Research on Construction Progress Management and Control of Municipal Road and Bridge Engineering Based on BIM Technology

Daoyu Li

Huainan City Jianfa Municipal Engineering Co., Ltd., Huainan, Anhui, 232000, China

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Abstract: Municipal road and bridge engineering projects are characterized by long construction periods, multiple participating parties, and complex spatial environments. Traditional progress management, which relies on two-dimensional drawings and Excel spreadsheets, is prone to issues such as inadequate coordination mechanisms, substandard quality control, and inefficient supply chain management, leading to project delays and cost overruns. This paper starts from the practical problems in municipal road and bridge engineering and studies the application paths of BIM technology in construction progress management of such projects. It aims to effectively improve the efficiency of progress management and reduce project delays through BIM technology, providing practical references for progress management in municipal road and bridge engineering.

1. Introduction

As an important part of the urban transportation network, the construction quality and progress of municipal road and bridge engineering directly affect the efficiency of urban operations and residents' travel experiences. BIM technology, as the core technology of digital transformation in the construction industry, features visualization, parametrization, and collaboration. It can integrate the full life-cycle data of road and bridge projects into three-dimensional models, offering new solutions for progress management. Therefore, in-depth research on the specific application methods of BIM technology in the construction progress management and control of municipal road and bridge engineering, and solving key practical problems, are of great practical significance for improving project management levels and ensuring on-time project delivery.

2. Problems in the Construction of Municipal Road and Bridge Engineering

2.1 Inadequate Construction Organization and Coordination Mechanisms

Municipal road and bridge engineering involves multiple participating parties, including construction, design, supervision, and material supply entities. The efficiency of organization and coordination among these parties directly impacts the pace of construction progress. Currently, some projects lack systematic planning in the construction organization phase. Construction plans mainly focus on the technical arrangement of work procedures but neglect the division of rights and responsibilities and the design of collaborative processes among participating parties. For example, there is a lack of regular communication mechanisms between design and construction units. After the design plans are delivered, construction units often find discrepancies between the designs and actual site conditions during on-site implementation (such as structural dimensions not matching the available space or material requirements not aligning with local supply capabilities). These issues require repeated communication and confirmation for adjustments, leading to work procedure delays. Meanwhile, the supervisory and coordinating role of supervision units is not fully utilized. Some supervision work is limited to quality sampling inspections and fails to actively coordinate issues such as cross-operation conflicts and resource allocation contradictions in construction progress, resulting in a situation where participating parties often "act independently" during construction handover. Additionally, some construction units have internal organizational

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management shortcomings. The project department lacks dynamic adjustment of task assignments among construction teams. When a team experiences delays due to technical deficiencies, it fails to promptly reallocate resources from other teams to compensate, further exacerbating construction progress delays. Moreover, insufficient technical disclosures among teams can easily lead to rework due to differences in understanding construction standards, increasing additional time and cost consumption.

2.2 Substandard Construction Technology Management and Quality Control

Municipal road and bridge engineering has high requirements for the professionalism and standardization of construction technologies, and different work procedures have varying technical standards. However, there are obvious loopholes in the technology management of some projects. On the one hand, the preparation of technical plans lacks pertinence and feasibility. Some construction units overly rely on general technical templates and fail to optimize plans based on actual factors such as the geological conditions, climate environment, and traffic conditions of the project location. For example, in the subgrade construction of soft soil foundation sections, a special reinforcement plan is not formulated according to the compressibility and water content of the soil. Instead, only conventional compaction processes are used, resulting in uneven settlement of the subgrade after it is opened to traffic and requiring subsequent repairs. On the other hand, there is a gap between technical disclosures and on-site guidance. When technicians convey technical requirements to construction teams, they often use oral or simple written forms without combining visualization tools to ensure full understanding by the teams. This leads to technical deviations during construction. In terms of quality control, some projects have an unsound quality inspection system. The frequency and coverage of inspections do not meet regulatory requirements, and the recording and analysis of inspection data lack systematicness. Only surface quality issues can be identified, and it is difficult to recognize potential hidden dangers in concealed works. Furthermore, the technical literacy of construction personnel varies. Some front-line workers have not undergone systematic technical training and are not proficient in operating new construction equipment. This not only affects construction efficiency but may also lead to quality accidents due to operational errors, further increasing the project's rectification costs and schedule pressure.

2.3 Inefficient Resource Allocation and Supply Chain Management

Municipal road and bridge engineering projects have long construction periods and large resource consumption, placing high demands on the rational allocation of human, mechanical, and material resources and the stable operation of the supply chain. However, there are significant shortcomings in resource management in some current projects. In terms of human resource allocation, there is a lack of scientific demand forecasting and dynamic allocation mechanisms. During the early stages of construction, there is often insufficient estimation of peak-period labor demands, leading to labor shortages in key work procedures. In the off-season of construction, there is labor idleness, resulting in waste of labor costs. At the same time, there is a shortage of technical talents, such as those with BIM technology application capabilities and special mechanical operation qualifications. This prevents some advanced construction technologies and equipment from being fully utilized, restricting the improvement of construction efficiency. In mechanical equipment management, there are problems of unreasonable equipment selection and inadequate maintenance. Some construction units choose underperforming equipment to reduce costs or fail to reasonably match equipment according to construction procedure requirements, resulting in low equipment utilization rates. Moreover, the daily maintenance and repair system for equipment is not well-established. Maintenance is only carried out after equipment failures occur, which not only delays construction progress but also increases equipment repair costs. In material supply chain management, there is a lack of long-term stable cooperation mechanisms with suppliers. Material procurement often adopts a short-term and fragmented model. When market material prices fluctuate or supplies are tight, delays in material supply are likely to occur. Meanwhile, the storage and management of materials after they enter the site are not standardized. Some materials that are susceptible to moisture and deterioration are not protected effectively, leading to high material loss rates. This not only increases material costs but may also cause construction interruptions due to material shortages, further exacerbating the risk of project delays.

3. Application Paths of BIM Technology in Construction Progress Management of Municipal Road and Bridge Engineering

3.1 Construct a 4D Progress Integration Model to Achieve Precise Association between Progress Plans and Physical Projects

The core starting point of BIM technology application in progress management is to deeply integrate traditional two-dimensional progress plans with three-dimensional physical models to construct a 4D progress integration model that includes a time dimension, breaking the limitation of the traditional disconnect between progress plans and engineering entities. During the model construction process, it is first necessary to complete the refined construction of a three-dimensional physical model, covering all structural units of the road and bridge project such as subgrades, pavements, bridge piers, cover beams, and prefabricated components, ensuring that the geometric parameters and material properties of the model are completely consistent with the actual project. Subsequently, the time information of the progress plan needs to be precisely bound to the structural units of the three-dimensional model. Through the parametrization function of BIM software, each structural unit is assigned corresponding construction start time, end time, duration, and work procedure logical relationships to form a complete 4D progress model.

This model can visually present the entire construction process sequence and spatial layout of the road and bridge project from the start to completion. Construction managers can clearly grasp the sequential connection relationships and spatial distribution ranges of various work procedures, avoiding progress delays caused by chaotic work procedure logic or spatial conflicts. At the same time, the 4D progress model supports dynamic simulation functions. By simulating the construction process, key route work procedure nodes can be sorted out in advance, and the core work procedures affecting the total project duration can be identified, providing a basis for determining the key points of subsequent progress control. In addition, the model has a progress visualization query function. Managers can quickly obtain the construction time plan, corresponding resource requirements, and associated work procedure information of any structural unit by clicking on it, facilitating real-time verification of progress execution during construction and timely detection of the embryonic stage of progress deviations, thus buying time for progress adjustments [1].

3.2 Build a Collaborative Management Platform to Open Up Information Transmission Channels among Multiple Participating Parties

Municipal road and bridge engineering involves many participating parties, and information barriers among these parties are an important reason for the low efficiency of progress management. BIM technology can build a collaborative management platform to achieve real-time sharing and efficient transmission of progress information among multiple participating parties. The collaborative management platform takes the BIM model as the core carrier and integrates the information needs of design, construction, supervision, construction, and material supply parties. It sets up operation ports with different permissions to ensure that each participating party can complete progress-related information uploading, viewing, feedback, and collaborative processing within the platform.

During platform operation, design units can promptly upload design change documents and corresponding model adjustment content, indicating the scope and degree of the impact of changes on related work procedure progress, facilitating construction units to quickly assess the impact of changes on the overall progress. Construction units need to update on-site construction progress information daily, mark the completed structural units in the BIM model, and synchronously upload problems encountered during construction to provide a basis for supervision and construction units to grasp progress dynamics. Supervision units can conduct progress deviation checks based on the progress plans and actual progress data within the platform. When deviations are found, they can promptly initiate warnings within the platform and propose rectification suggestions. Construction units can summarize the progress information of all participating parties through the platform to comprehensively grasp the overall progress of the project. They can organize coordination meetings in a timely manner to address key node progress delays, and the collaborative management platform also has a progress information traceability function, which can record the operation traces and information transmission times of each participating party. When progress responsibility disputes arise, it can provide clear information evidence for responsibility determination, avoiding low progress management efficiency caused by untimely information transmission or unclear responsibilities [2].

3.3 Implement Dynamic Progress Monitoring and Deviation Correction to Ensure Progress Objectives are Controllable

BIM technology can achieve dynamic monitoring and deviation correction of the construction progress of municipal road and bridge engineering projects by integrating real-time data collection, progress deviation analysis, and dynamic plan adjustment functions, ensuring that progress objectives remain within a controllable range. In the real-time data collection phase, the BIM system can be combined with Internet of Things technology to automatically collect progress-related data on-site such as human input, mechanical operation, material arrival, and work procedure completion, eliminating the need for manual statistical entry and reducing data collection lag and error rates. The collected data is transmitted to the BIM model in real time and automatically compared with the preset progress plan data to form a dynamic visual report on progress execution. Managers can quickly grasp key information such as the progress completion rate and the number of days behind or ahead of schedule for each work procedure through the report. When the system detects a progress deviation, it automatically initiates a deviation analysis process, tracing the causes of the deviation from multiple dimensions such as technology, resources, and management. For example, if a foundation construction work procedure of a road and bridge project is behind schedule, the system can analyze whether there is a material supply delay by checking the material arrival records, verify whether there is a mechanical failure by examining mechanical operation data, and investigate whether there is a technical execution deviation by reviewing technical disclosure records, ensuring a comprehensive and accurate analysis of the deviation causes. In terms of deviation impact assessment, the BIM system can simulate the degree of impact of the deviation on subsequent work procedures and the total project duration based on the logic of the progress network plan, clarifying whether the deviation will lead to a key route transfer or a total project duration delay, providing a scientific basis for formulating deviation correction plans.

In the dynamic plan adjustment phase, managers can rely on the progress optimization function of BIM software to formulate targeted correction plans based on the deviation analysis results. If the deviation is caused by resource shortages, the resource allocation plan can be adjusted to shorten the work procedure duration; if the deviation is caused by technical problems, the construction team can be jointly organized to optimize the construction process and improve construction efficiency; if the deviation has a significant impact on the total project duration, the logical relationships of subsequent work procedures can be adjusted on the premise of ensuring project quality, such as changing some non-key work procedures to parallel operations to compress the total duration of the key route. The adjusted progress plan will be synchronously updated to the BIM model and the collaborative management platform to ensure that all participating parties promptly obtain the latest progress requirements, achieving a dynamic closed-loop control of progress management and ensuring that the project progresses as planned.

3.4 Conduct Construction Simulation Analysis to Proactively Avoid Progress Risks and Construction Conflicts

Municipal road and bridge engineering projects have numerous work procedures and frequent cross-operations. If risks are not fully predicted before construction, work procedure conflicts or safety accidents are likely to occur, affecting progress. BIM technology can proactively identify risks and formulate response measures through construction simulation analysis. Construction simulation is based on the BIM model and combines the project's construction process, site environment, resource allocation, and other factors to simulate the entire construction process of the project in a virtual environment and predict possible progress risks and construction conflicts [3].

In risk prediction, the simulation first checks the logical sequence of work procedures for risks. Through the BIM model, it verifies whether the sequence of various work procedures is reasonable and whether there are issues such as work procedure inversion or omission. For example, it checks whether road surface paving is scheduled before subgrade construction is completed or whether cover beam construction is planned before bridge pier casting reaches the required strength, ensuring that the work procedure logic complies with construction specifications and technical requirements. Secondly, in terms of spatial conflict risks, it simulates the spatial occupation of different disciplines and work procedures during construction. For example, it analyzes whether there is overlap in the space between the lifting of bridge prefabricated beams and ground pipeline construction or whether there will be interference between road construction and the renovation of surrounding underground pipe networks. If spatial conflicts are found, the construction sequence is adjusted in advance or the construction plan is optimized to avoid construction stagnation caused by on-site conflicts.

4. Conclusion

In conclusion, from the construction of 4D progress models to achieve plan visualization, to the collaborative management platform breaking information barriers, to real-time data collection supporting dynamic monitoring, and construction simulation analysis proactively avoiding risks, BIM technology is gradually changing the problems of inadequate coordination mechanisms, substandard quality control, and inefficient supply chain management in traditional progress management. It provides a systematic solution for precise control of project progress. In the future, with the further penetration of digital technologies in the construction industry, BIM technology will play a greater role in the construction progress management of municipal road and bridge engineering, providing stronger technical support for ensuring on-time project delivery and improving the quality of urban infrastructure construction.

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