Research on Real-time Control of Construction Progress

Li gang¹, Zhao peng²*, Sun Shu-hong²,³

¹Tianjin Beida Port Reservoir Management Office, Tianjin 300384, China;
²Department of Hydraulic Engineering, Tianjin Agricultural University, Tianjin 300384, China;
³Tianjin Agricultural Hydraulic Engineering Center, Tianjin 300384, China

*Corresponding author’s e-mail: 614184280@qq.com

Abstract: combining with the chilong river management project, this paper analyzes the factors that affect the progress and the related methods of the progress control. By compiling the network plan, the free time difference and the total time difference in the construction process are analyzed and calculated. It is determined that the key work of construction is Xiaobo pump station, and the key route is Xiaobo pump station excavation-Xiaobo pump station concrete pouring-Xiaobo pump station backfill, and the construction progress is further optimized and analyzed, and the purpose of shortening the construction period is achieved. It is verified that the reasonable arrangement of construction schedule can achieve the purpose of shortening the construction period without increasing the additional cost.

1. Introduction

If there is a deviation in the progress of the construction, it will affect the construction unit to cause unnecessary waste on personnel, funds and materials, which may affect the overall quality of the project. Under the premise of ensuring the quality of the project, whether the best balance between construction cost and construction progress can be achieved is the key to measuring the success of project management. By monitoring the actual construction schedule in real time and comparing with the construction schedule, corresponding measures are taken for the work that does not meet the relevant schedule, so as to ensure that the project is carried out according to the original plan. In this way, the project can be completed on time within the contracted construction period.

In the 1950s, project schedule control gradually matured. At that time, the Critical Path Method (CPM) and the Project Evaluation and Review Technical (PERT) were introduced in the United States. PERT was proposed by the US Navy in developing the Polaris missile. It took only four years to complete the project that took six years to complete.

In summary, it can be seen that most of the research on construction progress at home and abroad is based on the network plan, but the content is different. Some use the double-code network diagram to calculate the free time difference to optimize the construction progress; some establish the relevant model to optimize the progress; and some evaluate the construction through probability calculation. The purpose of shortening the construction period can be achieved by selecting the corresponding method for different projects.
2. Project Progress Control Network Diagram Technology

2.1 Network Planning Technology
Network planning technology is a management plan that uses the network plan to plan the progress of the project to ensure the completion on time. Network planning techniques consist of network diagrams and time parameters. The network diagram includes a double-code network diagram and a single-code network diagram. The most commonly used is the double-code network diagram. The study also uses a double-code network diagram. The time parameter is another very important component, which includes the earliest start time, the earliest completion time, the latest start time, the latest completion time, the total float, and the free float.

2.2 Network Diagram Plan
The calculation steps are as follows:

\[ ES_{i,j} = 0 \]  \hspace{1cm} (1)

\( ES_{i,j} \) indicates the earliest start time of the work in the formula.

The earliest start time of other work should be equal to the maximum value of the earliest completion time of front closely activity.

The rest work such as \( j - k \), its front closely activity is \( i - j \), and its initial starting time calculation formula is:

\[ ES_{j-k} = \max[ES_{i,j} + D_{i,j}] \]  \hspace{1cm} (2)

\( ES_{j-k} \) is the earliest start time of back closely activity;

\( ES_{i,j} \) indicates the earliest start time of a project;

\( D_{i,j} \) indicates the duration of the work.

The earliest completion time can be calculated using the formula:

\[ EF_{i,j} = ES_{i,j} + D_{i,j} \]  \hspace{1cm} (3)

The calculation of the latest completion time and the latest start time should start from the end of the network plan and proceed in the direction of the arrow. The calculation steps are as follows:

The network plan endpoint \( n \) is used to complete the node work, and the latest completion time is equal to the network plan duration.

\[ t_p = LF_{j-n} \]  \hspace{1cm} (4)

In the formula, \( t_p \) represents the planned duration, and \( LF_{j-n} \) represents the latest completion time of the segment.

The latest completion time for other work should be equal to the minimum value of the latest start time of the back closely activity after it. Assuming that for the other work \( i - j \), the back closely activity is \( j - k \).

\[ LF_{i,j} = \min[LF_{j-k} - D_{j-k}] \]  \hspace{1cm} (5)

After the latest completion time for each job, the latest start time of the work is calculated using the formula:

\[ LS_{i,j} = LF_{i,j} - D_{i,j} \]  \hspace{1cm} (6)

where \( LS_{i,j} \) represents the latest completion time for \( i - j \).

The total float difference is equal to the latest completion time minus the earliest completion time, or the latest start time of the work minus the earliest start time.

\[ TF_{i,j} = LF_{i,j} - EF_{i,j} \]  \hspace{1cm} (7)
where $TF_{i-j}$ represents the total float difference of $i - j$.

The free float difference is the maneuver time without affecting the logical relationship of the work. Assuming that its original work is $j - k$ and the back closely activity is $j - k$, so the formula is:

$$FF_{i-j} = ES_{j-k} - EF_{i-j}$$

(8)

where $FF_{i-j}$ represents the free float difference of the segment $i - j$.

3. Research case analysis of real-time control of project schedule

3.1 Construction conditions

The Chilong River treatment project is taken as the research goal. The starting point of the Chilong River is located at the Dagu Drainage River intake sluice (Dagu Drainage River Station No. 25+280), which flows through Jinnan District and Xiqing District, and then enters the Duliujian River in Xiaobo Pumping Station with a total length of 10.1km. The Chilong River treatment project mainly include the river project and the building project.

The river project mainly include river dredging and expansion project, and breakwater buildings project. The first one is mainly for dredging and expansion of 0+000 to 10+100 in the Chilong River. The second project includes the relocation of the reconstruction section of the two rivers and three embankments, building reconstruction of the three rivers, and the demolition of a building for river excavation.

According to the Design Code for Embankment Engineering (GB 50286-2013), the engineering level of the embankment construction is the same as that of the embankment. The Xiaobo Pumping Station passes through the crossing-dyke culvert and sluice in the left bank of the Duliujian River, and its level is the same as that of the embankment, which is level 1. The Dagu River passes through crossing-dyke culvert and intake sluice in the right bank of the Dagu Drainage River, and its level is the same as that of the Dagu Drainage River, which is level 3.

3.2 Construction schedule

| sequence number | project | unit | works                      | First year | Second year |
|-----------------|---------|------|---------------------------|------------|-------------|
|                 |         |      |                           | 8 9 10 11 12 | 1 2 3 4 5 6 7 |
| I               |         |      |                           |            |             |
| 1               | Construction preparation period | | | | |
| 2               | Construction of temporary roads | item | 1 | | |
| 3               | Construction of Concrete Production System | item | 1 | | |
| 4               | Construction auxiliary plant construction | item | 1 | | |
| II              | Main project construction period | | | | |
| 1               | Temporary works | m³ | 20984 | | |
|                 | cofferdam demolition | | | | |
|                 | Construction drainage | item | 226 | | |
| 2               | Dredging | m³ | 857529 | | |
|                 | excavation | | | | |
3.3 Time parameters and network diagram

According to the plan for the progress in the overall layout of the construction, the following progress chart and double code network diagram is drawn:

![Figure 1 Progress chart](image-url)
Note that in Figure 2, A represents temporary construction drainage; B represents dredging and excavation; C stands for Xiaobo pumping station excavation; D stands for Zhongxinghe node project excavation; E stands for Dagu River node project; F stands for concrete pouring in the c Xiaobo pumping station; G means embankment filling; H means Xiaobo pump station backfilling; I means Zhongxing River project concrete pouring; J means Zhongxinghe node project backfilling; k means installation of electromechanical and metal structures; L means tail work.

(1) Since the starting point of the network map plan is the work of the start node, when the earliest start time is not specified, the earliest start time is zero, so in Figure 2 \( ES_{1-2} = 0 \) (\( ES_{1-2} \) indicating the earliest start time of work 1-2).

The earliest start time of other work in Table 3 is calculated by formula (2). The results are as follows:

\[
ES_{2-3} = ES_{2-4} = ES_{2-5} = ES_{2-6} = 15 + 60 = 75;
\]

\[
ES_{6-9} = 15 + 90 = 105; ES_{7-12} = 15 + 60 + 150 = 225;
\]

\[
ES_{10-11} = 15 + 90 + 90 = 195; ES_{11-13} = 15 + 90 + 90 + 90 = 285;
\]

\[
ES_{6-14} = 15 + 150 = 165; ES_{12-15} = 15 + 60 + 150 + 120 = 345;
\]

(2) The earliest completion time can be calculated using formula (3):

\[
EF_{1-2} = 0 + 15 = 15; EF_{2-3} = 15 + 210 = 225;
\]

\[
EF_{2-4} = 15 + 60 = 75; EF_{2-5} = 15 + 90 = 105;
\]

\[
EF_{2-6} = 15 + 150 = 165; EF_{4-7} = 75 + 150 = 225;
\]

\[
EF_{8-9} = 150 + 90 = 195; EF_{7-12} = 225 + 120 = 345;
\]

\[
EF_{10-11} = 195 + 90 = 285; EF_{11-13} = 285 + 75 = 360;
\]

\[
EF_{6-14} = 165 + 150 = 315; EF_{12-15} = 346 + 60 = 405;
\]

(3) Since the maximum value of the earliest completion time is \( EF_{12-15} = 405 \) days, it can be obtained by formula (4): \( LF_{12-15} = t_p = 405 \) days.

The latest completion time of other work in Figure 2 is calculated using formula (5). The results are as follows:

\[
LF_{1-2} = 225 - 210 = 15; LF_{2-3} = 345 - 120 = 225;
\]

\[
LF_{2-4} = 225 - 60 = 165; LF_{2-5} = 240 - 90 = 150;
\]
\[ LF_{2-6} = 405 - 150 = 255; LF_{4-7} = 345 - 120 = 225; \]
\[ LF_{9-9} = 330 - 90 = 240; LF_{7-12} = 405 - 60 = 345; \]
\[ LF_{10-11} = 405 - 75 = 330; LF_{11-13} = LF_{6-14} = LF_{12-15} = 405; \]

(4) The latest start time can be calculated using formula (6). The results are as follows:
\[ LS_{1-2} = 15 - 15 = 0; LS_{2-3} = 225 - 210 = 15; \]
\[ LS_{2-4} = 150 - 60 = 90; LS_{2-5} = 150 - 90 = 60; \]
\[ LS_{2-6} = 255 - 150 = 105; LS_{4-7} = 225 - 150 = 75; \]
\[ LS_{8-9} = 240 - 90 = 150; LS_{7-12} = 245 - 120 = 125; \]
\[ LS_{10-11} = 330 - 90 = 240; LS_{11-13} = 405 - 75 = 330; \]
\[ LS_{6-14} = 405 - 150 = 255; LS_{12-15} = 405 - 60 = 345; \]

(5) The total float is calculated using formula (7). The results are as follows:
\[ TF_{2-2} = 0 - 0 = 0; TF_{2-3} = 15 - 15 = 0; \]
\[ TF_{2-4} = 90 - 15 = 75; TF_{2-5} = 60 - 15 = 45; \]
\[ TF_{6-6} = 105 - 15 = 90; TF_{4-7} = 75 - 75 = 0; \]
\[ TF_{9-9} = 150 - 105 = 45; TF_{7-12} = 225 - 225 = 0; \]
\[ TF_{10-11} = 240 - 195 = 45; TF_{11-13} = 330 - 285 = 45; \]
\[ TF_{6-14} = 255 - 165 = 90; TF_{12-15} = 345 - 345 = 0; \]

(6) The free float difference is calculated according to formula (8). The results are as follows:
\[ FF_{1-2} = 0 - 0 = 0; FF_{2-3} = 225 - 225 = 0; \]
\[ FF_{2-4} = 75 - 75 = 0; FF_{2-5} = 105 - 105 = 0; \]
\[ FF_{2-6} = 165 - 165 = 0; FF_{4-7} = 225 - 225 = 0; \]
\[ FF_{8-9} = 195 - 195 = 0; FF_{7-12} = 345 - 345 = 0; \]
\[ FF_{10-11} = 285 - 285 = 0; FF_{11-13} = 405 - 360 = 45; \]
\[ FF_{6-14} = 405 - 315 = 90; FF_{12-15} = 0. \]

It can be seen from the calculation results that there is a total float in the excavation section in the Xiaobo Pumping Station, the dredging section, the excavation section of the Zhongxing River node, concrete pouring and the backfilling section during the construction process. There is a free float in the backfilling section of the Zhongxing River node and the installation section of electromechanical and metal structures. Due to the planned construction schedule, a free float of 5%-10% is originally considered.

Therefore, the construction period of the excavation section of the Xiaobo Pumping Station in the critical route can be shortened by 10% from 60 days to 54 days. At the same time, the 150-day construction period of concrete pouring is shortened by 10% to 135 days, and the 120-day period of backfilling section in the pumping station is shortened by 10% to 108 days. In this case, according to the construction schedule of Table 3, it can be calculated that the construction period is 237 days, which is shortened by 33 days, from 270 days to 237 days. Period shortening will inevitably bring about changes in construction intensity, personnel, machinery, materials, etc. In order to ensure that it is shortened without affecting the normal construction order and increasing unnecessary costs, the following suggestions are made:

(1) For the excavation section, the concrete pouring section, the backfilling section of Xiaobo Pumping Station, and the opening and closing section of the Zhongxing River node, it is recommended to increase the construction intensity and establish a complete management system for
personnel deployment. There is a sound reward and punishment system to improve the construction workers’ enthusiasm for construction.

(2) For the mechanical arrangement in earthwork excavation, filling and concrete pouring backfilling, detailed arrangement shall be arranged to achieve the best use of materials and avoid idle or shortage of construction machinery on the site.

(3) It is suggested to coordinate the owner and the construction party and deal with the problems of funds and materials supply, so as to avoid delays in the construction period due to insufficient funds, untimely supply of materials, and unqualified quality.

4. Summary
This paper begins with the purpose and significance of the construction progress, and describes the domestic and international research status of the construction progress, as well as the construction progress control characteristics and contents. Through optimization calculation, the construction period of the main section is shortened by 270 days from 33 days to 237 days. This effectively shortens the construction period of the main project, and meets the expectation of the initial writing of the thesis, achieving the purpose of optimizing the construction progress and shortening the period. Through this paper, it is possible to draw the appropriate method for the construction progress (the network planning technology used in this paper), analyze and calculate the progress so as to shorten the construction period.

Acknowledgment
Fund project: Water Pollution Control and Governance National Science and Technology Subprojects (2017ZX07106003)

References
[1] Butcher wS. Dynamic programming for project cost-time curve. Journal of Construction Division, ASCE[J].1967,93(CO1): 59-73
[2] Meyer wL, Shaffer LR. Extending CPm for multiform project time-cost curves. Journal of the Construction Division, ASCE[J].1965,91(CO1):45-67
[3] Xingliyan, Li Jicheng. The application of dynamic planning method in network cost duration optimization [J]. Shandong Science. 1998(3): 60-64
[4] Liu Jinming. Practice of construction cost method on computer [J]. Infrastructure improvement. 1998(4): 6-8
[5] Llguanbao, Liu Yongqing. Decision analysis based on network planning technology [J]. Systems engineering. 1994(1): 29-35
[6] Yu Zongwei. Resource optimization of network plans [J]. Infrastructure improvement. 1998(3): 24-26