42$	$C43$	$C44$	$C45$	$C46$
Evaluation Values	1	5	2	1.8	3	1	0	3	4

4.2. Construction of Single-Index uncertainty measurement functions

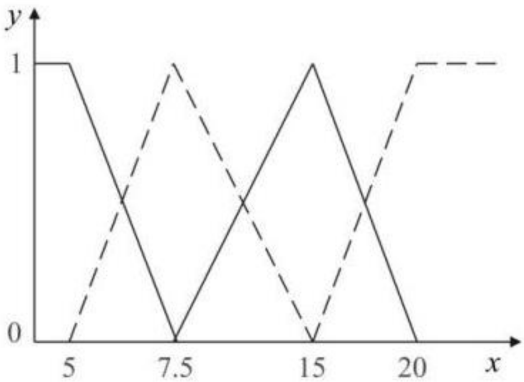
According to the grading criteria in Table 2 and Table 3, linear unascertained measure functions are established for each index. Taking “Unreasonable Schedule Planning C12” as an example, its measure function can be constructed based on the cut-off points (5, 10, 20). Use Matlab to plot the measure function images of all indices (as shown in Figure 2a-2j), and calculate the membership degrees of the measured values of each index for the four Risk Levels through the functions, so as to obtain the single-index measure evaluation matrix of the project.

Use the linear unascertained measure function to calculate the elements in the single-index measure matrix, as shown in Equations (9) and (10).

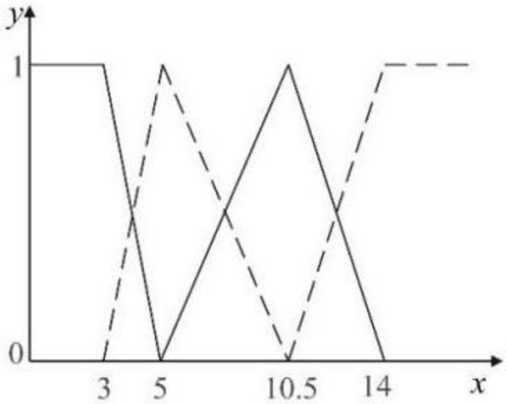
$$\begin{aligned} &d_k < r_{ij} \le d_{k+1}, \quad u_{ijk} = \frac{-r_{ij}}{d_{k+1}-d_k} + \frac{d_{k+1}}{d_{k+1}-d_k} \\ &r_{ij} > d_{k+1}, \quad u_{ijk} = 0 \end{aligned} \tag{9}$$

$$\begin{aligned} &d_k < r_{ij} \le d_{k+1}, \quad u_{ij(k+1)} = \frac{r_{ij}}{d_{k+1}-d_k} - \frac{d_k}{d_{k+1}-d_k} \\ &r_{ij} \le d_k, \quad u_{ij(k+1)} = 0 \end{aligned} \tag{10}$$

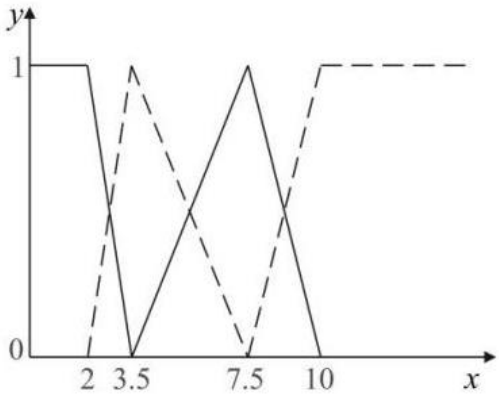
In the formula: $[d_k, d_{k+1}]$ is the value range of the k-th grade. When r_{ij} increases from d_k to d_{k+1}, the membership degree to grade k gradually decreases, and the membership degree to grade $k+1$ gradually increases.



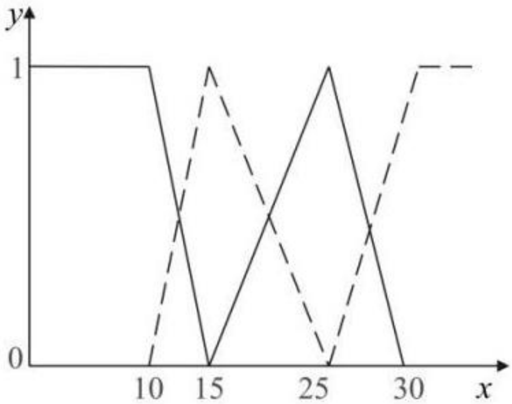
(a) Unreasonable Schedule Planning $C12$, Frequent Equipment Failures $C23$ / %



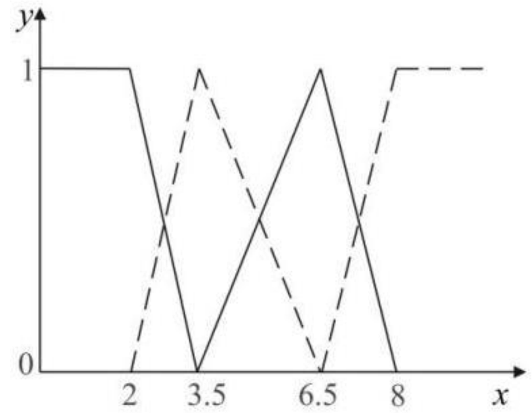
(b) Material Supply Delay $C22$ /days



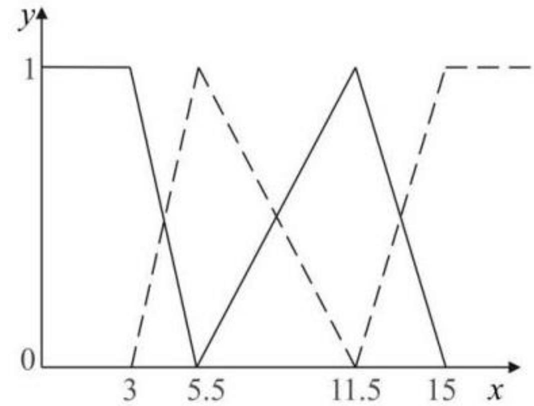
(c) Quality and Safety Accidents $C14$ /days, Surrounding Residents' Interference $C46$ /times



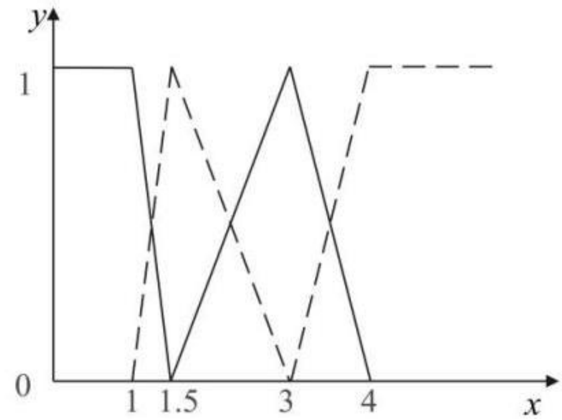
(d) Capital Turnover Difficulties $C24$, Labor Shortage $C21$, Insufficient Adaptation to New Technologies $C32$ /%



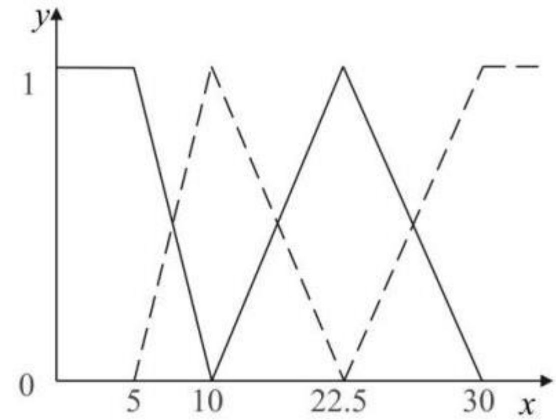
(e) Frequent Design Changes $C33$ /times



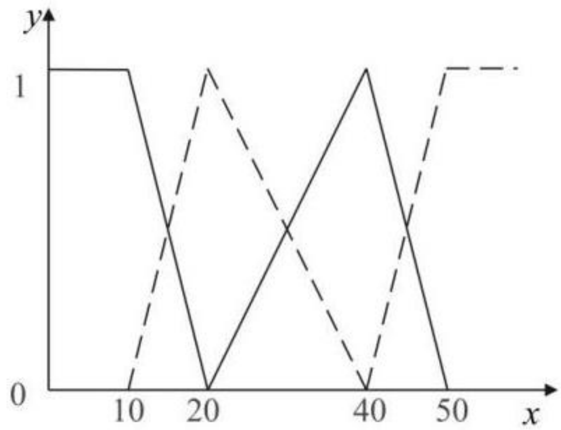
(f) Meteorological Disaster Impact $C42$ /days



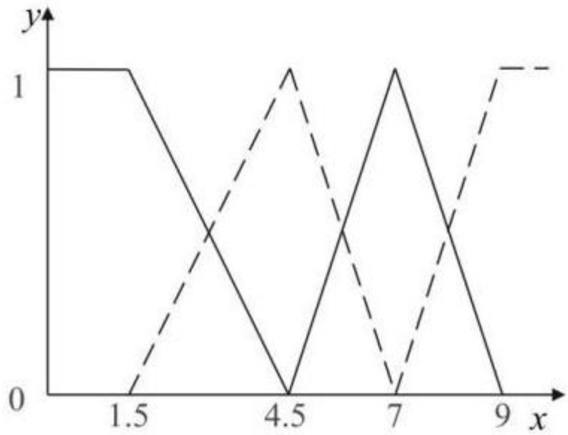
(g) Environmental Protection Policy Tightening $C43$ /(times/year)



(h) Cultural Relics Protection Intervention $C44$ /days



(i) Pandemic and Other Public Emergencies $C45$/%



(j) Qualitative index measurement $C11, C13, C15, C31, C41$

Figure 2. Single-index measurement functions of each Risk Factors

Based on the single-index measurement functions of each Risk Factors in Figure 2 and the risk index evaluation values in Tbale 6 for project construction progress, the corresponding single-index measurement evaluation matrix in the construction of Rongchuang Yuhe Chenyuan DK-1 Project can be calculated.

$$(\mu_{ik})_{18\times4} = \begin{pmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \\ S_7 \\ S_8 \\ S_9 \\ S_{10} \\ S_{11} \\ S_{12} \\ S_{13} \\ S_{14} \\ S_{15} \\ S_{16} \\ S_{17} \\ S_{18} \end{pmatrix} = \begin{bmatrix} 0 & 0 & 0.7 & 0.3 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0.17 & 0.83 \\ 0 & 0 & 0.5 & 0.5 \\ 0 & 0.07 & 0.93 & 0 \\ 0 & 0 & 0.8 & 0.2 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0.1 & 0.9 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0.125 & 0.875 & 0 \end{bmatrix}$$

4.3. Comprehensive Measurement Evaluation Matrix of Multiple Indicators

By calculating the corresponding data of each evaluation indicator through the entropy weight method, the weight of each evaluation indicator can be obtained as:

$w_1 = 0.0332, w_2 = 0.0340, w_3 = 0.0658, w_4 = 0.0325, w_5 = 0.1063, w_6 = 0.0325, w_7 = 0.0604,$
$w_8 = 0.0325, w_9 = 0.0267, w_{10} = 0.0658, w_{11} = 0.0658, w_{12} = 0.1063, w_{13} = 0.0618, w_{14} = 0.0604,$
$w_{15} = 0.0693,\ w_{16} = 0.0429, w_{17} = 0.0325, w_{18} = 0.0710$。

Then, using formula (5), the comprehensive measurement evaluation vector of multiple indicators is obtained as: $\mu = [0.1063, 0.1311, 0.2657, 0.4376]$

4.4. Confidence identification

According to the multi-index comprehensive evaluation vector μ and the confidence criterion [10], the confidence is λ=0.5 . Therefore, in ascending order, we have: $0.4376+0.2657=0.7033>\lambda=0.5$. Then it is determined that the construction progress Rongchuang Yuhe Chenyuan DK-1 Project Risk Levels is Level III (moderate risk); and $0.1063+0.1311+0.26357=0.50097>\lambda=0.5$ in descending order.

It can be seen from this that the results of the two judgments are consistent. That is to say, it can be considered that the Risk Levels of the project progress is moderate risk and the confidence is not less than 50%.

4.5. Analysis of Evaluation Results

From the evaluation process and results, the Risk Factors with the highest weights are Labor Shortage (0.1063), Frequent Design Changes (0.1063), Surrounding Residents' Interference (0.0710), and Environmental Protection Policy Tightening (0.0693). In the actual performance of the case project, indicators such as Capital Turnover Difficulties, Labor Shortage, and Insufficient Adaptation to New Technologies are all in the Level II or Level III risk intervals, which is consistent with the final determination of "general risk". This indicates that although the overall project risk is controllable, key attention should be paid to the capital chain, human resource coordination, and external relationship management. Potential risks of schedule delays can be effectively reduced through measures such as strengthening personnel training, optimizing the capital plan, and communicating with the surrounding community in advance.

The evaluation results of this study based on the uncertainty measurement theory are basically consistent with the actual situation at the project site, which verifies that the model has strong accuracy and engineering application value.

5. Conclusion

A risk management model for construction schedule is established in this paper, which integrates work breakdown structure (WBS), risk breakdown structure (RBS) and uncertainty measurement theory (UMT). Risk factors are identified through WBS-RBS double-layer structural decomposition, and an assessment system covering 18 key risks in four categories: organization management, resource supply, technology implementation and external environment is formed. Index weights are determined by combining expert scoring method and entropy weight method, and single index and multi-index unascertained measurement matrices are constructed. Finally, DK-1 project of Rongchuang Yuhe Chenyuan is taken as a case to verify the validity of the model, realizing systematic identification, quantitative assessment and grade judgment of construction progress risks.

Through the two-layer structural decomposition of WBS-RBS method, in addition to identifying conventional risks, hidden risks such as "public emergencies such as epidemic diseases" and "cultural relics protection interventions" that are easily missed by traditional methods are accurately captured. Based on entropy weight method calculation, labor shortage, frequent design changes (all 0.1063), interference from surrounding residents (0.0710), tightening of environmental protection policy (0.0693), insufficient adaptation of new technology and defects in construction scheme (all 0.0658) are the most influential risk factors. The model is applied to DK-1 project of Rongchuang Yuhe Chenyuan, and the risk level is determined to be III (general risk), which is consistent with the actual situation. Compared with the traditional method, the accuracy rate of risk identification is improved by about 30%, and the effectiveness of the method is verified.

In the future, BIM technology and real-time data of Internet of Things can be combined to dynamically update model parameters to enhance response to dynamic changes of risks; expand case sample size, optimize index system for different types of construction projects, and improve universality; develop corresponding early warning threshold and intelligent control strategy based on influence mechanism of key risk factors, and realize closed-loop management from risk assessment to intelligent prevention and control.

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