Journal of Architectural Research and Development, 2025, Volume 9, Issue 4
https://ojs.bbwpublisher.com/index.php/JARD
Online ISSN: 2208-3537
Print ISSN: 2208-3529

Optimization of Schedule Management for Small Municipal Engineering Projects

Chuhong Chen*

Shenzhen Haiyi Construction Engineering Co., Ltd., Shenzhen 518110, Guangdong, China

**Author to whom correspondence should be addressed.*

Abstract: Small municipal projects, constrained by resources and extensive management models, commonly face issues of delayed progress and cost overruns. This study uses a road renovation project in a city as an empirical case. By integrating BIM collaborative platforms with real-time IoT monitoring systems, it achieves construction conflict prediction and dynamic resource allocation. Combining rolling planning methods and risk probability models, a "forecast-adaptation" dual-mode management framework is formed. After implementation, the total duration was shortened by 15%, the rework rate decreased by 20%, and inter-departmental communication efficiency improved by 30%. The case validates the effectiveness of digital tools and dynamic mechanisms working together to optimize, aligning with the requirements for refined control outlined in the "Construction Engineering Quantity List Pricing Standard" (GB/T50500-2024). It provides a replicable progress management paradigm for similar projects.

Keywords: Small municipal engineering; Progress management optimization; BIM technology

Online publication: August 6, 2025

1. Introduction

As urbanization accelerates, the efficiency of progress management in municipal engineering projects—central to urban infrastructure development—plays a crucial role in optimizing public resource utilization and supporting sustainable urban growth. In recent years, while the scale of municipal projects in China has continued to expand, small-scale projects commonly face challenges like delays and cost overruns due to limited resources and fragmented management practices. Traditional experience-based management relies heavily on manual expertise and lacks digitalization, resulting in poor task coordination, delayed risk responses, and difficulty adapting to complex construction environments.

Meanwhile, multiple policies enacted by 2025 offer new opportunities for optimizing progress management. For example, the "Standard for Bill of Quantities Valuation of Construction Works" (GB/T 50500-2024) promotes standardization in quantity and cost accounting; green procurement policies strengthen sustainability requirements in construction processes; and Shanghai's Pudong New Area has implemented an architect responsibility system, clarifying accountability to boost management efficiency.

Against this backdrop, integrating digital tools (such as BIM collaborative platforms and IoT real-time monitoring) with agile management theories—to establish dynamic adjustment mechanisms and risk early-warning systems—has become a key solution to the progress management challenges of small municipal projects. Combining theoretical and empirical research, this study aims to provide a systematic approach to enhance progress management efficiency and align with policy directives, supporting the high-quality development of urban infrastructure.

2. Basic theory of project schedule management in municipal engineering projects

2.1. Concept and characteristics of project schedule management in municipal engineering projects

Schedule management in municipal engineering projects is a systematic management activity oriented towards the project duration target, dynamically coordinating the allocation of project resources, the connection of construction processes, and potential risks. Its essence lies in ensuring the project progresses according to the predetermined timeline through scientific planning and real-time monitoring, while also taking into account quality, cost, and safety objectives [1]. The particularities of municipal engineering determine the uniqueness of its schedule management: First, there is a significant feature of multi-department collaboration, involving the coordination among government agencies, design units, construction parties, and supervision departments, necessitating the establishment of an efficient communication mechanism to eliminate information barriers. Second, there is a strong dependence on the environment; construction progress can be easily affected by natural conditions (such as weather, geology), policies and regulations, and social factors (such as public demands), requiring dynamic adaptability. Third, the social impact is extensive; municipal projects often involve public infrastructure, and schedule delays can easily cause public dissatisfaction and resource wastage; hence, schedule management needs to balance efficiency with social benefits.

2.2. Current status and challenges in schedule management for small municipal projects

Current schedule management of small municipal projects remains dominated by traditional experience-based approaches. Heavy reliance on manual expertise for planning and insufficient adoption of digital tools result in low management efficiency. In practice, schedules often lack scientific rigor due to inadequate preliminary research or unclear task dependencies, manifesting as significant timeline estimation errors and vague critical path identification [2]. During execution, the absence of dynamic monitoring methods makes it difficult to promptly detect progress deviations. Coupled with rigid resource allocation (e.g., delayed deployment of labor/equipment), these issues further widen the gap between plans and implementation. Additionally, weak risk response mechanisms—with insufficient contingency plans for emergencies like extreme weather or utility clashes—often lead to reactive timeline extensions.

These problems not only cause cost overruns but may also trigger public distrust, highlighting the urgent need for standardized, refined, and intelligent transformation in schedule management for small municipal projects.

3. Theoretical basis and methods for schedule management optimization

3.1. The integration of Critical Path Method (CPM) and agile management theory

The Critical Path Method (CPM), as a core tool of traditional schedule management, provides a structured framework for duration forecasting by identifying critical tasks and minimum float times. Its strength lies in using network diagrams to quantify the logical relationships between tasks, clarifying the minimum duration, but its limitations are evident in its lack of adaptability to dynamic changes: On one hand, CPM assumes ample resources and fixed logical relationships between tasks, making it difficult to cope with unexpected disruptions during construction (such as equipment failure or design changes). On the other hand, its static model struggles to update progress data in real-time, leading to delayed risk response. Agile management theory compensates for the shortcomings of CPM through iterative planning and dynamic feedback mechanisms, emphasizing short-term goal decomposition and cross-functional team collaboration. For instance, by using “sprint planning” to break down long-term projects into deliverable units, and combining daily stand-up meetings to quickly identify schedule deviations, resources can be allocated flexibly [3]. The combination of the two forms a “forecast-adapt” dual-mode management framework, where CPM provides a baseline plan, and agile methods optimize the execution path through dynamic adjustments, thereby balancing planning and flexibility.

3.2. BIM technology and visual schedule management

Building Information Modeling (BIM) technology integrates multi-source data from design, construction, and operation phases through three-dimensional digital modeling, providing visual decision support for schedule management. At the resource integration level, BIM models can link information about materials, equipment, and labor, automatically generating resource requirement lists to reduce manual statistical errors; its clash detection function identifies issues such as pipeline intersections and spatial conflicts through collision analysis, preventing rework delays. 4D progress simulation technology further integrates the temporal dimension into BIM models, dynamically associating construction plans with three-dimensional space to visually present the status of the project at each stage [4]. Managers can use simulation results to anticipate conflicts in task connections and optimize construction sequences; compare plans with on-site progress in real-time to identify the root causes of deviations. This data-based visual analysis significantly enhances the scientific nature of decision-making, for example, by simulating construction plans under different weather scenarios to establish risk response priorities, thereby reducing the impact of uncertainty on the project schedule.

4. Optimization paths for small municipal project schedule management

4.1. Technical optimization: Application of digital tools

4.1.1. Building a BIM-based schedule collaboration platform

The BIM-based schedule collaboration platform integrates data flows from design, construction, and supervision teams to enable lifecycle-wide information sharing and real-time updates. Centered on the BIM model, the platform digitizes blueprints, material lists, construction schedules, and other key elements, supporting multi-role online collaborative editing and version control. For instance, design changes can be instantly pushed to contractors, preventing rework caused by information delays. Supervisors can directly flag quality issues through model annotations, shortening rectification cycles [5]. The built-in clash detection module automatically identifies conflicts like pipeline intersections or spatial occupancy issues, allowing proactive optimization of construction sequences. Additionally, tiered access control ensures data security and accountability. Such platforms significantly enhance cross-departmental coordination efficiency and reduce schedule delays caused by information silos in traditional workflows.

4.1.2. IoT real-time monitoring system

The IoT real-time monitoring system utilizes sensors, RFID tags, and smart devices to enable round-the-clock tracking of construction progress and resource consumption. For example, vibration sensors monitor concrete pouring progress, GPS locators record equipment operation duration, and RFID tags provide dynamic inventory updates [6]. Collected data is uploaded to a cloud-based analytics platform, generating visual reports on key metrics like resource utilization rates and task completion percentages. Managers can adjust resource allocation based on real-time datasuch as redeploying work crews when labor shortages occur, or triggering automatic procurement requests when material stocks fall below thresholds. Integrated with BIM models, the system feeds field data back to update digital twins, creating a “sense-analyze-act” closed-loop that reduces manual inspection costs while enhancing the timeliness and precision of schedule control [7].

4.2. Management optimization: Improvement of processes and mechanisms

4.2.1. Dynamic schedule adjustment mechanism

The dynamic schedule adjustment mechanism combines rolling wave planning with the PDCA cycle to build a progressively detailed schedule control system. Rolling wave planning uses short-term units (such as weekly plans) for execution, with long-term plans being refined periodically as the project progresses, avoiding the rigidity of traditional static plans [8]. The PDCA cycle continuously optimizes and adjusts strategies through the four stages of “Plan-Do-Check-Act”: the planning stage establishes a baseline based on BIM simulations and historical data; the execution stage monitors actual progress through IoT systems; the checking stage compares deviations and analyzes their causes; the acting stage revises subsequent plans in response to issues. For instance, when delays occur due to rain, progress can be recovered by compressing non-critical path tasks or increasing parallel operations. This mechanism enhances management flexibility, shifting schedule control from passive response to proactive intervention, thereby shortening the decision-making lag period.

4.2.2. Risk early warning and emergency plans

The risk early warning system relies on historical project data and machine learning algorithms to construct probability models that quantify and identify the likelihood and impact of high-frequency risk events (such as extreme weather, equipment failure, policy adjustments) [9]. The model dynamically updates risk levels by accessing real-time external data sources like weather and public opinion, triggering tiered early warning signals. Emergency plans are designed modularly, with predefined response processes for different types of risks: Level one risks (like collapses) trigger work stoppages for investigation and expert intervention; Level two risks (like material shortages) involve calling on alternative suppliers or backup plans [10]. Plan drills use BIM virtual construction scenarios to simulate risk situations, enhancing the team’s emergency response capabilities. For instance, a pipeline relocation project, by pre-enacting underground pipeline conflicts, prepared in advance with emergency construction teams and equipment, reducing risk handling time by 40%. Such mechanisms shift from post-incident remediation to pre-emptive prevention, systematically reducing schedule uncertainty.

5. Empirical analysis: Case study of a municipal road rehabilitation project

5.1. Project overview and schedule management challenges

5.1.1. Project background

This urban road rehabilitation project spans 2 kilometers along a central arterial road, involving old pavement removal, subgrade reinforcement, asphalt paving, green belt reconstruction, and traffic marking renewal, with simultaneous relocation of underground utilities (power, telecom, water supply/drainage). Located in a dense residential/commercial zone, the project requires maintaining two-lane bidirectional traffic during construction, creating significant traffic management challenges. The 6-month schedule involves coordination between municipal authorities, three contractors, and two supervision firms. As a key urban renewal initiative, it aims to improve civic infrastructure while enhancing public welfare. However, outdated underground utilities and complex stakeholder coordination led to frequent pipeline mapping inaccuracies during pre-construction, substantially increasing schedule uncertainty.

5.1.2. Key flaws in the original schedule plan

The original schedule, developed using traditional Gantt charts, suffered from overly broad task segmentation and inadequate consideration of multi-trade workflow interfaces. For instance, earthwork excavation and utility relocation—assigned to different contractors—had only a 1-day buffer for work handover at interfaces. In practice, delays in clearing underground obstacles forced subsequent pipeline installation to halt. Resource allocation showed inefficient decentralized patterns, with equipment and labor scheduling relying on empirical estimates. This caused simultaneous equipment shortages and idle time during peak periods (e.g., asphalt pavers operated below 60% daily utilization). Risk management deficiencies included no contingency buffers for the rainy season (30% of project duration). When prolonged rainfall extended subgrade curing time, the static schedule failed to dynamically adjust downstream tasks, compounding delays. Furthermore, manual progress reporting caused 3–5 day data delays, preventing management from timely deviation detection until optimal intervention windows had closed.

5.2. Implementation of optimization strategies

5.2.1. BIM platform deployment and schedule simulation

The project implemented a BIM collaboration platform integrating 3D models from designers, contractors, and utility owners. Clash detection identified 12 underground conflicts (e.g., power conduits overlapping drainage pipes at conflicting elevations). This prompted resequencing construction using the "deeper utilities first" principle—prioritizing water/sewer line relocation to prevent damage during later excavation. The platform linked schedule data to model components, generating 4D simulations that revealed asphalt paving and landscaping activities overlapping, resulting in inadequate equipment maneuvering space. Consequently, landscaping was delayed by two weeks with temporary material staging areas added. Validated through stakeholder workshops, the optimized baseline schedule reduced projected rework due to conflicts by 80%.

5.2.2. Dynamic progress monitoring and adjustment

After deploying an Internet of Things (IoT) monitoring system, vibration sensors are installed on site to monitor the strength of concrete curing, GPS locators track the operational paths of excavators, and RFID tags count the number of asphalt transport trips. The system collects data hourly and synchronizes it with the BIM platform to generate a real-time progress dashboard. The project management team, in conjunction with IoT data, dynamically adjusts plans during weekly progress meetings: for instance, if rain delays subgrade curing by 3 days in a week, they can recover 2 days by shortening subsequent non-critical tasks (such as curbstone installation) and adding night shifts. At the same time, the system's early warning indicates that the daily consumption of concrete in a certain section exceeds the plan by 15%, and they promptly allocate resources from a backup mixing station to avoid work stoppages due to material shortages. The frequency of plan updates has been increased from monthly to weekly, and the response delay has been shortened from 5 days to within 8 hours.

5.3. Assessment of implementation effects

5.3.1. Reduction in duration and cost savings

The actual total project duration was reduced from the original plan of 180 days to 153 days, a decrease of 15%, mainly attributed to BIM's conflict prediction that reduced rework time, and the dynamic adjustment mechanism that mitigated weather risks. The rework rate was lowered from 12% to 9.6%, saving approximately 870,000 yuan in wasted materials such as concrete and asphalt; the optimization of machinery scheduling reduced equipment idleness from 35% to 18%, cutting rental costs by 410,000 yuan. Comprehensive calculations show that the optimized schedule management measures directly contributed to a cost reduction of 6.2% of the total budget, and indirectly reduced the compensation costs for citizen complaints due to traffic control extensions by about 230,000 yuan.

5.3.2. Improvement in management efficiency

Inter-departmental collaboration efficiency has significantly improved, with the approval cycle for design changes reduced from an average of 7 days to 2 days, thanks to the online collaboration features of the BIM platform, which also decreased the error rate of drawing versions by 90%. Among the 237 quality issues submitted by the supervision unit through model annotations, 92% were closed and rectified within 48 hours, speeding up the process by 65% compared to the traditional paper-based workflow. The duration of weekly progress meetings was shortened from 4 hours to 1.5 hours, as IoT data replaced manual reporting, reducing contentious issues by 70%. In the project's final stage, completion documents were automatically generated through the BIM model, reducing the compilation time from 14 person-days to 3 person-days, and increasing the completeness of information to 98%, laying a data foundation for subsequent operations and maintenance.

6. Conclusion

Research indicates that dual-dimensional optimization of technology and management significantly enhances the efficiency of schedule management in small-scale municipal projects. The integration of BIM collaborative platforms with IoT real-time monitoring systems achieves full-process data visualization and dynamic tracking of construction, effectively reducing rework and resource waste. The dynamic adjustment mechanism combining rolling wave planning with the PDCA cycle strengthens the adaptability of schedule plans and the ability to respond to risks. Empirical cases show that after optimization, the schedule was shortened by 15%, and costs were saved by 6.2%, validating the effectiveness of the methodology. However, the research conclusions are based on a single case, with a limited sample scope, and do not fully verify the universality of the optimization path under different regional, scale, and environmental conditions. Future research needs to further refine model parameters through comparative analysis of multiple cases. Additionally, the impact of macro factors such as policy changes and supply chain fluctuations on schedule management has not yet been quantified and incorporated into the evaluation system. Future research could explore the deep integration of AI predictive models with blockchain technology: AI can improve the accuracy of schedule forecasting and risk early warning by mining historical data patterns through machine learning; blockchain technology ensures the transparency and traceability of collaborative data among multiple parties, reducing the risk of data tampering. Such technological iterations are expected to promote the transformation of municipal project schedule management from "experience-driven" to "data intelligence-driven," providing a more efficient decision support framework for new urbanization construction.

Disclosure statement

The author declares no conflict of interest.

References

[1] Cooke B, Williams P, 2025, Construction Planning, Programming and Control. John Wiley & Sons, USA.

[2] Kerzner H, 2025, Project Management: A Systems Approach to Planning, Scheduling, and Controlling. John Wiley & Sons, USA.
[3] Dasović B, Galić M, Klanšek U, 2020, A Survey on Integration of Optimization and Project Management Tools for Sustainable Construction Scheduling. Sustainability, 12(8): 3405.
[4] Ansari R, Khalilzadeh M, Hosseini MR, 2022, A Multi-Objective Dynamic Optimization Approach to Project Schedule Management: A Case Study of a Gas Field Construction. KSCE Journal of Civil Engineering, 26(3): 1005–1013.
[5] Rosłon J, Książek-Nowak M, Nowak P, 2020, Schedules Optimization with the Use of Value Engineering and NPV Maximization. Sustainability, 12(18): 7454.
[6] Parsamehr M, Perera U S, Dodanwala T C, et al., 2023, A Review of Construction Management Challenges and BIM-Based Solutions: Perspectives from the Schedule, Cost, Quality, and Safety Management. Asian Journal of Civil Engineering, 24(1): 353–389.
[7] Pregnolato M, Gunner S, Voyagaki E, et al, 2022, Towards Civil Engineering 4.0: Concept, Workflow and Application of Digital Twins for Existing Infrastructure. Automation in Construction, 141: 104421.
[8] Suresh D, Sivakumar A, 2021, An Empirical Study, Analysis and Investigation About Impact of Schedule Management Plan in Project Management Effectiveness Using Structural Equation Modeling. Int J Adv Eng Manag, 3(9): 810–834.
[9] Assaad R, El-Adaway IH, Abotaleb IS, 2020, Predicting Project Performance in the Construction Industry. Journal of Construction Engineering and Management, 146(5): 04020030.
[10] Jackson BJ, 2020, Construction Management JumpStart: The Best First Step Toward a Career in Construction Management. John Wiley & Sons, USA.

Publisher's note

Bio-Byword Scientific Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.