Simulation model for risk analysis of construction progress of water resources and hydropower projects

Qin Yongrong
Engineering college, Yunnan University Of Business Management, KunMing, YunNan 650106
Corresponding author e-mail: 690861273@qq.com

Abstract. There are many uncertainties in the construction process of water conservancy and hydropower projects. The risk analysis of project completion should consider the constraints and overlaps of various resource allocations and procedures. A fault tree risk analysis method is used to comprehensively evaluate the risks of various factors affecting the construction progress of the project. A large-scale water conservancy project construction schedule risk estimation model is solved using an appropriate method, which improves the calculation and application of schedule risk estimation, proposes control concepts of baseline schedule risk and revised schedule risk, and is verified using engineering examples.

1. Introduction
As one of the three control objectives (quality, schedule, and investment) of construction management of large-scale water conservancy projects, schedule control is very important. During the implementation of the project, it will inevitably be affected by a variety of uncertain factors and cause risks that the quality, schedule and investment control objectives of the project cannot be achieved. If the progress of the project is out of control, it will inevitably lead to waste of resources and economic loss, and may even affect the quality and safety of the project construction [1]. Through the risk assessment analysis [2], you can understand how big the risks of the schedule plan are. At the same time, according to the risk analysis and correction of the actual construction situation during the implementation process, control the implementation progress and take measures to respond and prepare to ensure that the project is in line with the target was successfully completed.

The construction progress is affected by its scale, complexity, management difficulty, and technical content and other risk factors [3], and it is restricted by funds and resources. This requires scientific methods to quantitatively study uncertainty and random phenomena in order to reduce the degree of risk and provide a reliable basis for decision-making. Therefore, it is more appropriate to use the fault tree analysis method [4] to analyze the construction schedule risk of water conservancy and hydropower projects. Earlier research focused on the effectiveness of various components, including mechanical, electrical and Hydraulic components were then expanded to study the impact of component failure on the organizational system at all levels. In the era of the development of intercontinental missiles and the subsequent launch of the "Mercury" and "Gemini Constellation" into the rocket program, the requirement of "guaranteeing success" has been accelerated [5]. The rocket launch must successfully exacerbate this requirement once, and counting down the functions of the rocket engine pen's various systems on the launch pad before the launch of the rocket has reached this climax. In the "Aerospace Age", much work has been done on functional testing of components and systems. Records of defect inspections found in the analysis and investigation of each failure are

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd
maintained. The failure mode, mechanism, cause and effect of each component on the system were evaluated [6], and remedial measures were taken accordingly to prevent recurrence.

2. Risk analysis of construction progress of large-scale water conservancy and hydropower projects

2.1. Fault tree method principle
The result event of interest is regarded as the top event, which is represented by a prescribed logical symbol to find all the events that cause this result event. The direct factors and causes are in the middle of the transition. Therefore, the in-depth analysis is performed until the basic event of the accident is found. The steps are as follows: (1) choose a reasonable top event, which is the key to success; (2) collect Technical information to build a fault tree; (3) simplify the fault tree; (4) perform a qualitative or quantitative analysis of the fault tree.

2.2. Application of fault tree method in risk analysis of construction progress
Funding risks, technical risks, and risks generated by project actors during construction are foreseeable. Social and environmental risks can be avoided through careful study of policies, laws, and regulations for large-scale water conservancy and hydropower projects. Natural environmental risks are unpredictable because they affect many factors. This article mainly discusses the natural environment, funds, technology, and risk factors of project actors that affect the construction progress.

(1) The establishment of the concept of a fault tree. During the construction, any of the four parts: capital risk, technical risk, risk generated by the project actor, and natural environment risk, the construction progress risk will occur. The fault tree is shown in Figure 1.

(2) Simplification of the fault tree. The ultimate goal of the fault tree analysis is to obtain the occurrence probability of the top event calculated from the occurrence probability of the basic event, which requires the original fault tree to be simplified. For each file in Figure 1, you can Assume that they are coded as follows: {T= Construction progress risk}; {A= Finance risk, B= Risk generated by project actors, C=Technical risk, D= Natural environmental risk}; {A1= Owned capital risk, A2 =Financing risk, B1=Project manager risk, B2=Contractor risk, C1=Design risk, C2=Construction technology risk, D1=Geological risk, D2= Natural condition risk, D3= Climate risk, D4 }; {All = Corporate fund turnover risk, A12=Corporate benefit risk, A21= Bank borrowing risk, A22= Lease financing risk, A23= Stock financing risk, B 11-Unfavorable macro management, B12-Project decision risk, B21= Management Risk, B22=adverse performance risk, C11= design error risk, C12 = design delay risk, C21= construction risk, C22= technical plan risk}. 

Figure 1 Fault tree in construction progress risk of hydropower station
The equivalent Boolean representation of each gate is as follows:

\[ T = A + B + C \]
\[ A = A_1 + A_2, B = B_1 + B_2, C = C_1 + C_2, D = D_1 + D_2 + D_3 + D_4 \]
\[ A_1 = A_{11} + A_{12}, A_2 = A_{21} + A_{22} + A_{23}; \]
\[ B_1 = B_{11} + B_{12}, B_2 = B_{21} + B_{22}; \]
\[ C_1 = C_{11} + C_{12}, C_2 = C_{21} + C_{22}. \]

Use the downward permutation method to perform permutation and expansion from the Boolean expression of the top event until the expression of the minimum cut set of the top event is obtained as follows:

\[ T = A + B + C + D = A_1 + A_2 + B_1 + B_2 + C_1 + C_2 = A_{11} + A_{12} + A_{21} + A_{22} + A_{23} + B_{11} + B_{12} + B_{21} + B_{22} + C_{11} + C_{12} + C_{21} + C_{22} + D_1 + D_2 + D_3 + D_4 \]

3. Risk estimation model for construction schedule control

Monte Carlo method is one of the most commonly used methods in deterministic and probabilistic simulations. Simulation is to use the system or the description model of the problem to carry out experiments to find out the possible changes and changes in the future. The so-called deterministic simulation means that the inherent factors of the model are certain, that is, there is a certain relationship curve between the output and input of the model; and the intrinsic factors of the probabilistic simulation model are uncertain. The results obtained when the simulation is repeated may for different curves, the average value of the values corresponding to each time point on the curve represents the average state of the appearance image, and its distribution represents the degree of dispersion of the appearance image. The more the simulation is repeated, the closer the average value is to the actual average state.

The basic idea of the Monte Carlo risk simulation method is to treat the risk variable to be treated as a characteristic random variable, and to calculate the statistical value of the digital characteristic through a large number of random values of a given distribution law as the required risk variable. The specific method is to use a random variable function generator to generate a probability simulation of a certain random number, from with a random simulation method, statistical test method, or probability simulation method is performed. In theory, the more the number of tests, the closer it is to the true value, but the distribution function no longer changes significantly after reaching 50 to 300 times in practice.

The basic steps of Monte Carlo risk simulation are:

1. Establish a mathematical model. Establish corresponding curve functions for deterministic risk simulation, and establish corresponding probability models for probabilistic risk simulation;
2. Use a random number generator to generate a random number sequence. Generally, there are equal probability random number generators between 0-1 in the computer, which can perform certain transformations as corresponding distributed random numbers;
3. Perform simulation tests on the data sampled by random numbers, and find the regularity after obtaining the calculation results;
4. Use the standard deviation test results to determine the reliability of the simulation and determine whether to perform the test again.

The maximum entropy is used to set the probability distribution of the risk factors, which essentially transforms the problem into an information processing and optimization problem. In the risk analysis of water resources projects, the random characteristics of many risk factors have no prior samples, and only some numerical characteristics, such as the mean \( p \), can be obtained. However, there are infinitely many probability distributions with mean value \( p \). To choose a distribution as a true distribution, the preferred criterion is the maximum entropy criterion. Let the random variable \( X \) be a continuous variable, then the following risk estimation model based on the maximum entropy criterion can be established:

\[
\max S = -\int f(x) \ln[f(x)] dx
\]

(1)
Solve the density function:

\[ f(x) = \exp(\lambda_0 + \sum_{i=1}^{n} \lambda_i x_i) \]  

(2)

Construction schedule risk refers to the probability that the calculated completion date of the network schedule for a construction project exceeds the prescribed (or planned) completion date within a specified period of time. The mathematical expression of construction schedule risk is:

\[ P_r = P(T_c - T_p) \]  

(3)

Pre-implementation risk estimation is the risk analysis and evaluation of the baseline schedule. The baseline schedule is a contract plan that guides the entire project progress and is the benchmark for the implementation of the project. Therefore, the review and approval of the baseline schedule is particularly important. In order to ensure the scientificity and thoroughness of the approval of the baseline plan, a risk estimate for the baseline schedule is proposed.

4. Experimental verification

Most of the overlap relationships of the construction overlap network schedule of a project are basically FTF overlap relationships, and the time from the process duration is also somewhat random. See Table 1 for the logical relationship and estimated duration of each construction process (including the time interval process).

Table 1 Logic and duration estimation of construction process of cast-in-place prestressed double circular pipe key line

| Operation i, j | a(day) | m(day) | b(day) | Immediately before | Mean | Variance | Note               |
|----------------|--------|--------|--------|-------------------|------|----------|--------------------|
| 1,2            | 45     | 46     | 46     | -                 | 46   | 1.38     | Time interval process FTS |
| 2,3            | 599    | 624    | 624    | 1.2               | 616  | 32.21    | Time interval process FTF |
| 3,4            | 578    | 622    | 615    | 2.3               | 602  | 38.23    | Time interval process FTF |
| 4,5            | 614    | 562    | 644    | 3.4               | 622  | 35       | Time interval process FTF |
| 5,6            | 615    | 525    | 646    | 4.5               | 623  | 37       | Time interval process FTF |
| 6,7            | 534    | 196    | 567    | 5.6               | 558  | 33.21    | Time interval process FTF |
| 7,8            | 501    | 195    | 527    | 6.7               | 522  | 18.88    | Time interval process FTF |
| 8,9            | 184    | 60     | 196    | 7.8               | 196  | 5.46     | Time interval process FTF |
| 9,10           | 183    | 46     | 198    | 8.9               | 194  | 5.67     | Time interval process FTF |
| 10,11          | 59     | 61     | 65     | 8,10              | 60   | 0.43     | Time interval process FTF |

\[ E(T_r) = \sum D_j = 819 \]  

\[ T_r = 816 \]  

\[ \lambda = 1.2 \]  

\[ P_r = 0.136 \]  

The progress risk rate is 13.6%, and the risk of completing the project as planned is high. Mainly, the main water pipeline is a new building, which is a breakthrough from design and construction, and there is a large technical risk.
Figure 2 Risk analysis of project progress based on influencing factors

As shown in Figure 2, under the ideal conditions that do not consider the distribution of the construction period, the influencing factors during the construction process, and the controllability of the construction period, the total construction period of the project is 2995 days. The average total construction period of the project is 2965 days, a difference of 32 days from the original total construction period. If all factors in the construction process are considered, the average total construction period of the simulated project is 3026 days, which is an increase of 32 days from the original total construction period. Under the conditions of management's response measures to risks during the process, the average total construction period of the simulation project was 2952 days, which was 46 days shorter than the original total construction period. The above situation is in line with the general situation in the actual project construction process.

5. Conclusion
The construction process of water conservancy projects has many uncertainties, and risks are affected by multiple factors. In the formulation of the project construction schedule, the constraints and overlaps between the allocation of resources and procedures must be considered. The use of the fault tree risk analysis method will affect the construction progress of the project. Comprehensive risk assessment of various factors, the use of classic PERT, MC simulation method to analyze the progress risk analysis of schedule risk, which has the advantages of intuitive calculation, convenience and high accuracy, which can be used to easily analyze and calculate the risk of project progress. Select effective technical and managerial personnel for the management project, adopt effective management organization form, and implement strict control in the implementation process, strengthen planning work, pay close attention to stage control and intermediate decision-making.

References
[1] K. Sun, Q. Li, X. Xu. Risk analysis on human factors in operation of high risk construction based on dynamic Bayesian network[J]. Journal of Hydroelectric Engineering, 2017, 36(5):28-35.
[2] Judith Plummer Braeckman, Peter Guthrie. A typology of the effects of pre-construction delay for large hydropower projects[J]. International Journal on Hydropower & Dams, 2016, 2016(2):105-113.
[3] X Wang, Y H Xu, Z Y Du. Risk factor analysis of the patients with solitary pulmonary nodules and establishment of a prediction model for the probability of malignancy[J]. Zhonghua Zhong Liu Za Zhi, 2018, 40(2):115-120.
[4] Bing Wang, Wei Wei, Suna Ma. Construction of one-step H2/O2 reaction mechanism for predicting ignition and its application in simulation of supersonic combustion[J]. International Journal of Hydrogen Energy, 2016, 41(42):19191-19206.

[5] J. Alam, Dookie Kim, B. Choi. Uncertainty reduction of seismic fragility of intake tower using Bayesian Inference and Markov Chain Monte Carlo simulation[J]. Structural Engineering & Mechanics, 2017, 63(1):47-53.

[6] Bobbi M Johnson, Brian M Kemp, Gary H Thorgaard. Increased mitochondrial DNA diversity in ancient Columbia River basin Chinook salmon Oncorhynchus tshawytscha[J]. Plos One, 2018, 13(1):541.