Research on the Application of Optimization Methods of Network Planning Technique in Construction Management of Building Engineering

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Keywords: Network Planning Technique; Building Engineering; Construction Management; Duration Optimization; Resource Allocation

Abstract: In the context of the increasing scale of construction engineering and structural complexity, conventional construction management based on experience has been difficult to satisfy with complex multi-process coordination, resource allocation, and cost control along the period of project. In order to monitor and control the construction process of building engineering projects in real-time, strengthen the economic benefits of building engineering and avoid unreasonable cost investment through analyzing project schedule, it is essential to apply network planning technique from the perspective of construction information management (Wang et al. 2011). This paper is dedicated to the systematic review of key methods and implementation logic from network planning technique; based on which, combined with the overall construction management process of building engineering, some multi-dimensional application optimization strategies are put forward, in an attempt to provide useful reference for improving the refinement level of construction management in building engineering.

1. Introduction

With the rapid development of China's building engineering industry in recent years, more and more complex projects such as super high-rise buildings, large-scale complexes and transportation hubs have been emerged year by year. These projects have characteristics such as long construction period, many overlapping processes, high resource consumption and difficulty in cost control, which put higher requirements on the systematicness and scientificity of construction management. Network planning technique has been widely used in construction management since it was applied to the field of building engineering, as its mathematical logic and systematic analysis make it a promising project management tool; its graphical description of constructing steps, highly organized logical relations and multi-dimensional optimization powered design tools help alleviate various pain points within construction projects.

2. Core Optimization Methods of Network Planning Technique

2.1 Focusing on Critical Path and Precisely Compressing Critical Activities

The objective of this process is to reduce the total duration required for the entire project or to comply with the contractually agreed-upon duration while still complying with construction processes and quality safety. At the heart of this is critical path method in the network plan—the string of activities that has the longest-total duration and determine(s) total time for the project. The optimization logic can be divided into three steps: 1) by calculating the four time parameters for each construction activity—namely earliest start, earliest finish, latest start and latest finish—to screen out zero total float activities to form a critical path, find core objects for subsequent optimization. Second, focusing on "high cost-effectiveness ratio for compression" selection of critical activities: the duration proportion is large, compress resource investment required minimum;The impact on subsequent processes should be small to avoid blind compression leading to management chaos. Finally, strictly limit the compression range to avoid quality risks caused by excessively shortening the activity duration, and dynamically monitor whether a new critical path is

  DOI: 10.25236/icacel.2025.120

born after compression. This is required to not leave any loopholes in our duration control, in case there are newly generated critical paths simultaneously. The compression plan is to be developed during construction process logic and professional software should replace manual calculations in order to improve the accuracy of compressed effects, avoid calculation errors leading to optimization failure [1].

2.2 Balancing Duration and Cost to Identify the "Lowest-Cost Duration"

The essence of cost optimization is to determine the conflict between building engineering duration and cost—shortening the duration needs more resource investment, thus improving construction efficiency, which leads to increased direct costs including human resources, material resources and machine tools; on the other hand, extending the duration will lead to an increase of indirect cost such as project management fees or capital occupation interest. The optimization identifies the "lowest-cost duration," meaning the duration node that incurs the least overall cost. A cost-duration correlation curve is established to analyze the direct and indirect costs corresponding to different project durations through historical project data, while also referencing industry quota standards, clarifying that when a construction project's duration is shortened, its direct cost increases (expressed as fixed cost) and its indirect cost decreases (expressed as variable cost). Second, identify the lowest point of total cost by overlaying the direct cost curve and the indirect cost curve to arrive at a "lowest-cost duration." Third, dynamically account for any difference between the contractual duration of the treatment and its "lowest-cost duration." If the contract duration is shorter than "lowest-cost duration", which critical activities should be selected for compression with the lowest unit-time compression cost gradually to control the total costs increasing; if it is longer than "Lowest-Cost" Duration, how to adjust Noncritical Activities' rhythm to reduce Resources Idleness and Indirect Cost. When implementing optimization plans, it is important to distinguish controllable costs from uncontrollable costs and focus on optimizing controllable costs such as machinery rental time and labor scheduling, while also using intelligent software to realize visual linkage analysis of cost duration, so as to improve the scientific nature of optimization plan.

2.3 Resolving Supply-Demand Conflicts to Achieve Balanced Resource Allocation

Resource optimization tackles the supply-demand mismatch of resources like labor, machines and materials in building engineering types that are divided into two categories: "resource-constrained—shortest duration" (This type of resource can be limited to work for a shorter timeline) and "fixed duration—balanced resources". The essence is to use non-critical activities free float and total float, for the match between resource demand and supply, so as to improve resource utilization efficiency. Take "fixed duration—balanced resources" as an example. The optimization logic is executed in three steps: 1. Draw the resource demand curves, and summarize daily or weekly resource demands during the planned period to look for peaks and troughs of resource demand. Second, changing the timing of non-critical activities means to move the non-critical activities in a concentrated resource occupy period to trough periods, which can smooth vendor demand curve and avoid supply-demand conflict caused by resource concentrated occupation. Third, and if there are still resource gaps, determine the available resource demand priority for critical activities based on the total float in descending order (i.e., focusing on limiting as much as possible of the critical activities) to avoid that the shortening of non-critical activities piles up enough not to extend the overall duration. In the implementation stage, while establishing a "resource-activity" corresponding relationship table to clarify the type and quantity of resource demand for each activity, use Internet of Things-related technologies such as RFID material tracking and tower crane positioning systems to collect real-time resource use data, and rely on professional software to dynamically adjust allocation plans based on construction progress to ensure in the process of optimizing resources also meet the construction progress requirement.

3. Implementation Path of Network Planning Technique Optimization in Construction Management of Building Engineering

3.1 Preliminary Preparation: Constructing an Accurate Basic Network Plan Model

Before optimizing network planning technique, preliminary preparation is needed, and the primary point is to build a basic model that conforms to the actual project condition in order to provide data support for subsequent optimizations. To begin with, conduct task decomposition according to the "project—unit project—sub-project—sub-item project" hierarchy, which practice can bring the overall project into a series of small and operable work items, further clarifying the scope and content of each work item so that no ambiguous task decomposition would lead to logical confusion in model. Next, define logical relationships between work items and also separate them into "predecessor activities" and "successor activities" to indicate the requirements of the process sequence, creating a complete and compliant logical chain. Last, through industry quota standards, enterprise historical project database and technical disclosure documents; determine the time duration of each work item cycle; the demand for resources (human resource(s) type and quantity + machine + material); cost consumption. Parameter estimation is also a trade-off between reasonableness and accuracy because data deviation should not affect patches' optimization. In this step, it is necessary to ensure that the data of the basic model correspond with actual project conditions by having an interaction among technical, cost and construction departments in order to confirm possible decomposition of tasks, logical relationships and parameters estimations

3.2 Optimization Calculation: Selecting Appropriate Methods to Output Scientific Optimization Plans

The optimization calculation conducts the core link for realization value of network planning technique, which requires appropriate methods selection according to project control objectives and makes use of professional tools to promote optimization efficiency and accuracy. First, do the same about the optimization objectives — which ones are prioritized over others. For project duration control as the core, focused on critical path compression; for cost control for the goal, focus on "the lowest-cost duration" solution; major resource constraints as objective function, resources balanced optimized allocation. Identify importance of objectives and introduce objective weights to guide multi-objective optimization in the cases where coordination with multiple objective is required. Second, choose professional tools and algorithms and replace traditional calculations. Common tools are project management software like Project and Primavera P6, which easily generates the critical path automatically as well as simulating the effects of various optimization schemes. Software for multi-objective optimization scenarios will need to employ intelligent algorithms (like genetic algorithms and particle swarms) that yields Pareto optimal solutions through a software design decision, and screen plans to meet project targets. Finally, verify and improve the plan by verifying the feasibility of the preliminary optimization plan from construction processes, resource supply and cost budgets to evaluate whether it can be carried out. Back to the optimization parameters: If conflicts exist (such as resource allocation exceeds the actual supply capacity), change) return, until a scientific, reasonable final program is formed, by clarifying in the calculation process stage clearance optimization measures, implementation steps and expected effect] provide reference for subsequent execution.

3.3 Dynamic Control: Adjusting Optimization Plans in Conjunction with Actual Construction Conditions

Building engineering construction is influenced by external factors, and dynamic control is the core to realize optimized plans involving continuous effectiveness, which must form a "tracking—analysis—adjustment" dynamic mechanism. First, real-time tracking of construction progress and resource cost data: (1) Collect all actual data in a timely manner, including the actual complete time for each work item, the actual consumption of resources, and the actual cost expenditure based on site inspections or collaborative management platforms to ensure that they are not missed. Accurate real-time collection of relevant information. Second, compare and analyze deviations by contrasting actual data with planned data to identify deviations in progress (actual plan), resources (use of resources/installation) and costs (real actual pricing proposed); it is determined whether the work item where the deviation is found is a critical activity. In the case of critical activity deviation, impact on the total duration and total cost should be assessed; in the case of non-critical activity deviation, check if there has been float consumption to ensure it is not converted into a critical activity deviation. Finally, take corrective actions: Develop targeted measures according to the causes of deviations and adjust work parameters and optimization plans based on these corrective measures, then update the network plan model to ensure that it is aligned with actual construction conditions. At this stage, a routine summary of the dynamic control conditions every week or month should be established for analyzing deviation patterns between observed data and expected data and adjusting post-control priorities [2].

4. Application Optimization Strategies for Network Planning Technique Optimization Methods in Construction Management of Building Engineering

4.1 Consolidating Data Foundations: Establishing a Standardized Data Management System

Issue such as parameter estimation deviations and insufficient data sharing through standardized data management system must be resolved before proceeding to the next step of optimize network planning technique which is based on the accurate validation of aforementioned data. Build an enterprise-level project database, collect historical projects into task decomposition specifications, work duration data, resource consumption quotas, cost accounting data organization and classify storage by project type (this gives a reference to the new network plan modeling), avoiding the risk caused by experience-based estimation is too far away. Meanwhile, set standards for data collection and validation to specify the scope, frequency, and responsible entities at each construction stage; use " on-site collection + entry into the system" method to ensure timeliness of data, as well as safeguard data authenticity through cross-validation from technical, cost, and construction departments. On this basis, we can construct a data sharing platform to dissolve data barriers in each project management link, and realize the interconnectivity of network plan model with progress management system, cost management system and resource management system to guarantee that we could adjust optimization plans at the first time through getting data timely and improve the precision of optimization decision.

4.2 Strengthening Personnel Capabilities: Constructing a Tiered Professional Training Mechanism

Effectively applying network planning technique requires management personnel with high professional capabilities, and thus team professional capabilities must be enhanced through tiered training. Conduct basic operational training for frontline construction management personnel, so that network plan diagrams can be interpreted, and the critical path can be understood. Focus on progress deviation judgement ability to ensure that the staff can understand the optimization plan and implement it during on-site construction. For mid-level technical management personnel, carry out advanced application training: including network plan model construction, optimization method selection, professional software operation and other content training, guide them to lead the formulation of optimization plans for real-time adjustment of the network plan. In conclusion, provide senior management decision makers with targeted strategic cognitive training to emphasize the importance of network planning technique in the project control process and improve their attention to it. Make enterprise-level resource investment and system support for its application become a corporate culture through changing habits. In the training process, establish a training evaluation and incentive mechanism: integrate network planning application ability into personnel performance assessment, drive management personnel to learn actively and practice, from "training—application—assessment" form a closed loop to effectively improve quality and efficiency throughout building construction [3].

4.3 Promoting Technological Integration: Deepening the Synergy between Network Planning and Emerging Technologies

Building the deep synergy system between network planning and emerging technology that combines well under construction management of building engineering is a practical need to improve the dynamic perception and optimization accuracy of traditional application. Integrating scenarios into the BIM technology, combining the three-dimensional visualization and parametric characteristics of BIM models to unify each sub-item work in the network plan with model components and achieve spatial visualization of construction progress, based on which it is possible to intuitively identify having multi-process overlap leads to what spatial conflict, providing spatial dimensional support for resource allocation optimization. At the same time, pre-simulating construction processes based on simulated capabilities of BIM for optimization programs of network plans to proactively identify parts of the program inconsistent with construction processes and site conditions so as to reduce costs associated with adjustment on the assembly sequence and implementation process. Based on this, study the newly adaptive layout of intelligent algorithms in multi-objective optimization. Based on the sophisticated "duration—cost—resources" multi-objective coordinated optimization requirements of building engineering, allied with certain project limitations, choose appropriate intelligent algorithms to obtain a tool for multi-objective optimization, realize algorithm connection with network plan software through programming, and construct (in accordance with construction task defined) a comprehensive multi-objective optimization calculation model; automatically solve for the optimal plan sets that comply with constraint conditions in order to facilitate how well these solutions fit into constraints separating plans within the grievance (grievance here is distinct from complaint) under review, while performing allowable integration based on decision-making experience and judgment of individual management organization among them according project team demand attribute at both local and systematic levels respectively, ultimately achieve flexible discussion screening of collaborating enterprise alignment needs without exacerbating budget [4].

5. Conclusion

Network planning technique is the core tool for construction management in building engineering, and the optimized application of it reflects its depth and breadth directly related to project control effectiveness. As construction engineering projects are gradually moving towards the trend of scale and complexity and intelligence, traditional experience-based management models have been unable to adapt to the requirements of multi-objective coordinated control. The application of the network planning technique in an optimized way has gradually developed into a key guarantee of promoting the transformation from extensive to refined construction management. In the future, with the iterative evolution of relevant technologies (including intelligent algorithms and digital twins), network planning technique is expected to realize a leap from "passive optimization" to "active prediction," providing more effective and comprehensive technical support for construction management in building engineering and promoting improvement of comprehensive industry management ability.

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