Analysis of the Application of Mathematical Modeling Technology in Construction Management

Yuxin Xue

Hefei Baohe District Key Projects Construction Management Center, Hefei, Anhui, 230000, China

Keywords: Mathematical Modeling Technology; Construction Engineering; Construction Management

Abstract: Construction projects involve numerous interconnected links and variables, where quality, schedule, and cost constrain each other. Traditional experience-based management reveals its limitations against the backdrop of increasing data complexity and risk uncertainty. Introducing mathematical modeling into construction management can, on one hand, formalize multi-source data and constraint relationships to support rapid decision-making and dynamic correction; on the other hand, it can quantify hidden risks, resource conflicts, and cost deviations in advance, providing a methodological fulcrum and computational basis for refined whole-process governance. Based on this, this paper constructs corresponding modeling frameworks and application paths focusing on the four dimensions of construction management: quality, schedule, cost, and safety. The results indicate that this technical route can effectively improve efficiency, reduce costs, enhance quality and safety levels, and significantly increase project controllability and predictability.

1. Introduction

In recent years, the increasing scale of construction projects, longer organizational chains, and superimposed external uncertainties have created bottlenecks for traditional experience-driven construction management in terms of quality stability, schedule adherence, and cost control. Factors such as material price fluctuations, labor supply elasticity, and on-site environmental disturbances frequently trigger plan deviations and risk accumulation. Managers urgently need computable tools, using data as the link, to transform complex relationships into measurable, deducible, and actionable management operations. The value of mathematical modeling lies herein: it incorporates dispersed monitoring data, institutional constraints, and resource boundaries into a unified framework, providing verifiable hypotheses, comparable schemes, and executable optimization guidance. Embedding it into the entire construction management process not only helps suppress quality defects and safety hazards at the source but also forms closed-loop control on critical paths, resource allocation, and cost flows, thereby providing technical support and practical pathways for the industry's refined transformation.

2. Basic Theory of Mathematical Modeling

2.1 Definition and Characteristics

Mathematical modeling involves describing objects, constraints, and objectives from real-world situations in mathematical language, forming a deducible system representation through variables, parameters, and relational expressions to support explanation, prediction, and optimized decision-making. In the context of construction management, mathematical modeling can base itself on process logic, resource supply, quality standards, and safety boundaries to unify discrete events and continuous processes within the same framework, enabling the connection and verification of multi-source data[1]. Its prominent characteristics are reflected in three aspects: Firstly, structuring, extracting complex relationships into clear networks, functions, or probability structures, facilitating the identification of critical paths and bottleneck nodes. Secondly, verifiability, allowing model

DOI: 10.25236/icacel.2025.211

calibration and sensitivity testing against historical data and on-site monitoring to ensure conclusions align with the scenario. Thirdly, operability, where model outputs can be directly translated into schedule adjustments, resource reallocation, and risk warning strategies, forming closed-loop control. Furthermore, the modeling process emphasizes dynamic updates and iteration, keeping the model adaptable and stable under conditions like material price fluctuations, weather disturbances, and schedule changes.

2.2 Modeling Process and Methodology

For ease of implementation, the process can follow the sequence of " Define → Model → Verify → Apply → Iterate." Start by identifying business pain points, clarifying objectives and boundaries, listing stakeholders, constraints, and performance indicators to form a unified problem statement. Then, integrate data, unify calibers and time scales, handle missing and anomalous data to ensure a reliable foundation. Based on this, select models and tools suited to the context: schedules can use network planning and resource-constrained scheduling; materials and inventory can use supply-demand balance or stock-flow models; quality and safety can incorporate reliability and risk assessment; solving can employ linear/integer programming, heuristic algorithms, or simulation[2]. After the model takes shape, use historical samples and small-scale trial runs for calibration and sensitivity analysis to pin down key parameter ranges. In the application phase, set rolling update rhythms and warning thresholds, translating outputs into schedule adjustments, resource allocation, and risk alerts. Finally, continuously iterate and simplify based on on-site feedback, balancing stability and interpretability for cross-project reuse.

3. Core Content of Construction Management

3.1 Quality Management

Focusing on key divisions like structure, MEP (Mechanical, Electrical, Plumbing), and finishes, the core of quality management lies in unifying standards, processes, and results onto a measurable track. Methods include:

Firstly, detailing inspection lots and process nodes into traceable checkpoints, coupled with sampling ratios and release conditions, forming front-end control. Secondly, relying on statistical process control (SPC), set control limits for indicators like strength, dimensional deviation, and moisture content, continuously monitor trends, and identify anomalies. Thirdly, establish cause-and-effect chains combining material batches, crew records, and equipment status to quickly locate defect sources and implement closed-loop rectification. Fourthly, incorporate high-risk processes (e.g., deep excavation, waterproofing, concrete pouring) into standby supervision and witness sampling lists, strengthening threshold warnings and work stoppage mechanisms. Simultaneously, use sample comparisons and re-test data to update acceptable judgment intervals, optimizing inspection frequency and sampling size to match resource input with quality risk[3]. Ultimately, through the cycle of "standard→data→feedback→ improvement," stably output deliverable, traceable, and verifiable quality results.

3.2 Schedule Control

Schedule is as crucial as quality, cost, and safety, forming a vital part of on-site organization. In practice, it requires setting major goals in advance, then breaking them down into weekly plans and crew tasks, clarifying process sequences, overlap times, and equipment occupancy. Record daily variances between planned and actual progress, focusing on correction. Encountering delayed materials, worsening weather, or equipment failure triggers timely adjustments to the critical path and resource deployment according to preset thresholds. Implement time scheduling for shared equipment like tower cranes and pump trucks to reduce waiting; leave buffers for rhythmic operations like concrete pouring to avoid cascading delays. For chronically constrained processes, use staggered shifts and parallel scheduling to stabilize output capacity. Synchronize information through on-site boards and regular meetings, clarifying responsibilities and implementation timelines, making schedule control both predictable and rapidly responsive.

3.3 Cost Control

Within the core content of construction management, target costs need decomposing into divisions, sub-divisions, processes, and crews, clarifying consumption standards for materials, labor, machinery, and temporary works costs. Then, establish the "budget→contract→variation→ settlement" chain, promptly measuring quantities incurred on-site, and documenting variations and site instructions daily. For materials, align batches and usage with the schedule plan, controlling waste and redundant purchasing. For machinery, calculate utilization rates per shift, promptly replacing or regrouping inefficient equipment. For labor, verify unit price fulfillment based on productivity and attendance, avoiding idle time and stacked overtime. Set cost warning thresholds for key processes; once consumption deviates, immediately adjust from process parameters, crew configuration, or process sequencing without compromising quality and safety. Conduct monthly rolling comparisons of target vs. actual, reviewing unit prices, waste, and change sources, forming a traceable cost ledger, enabling cost control adjustments to proceed synchronously with schedule and quality adjustments.

4.Benefits Brought by Mathematical Modeling Technology to Construction Management

4.1 Improving Efficiency and Reducing Costs

Supported by mathematical modeling technology, construction management can incorporate dispersed information and constraints into a unified "accounting system," enabling more precise matching of organization and resources to tasks. Taking schedule as an example, using network logic and resource-constrained scheduling helps identify critical paths and potential conflict points in advance, reasonably schedule the operational periods for tower cranes, pump trucks, and labor crews, reducing waiting and rework. On the material side, supply-demand balance models align delivery rhythms with consumption curves, avoiding stockpiling and last-minute premium purchases. On the machinery side, optimize scheduling based on shift utilization and load curves, reducing idle time and overtime. At the cost level, use multi-objective optimization and sensitivity analysis to filter more cost-effective construction methods and procurement combinations, and set warning thresholds for highly volatile factors to adjust processes or batching strategies early. During on-site operation, rolling parameter calibration keeps deviations within acceptable limits, maintaining consistency between plan, execution, and settlement.

4.2 Improving Quality and Safety Assurance

With the introduction of mathematical modeling, quality and safety are no longer reliant solely on experience but are based on data and thresholds. For key indicators like concrete strength, rebar spacing, and weld defect rates, establish control limits and trend models; if on-site detection approaches the red line, the system prompts re-inspection and process adjustment, reducing batch rework. For high-risk links like deep excavation, high formwork, and lifting, construct risk scores combining working conditions, equipment status, and operational density; exceeding set values triggers standby supervision, flow limiting), or work stoppages, preventing minor issues from escalating into accidents[4]. Linking material batches and crew records enables rapid traceability of defect sources, shortening troubleshooting time. Integrating weather, noise, and dust data allows for scheduling in advance work windows and protective measures, reducing the impact of environmental disturbances. Through continuous parameter calibration, inspection frequency and sampling points can be dynamically optimized, focusing efforts on the most likely problem areas. Once quality stability improves and safety incident rates decrease, the costs of rectification and stoppages reduce simultaneously, making project delivery more controllable.

4.3 Enhancing Project Controllability and Predictability

Leveraging mathematical modeling, projects transition from "correcting errors after seeing results" to "identifying and avoiding issues in advance." In the planning stage, through joint deduction of process logic, resource supply, and site constraints, multiple construction paths and schedule ranges are provided, allowing management to identify risk locations and buffer settings before work begins. During implementation, the model places schedule, cost, quality, and safety data within the same coordinate system; any deviation is promptly amplified for display, facilitating quick root cause identification and action plan development. For external factors like material prices, weather changes, and labor mobility, use scenario analysis and probability distribution estimation to quantify the impact scope in advance, deciding whether to adjust the plan, change timings, or add backup resources. Once unexpected events occur, the system immediately recalculates the critical path and funding needs, suggesting the correction route with the least cost. As on-site data rolls in and parameters are continuously corrected, prediction intervals gradually narrow, reducing the gap between plan and actual, thereby making management actions steadier, faster, and more assured.

5.Application of Mathematical Modeling Technology in Construction Management

5.1 Quality and Safety Applications

Embedding models into quality and safety management on the construction site can specify "how to view, how to manage, when to intervene." For quality, incorporate indicators like concrete strength, rebound values, rebar cover thickness, and weld ultrasonic testing results into statistical models, setting upper and lower limits for process release; once trends approach thresholds, immediately trigger re-inspection, mix adjustment, or process change. Associating material batches, crew operation records, and equipment status enables rapid pinpointing defect sources, shortening troubleshooting time[5]. For safety, concerning high-risk operations like deep excavation, high formwork, lifting, and temporary electricity, construct risk scores integrating load, equipment health, operational density, and environmental parameters; exceeding preset values triggers flow control, standby supervision, or stoppage, and suggests alternative work windows. Integrating weather, dust, noise, and vibration data allows for scheduling in advance protection and risk avoidance. Through rolling calibration of model parameters, optimize sampling frequency and monitoring points, directing management resources to the most problematic links, achieving quality and safety control that is accurate with less sampling and stable with less stoppage.

5.2 Schedule Optimization Application

Applying mathematical modeling to scheduling focuses on integrating process logic, resource capabilities, and site constraints into a single "scheduling chart." First, use network models to delineate sequential relationships and critical paths, then introduce resource-constrained scheduling to assign specific time slots to tower cranes, pump trucks, formwork, and crews, reducing mutual waiting. For rhythmic operations, set buffers and pace points based on productivity curves, avoiding "fast start, slow finish." When material deliveries, weather changes, or equipment failures disrupt the plan, the model can instantly recalculate paths and resource deployment, listing several feasible adjustment options, such as inserting night shifts, using alternative machinery, or adjusting pouring zones, and estimating the impact on schedule and cost, facilitating rapid on-site decision-making. For long-term bottlenecks, use simulation to evaluate the effects of parallel operations, staggered mobilization, and temporary works optimization, selecting the combination with the least overall cost. During operation, update data daily on a rolling basis, continuously correcting productivity and rhythm parameters, increasing the fit between plan and actual, improving the fulfillment rate of key milestones, and making the overall schedule more stable and controllable.

5.3 Cost Control Application

First, establish a cost breakdown structure based on divisions and sub-divisions, mapping materials, labor, machinery, temporary works costs, and overheads to specific processes and time periods, forming progress-dependent cost curves. In procurement, use supply-demand and price fluctuation models to determine batch sizes and delivery rhythms, comparing the impact of spot purchasing vs. forward buying on cash flow and unit prices. During construction, optimize machinery and crew combinations based on shift utilization and productivity curves, identify inefficient shifts and adjust schedules, reducing idle time and stacked overtime. For high-consumption processes (e.g., concrete, rebar, formwork), set waste baselines and warning thresholds; upon deviation, correct from process parameters, work methods, or zoning. Handle variations and site instructions through rule engines for immediate measurement and booking, avoiding concentrated outbreaks during settlement. Conduct monthly rolling comparisons of target, committed, and actual costs, using sensitivity analysis to identify main cost drivers, prioritizing handling items with high shares and high volatility, enabling cost control adjustments to advance in linkage with schedule, quality, and safety adjustments, ensuring better input-output ratios.

6. Conclusion

In summary, the value of integrating mathematical modeling into construction management lies in supporting every on-site decision with clear logic and verifiable data. Focusing on the four dimensions of quality, schedule, cost, and safety, models provide a unified expression of standards, processes, and resource constraints, making key indicators traceable, deviations locatable, and adjustments quantifiable. As data quality and computing power improve, this technical pathway will further integrate planning -> implementation -> settlement -> operation and maintenance phases, driving project management from passive correction towards active control and proactive governance, ultimately achieving more stable delivery rhythms and better comprehensive benefits.

References

[1] Guan Zhanrong. Analysis of the Application of Mathematical Modeling Technology in Construction Management [J]. Building Science, 2024, 40(11): Insert 5.

[2] Wang Yingxia. Analysis of the Application Methods of Mathematical Modeling in Construction Management [J]. Building Science, 2024, 40(1): Insert 14.

[3] Li Jianjun, Jiao Yan, Zhong Yonghui. Application of Mathematical Modeling in the Teaching of Architectural Professional Courses [J]. Earthquake Resistant Engineering and Retrofitting, 2024, 46(4): Insert 5.

[4] Yao Juanfeng. Research on the Application of BIM Technology in Construction [J]. Construction Engineering Technology and Design, 2021(7): 820.

[5] Wang Jingjing, Xu Wenxia. Discussion on the Application of BIM Technology in Construction Engineering Management [J]. IT Manager World, 2021(7): 113-114.