Study on the Method of Dependence Measure of Durations in Construction Schedule Network

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Keywords: Duration dependence, Pearson product-moment correlation coefficient, Nonlinear structural equation, Network planning technique.

Abstract. Previous research of construction schedule is based on the classic model of network planning technique as the background, assume the duration of each process were independent of each other in the schedule network planning. In the process of the practical project, each duration of process is not independent of each other, but acting on each other. In this paper, through research, based on a series of assumptions, we used Product-Moment Correlation Coefficient to measure serial dependence between duration variables. We also propose to regard parallel duration dependency, the common influence factors and organization management as potential variables, establishing the nonlinear structural equation model to measure parallel dependency among duration variables. Finally, this paper applies dependence measure and duration forecast considered dependence to a practical project progress network, results show that the method has good applicability and scientificity.

Introduction

Previous research of construction schedule is based on the classic model of network planning technique as the background, the model assumes that the progress of network planning in the duration of each process were independent of each other. In the process of the practical project, each duration of process is not independent of each other, but acting on each other [1]. Battaineh [2] evaluated the progress report of 164 construction projects and 28 highway projects, the results show that the delay resulted from the mutual influence between each duration is universal: average ratio of highway engineering and construction projects to the actual construction period and the duration of the contract plan is 160.5% and 120.3% respectively. A project network plan is connected by the serial process and parallel process through a certain logic relationship and technological relationship. There is serial dependence between the former work and the successor in each line of works theoretically; and parallel work due to the common resource constraints, environmental factors and organizational management also can produce dependence to each other [3]. Based on establishing the network plan model about duration dependence in literature[4], this paper researches the measurement method about serial dependence and parallel dependence, and update the network of progress, apply the reference about the dependence of the progress.

Serial Dependence Measure

In order to measure serial dependence, establishing assumptions firstly:

(1) Assuming that there is a simple linear dependence between the serial processes, ignoring other nonlinear relationships;

(2) Assuming that the related duration data obey \( \beta \) distribution, and the parameter obtained from experienced engineering personnel according to some corresponding data of the existing project or similar projects

Because the Pearson product-moment correlation coefficient mainly describes the linear dependence between random variables, so the serial duration dependence is measured by the Pearson product-moment correlation coefficient in this paper.
The Pearson product-moment correlation coefficient between the two variables is defined as quotients between the covariance of these two variables and the product of the two standard deviations, namely:

\[
\rho_{xy} = \frac{\text{cov}(X, Y)}{\sigma_x \sigma_y} = \frac{E(X - \mu_x)(Y - \mu_y)}{\sigma_x \sigma_y}
\]  

(1)

Eq. (1) defines the overall correlation coefficient of working durations, and which is generally represented by the Greek letter \( \rho \). If the covariance and standard deviation of the sample duration instead of the overall covariance and standard deviation of the working durations, the correlation coefficient of the sample duration will be calculated, generally represented by \( r \):

\[
r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2}}
\]  

(2)

Because the K. Pearson correlation coefficient mainly describes the linear dependence between random variables, the serial duration dependence is measured by the K. Pearson correlation coefficient. Setting \((I, J)\) is a two-dimensional random variables, which represents a set of serial duration variables, and \(\text{Var}(I) > 0, \text{Var}(J) > 0\), then:

\[
\rho_{ij} = \frac{\text{cov}(I, J)}{\sigma_i \sigma_j} = \frac{E(I - \mu_i)(J - \mu_j)}{\sigma_i \sigma_j}
\]  

(3)

When \( |\rho_{ij}| = 1 \), the duration variables \( I \) and \( J \) are completely linear correlation; when \( |\rho_{ij}| = 0 \), the duration variables \( I \) and \( J \) are not related; when \( 0 < |\rho_{ij}| < 1 \), the duration variables \( I \) and \( J \) have a certain extent linear dependence, and the closer \( |\rho_{ij}| \) is to 0, the weaker the linear dependence between duration variables \( I \) and \( J \) is; the closer \( |\rho_{ij}| \) is to 1, the stronger the linear dependence between the duration variables \( I \) and \( J \) is. When \( |\rho_{ij}| > 0 \), the duration variables \( I \) and \( J \) are positive dependence, when \( |\rho_{ij}| < 0 \), the duration variables \( I \) and \( J \) are negative dependence.

**Parallel Dependence Measure**

Structural equation modeling is an important tool to study the relationship between observable variables and latent variables, as well as among the latent variables. The parallel duration dependence is an index which can not be directly observed; therefore it is needed to reflect the dependence evenly by calculating the quantity of the indicators which can be directly observed. In this paper, regarding the parallel dependence, the common influence factors and can organizational management as a potential variable, setting up observed variables which can reflect these indicators, and establishing the nonlinear structural equation model to measure the parallel dependencies.

**Assumption of parallel dependence measure:**

(1) Assuming that there is a nonlinear dependence between the parallel works due to the common influencing factors or management reasons, and the other dependences are ignored.

(2) The fitting regression equation is obtained by using the nonlinear structural equation to reflect the relationship between the parallel dependence and the various influence factors, and to select a factor which has the greatest influence degree as the quantitative index of the parallel dependence.

**Selection of Variables**

According to the reasons of the parallel duration dependence, the parallel duration dependence, the common influencing factor and the organization management are the potential variables, using six observed index to reflect the reason of the parallel duration dependence: the duration time ratio,
the material usage ratio, machinery shift ratio, capital ratio, the organizational management and the occupation time of working face ratio. The corresponding relations are shown in Table 1.

Table 1. Latent variables and observable variables.

| Latent variables                      | Observable variables | Observation variable description          |
|--------------------------------------|----------------------|-------------------------------------------|
| ξ₁ (dependence)                     | y₁                   | duration time ratio                       |
| ξ₂ (common influencing factors)     | y₂                   | material usage ratio                      |
|                                     | y₃                   | machinery shift ratio                     |
|                                     | y₄                   | capital ratio                             |
| ξ₃ (organizational management)      | y₅                   | the ratio of the number of managers       |
|                                     | y₆                   | the occupation time of working face ratio |

The path diagram of the nonlinear structural equation model is shown in Fig. 1.

Nonlinear Structural Equation Model

According to the relevant knowledge of the above nonlinear structural equation model, the following nonlinear structural equation model is established, which is based on the latent variables and the corresponding explicit variables as shown in the table 1.

Measurement equation:

\[ Y_i = \mu + \Lambda \xi_i + \epsilon_i \]  

Structural equation:

\[ \xi_i = r_{12} \xi_2 + r_{13} \xi_3 + r_{22} \xi_2^2 + r_{33} \xi_3^2 + r_{55} \xi_5 + \delta_i \]  

Eq. (4) and (5), \( Y_i \) is the 6*1 dimensional explicit variable of the first \( i \) individual, \( \mu \) is the mean vector of 6*1 dimension, \( \Lambda \) is 6*3 dimensional factor load matrix, \( \xi_i \) is the 3*1 dimension of the latent variables, and \( \epsilon_i \sim \text{N}(0,\Phi_{\epsilon}) \), \( \epsilon_i \) is 6*1 dimensional random measurement error, and \( \delta_i \sim \text{N}(0,\Phi_{\delta}) \). \( r \) is the coefficients to reflect the relationship among latent variables \( \xi_i \) and \( \xi_{i1}, \xi_{i2}, \xi_{i3} \). \( \Delta \sim \text{N}(0,\Phi_{\delta}) \) and it is independent of each other with \( \xi \).

Parallel Duration Dependence Measure

Through the WinBUGS software the required sample of the Bias analysis can be extracted from the joint distribution of the arbitrary unknown parameters, and then according to the sample, the parameters of the model and the unknown quantity can be obtained, in addition to the Bayesian estimation and its standard deviation can be obtained.

Because the influence degree of each influencing factor to the duration dependence of the parallel work is not the same, namely |\( r_i \)| is different, the bigger it is, the greater the degree of influence on the parallel duration dependence and on the contrary, the influence degree is smaller. Therefore, the factors that influence the parallel duration dependence lowly is ignored, selecting the maximum value of |\( r_i \)| as the effecting index of parallel duration dependent, that is measurement of parallel duration dependence:
\[ \tau_{ij} = \max \{ r_i \max |r_i|, i \neq j \} \] (6)

where, \( r_i > 0 \) indicates that the corresponding influence factors have a favorable effect on the parallel duration dependence, and the durations of the two parallel work may be shortened; \( r_i < 0 \), which indicates that the corresponding factors have a negative effect on the duration dependence of the parallel work, and the durations of the two parallel works may increase.

**Empirical Research**

**Project Overview**

This project is a single building for a company to develop a multi-story and high-rise residential buildings of large-scale projects. The scope of the project construction includes: foundation, underground structure, the main structure, building decoration, the roof of the building, construction of water supply drainage and heating, construction, electrical, fire protection, intelligent building, ventilation and air conditioning and energy saving et al.

**Logical Relations between Processes and Single Node Network Planning**

In this paper, the work and the logical relations between the works and three point estimating of working duration as shown in Table 2.

| Task classification | Node | Name                          | Successor | Minimum time | Most likely time | Maximum time |
|---------------------|------|-------------------------------|-----------|--------------|-----------------|--------------|
| Pile foundation engineering | A    | Pressure test pile            | E, F, D   | 6            | 10              | 15           |
|                      | B    | Pipe Engineering              | F, H      | 20           | 25              | 33           |
|                      | C    | Piles test pile               | E, F, G   | 5            | 10              | 17           |
|                      | D    | Engineering pouring pile      | I         | 20           | 30              | 43           |
|                      | E    | Project supporting pile, water stop curtain | I | 19 | 25 | 33 |
|                      | F    | Pile test                     | K         | 10           | 15              | 23           |
|                      | G    | Precipitation well construction | J       | 16           | 25              | 39           |
|                      | H    | Basement excavation crown beam, ring beam construction | I | 8 | 15 | 27 |
|                      | I    | Concrete ring beam curing     | L, M, N, K | 8 | 15 | 28 |
| Dewatering well construction | J    | Precipitation well work       | T         | 70           | 90              | 120          |
| Basement Construction | K    | Basement earth excavation     | P         | 16           | 30              | 48           |
|                      | L    | Cut pile                     | P         | 18           | 30              | 40           |
|                      | M    | Cushion construction          | O         | 26           | 32              | 44           |
|                      | N    | Precipitation well construction | S | 21 | 28 | 39 |
|                      | O    | Basement structure construction | U | 78 | 90 | 120 |
| Balcony foundation construction outside Basement | P    | Foundation Construction gallery | R, Q | 5 | 8 | 18 |
|                      | Q    | Cushion construction          | T         | 5            | 10              | 25           |
|                      | R    | Trench Inspection             | T         | 4            | 7               | 10           |
|                      | S    | Precipitation well construction | T | 6 | 10 | 15 |
|                      | T    | Construction of foundation and basement gallery | U | 24 | 30 | 42 |
| Construction of standard layer | U    | Basement Balcony standard outer layer construction | — | 380 | 403 | 440 |

On the basis of the above table, the single node network diagram is shown in Fig.4.
Duration Prediction and Completion Probability

Utilizing Monte Carlo method to simulate the duration of the project can be simulated is 592.89 days, the standard deviation is 9.97, the duration of the project is 552 days, and the maximum is 670.2 days, as shown in Fig.5. At the same time, there are two key lines in Fig.4, which are B, H, I, M, O, U and A, D, I, M, O, U respectively.

At the time, by formula \( \lambda = \frac{(T_K - T_S)}{\sum \sigma} \), the completion probability of the project can be calculated, after Monte Carlo simulation, the project time is 605 days and the completion probability is 87.977%, as shown in Fig.6.
Conclusions
This paper mainly measures the dependence of duration variable in the network of progress. Considering the duration dependence can reflect the real inner link between duration, get closer to the forecast consequence of construction period in practical situation. From the practical simulation results, this method has good applicability and high efficiency.

Acknowledgement
This project was supported by the National Natural Science Foundation of China, Project No. 70961004.

Reference
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