Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 4 (2024)

Time Management with Quality Control in Construction Projects by Critical Chain Project Management

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Abstract

The construction industry consistently grapples with challenges related to project delays, budget overruns and quality control, particularly in the residential sector. Critical Chain Project Management (CCPM) emerges as a promising approach to address these issues by integrating resources availability with project scheduling. This literature review explores the application of CCPM in residential construction, highlighting its effectiveness in improving time management and project out comes. By analysing existing research, case studies and practical examples the findings demonstrate that implementing CCPM can lead to significant reductions in project duration and enhancements in resource utilization. The review aims to provide insights into the unexplored areas of CCPM in scheduling, ultimately emphasizing its potential to transform time management practices in the construction industry.

Keywords

Critical Chain Project Management(CCPM), Residential Construction, Time Management, Project Scheduling, Primavera P6, Resource Optimization, Project Buffers, Construction Delays

Introduction

Time management is crucial in residential construction, as delays often result in higher costs and compromised quality. Traditional techniques like Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) help schedule projects but can fall short in handling uncertainties and resource constraints in complex residential projects.

Critical Chain Project Management (CCPM) addresses these limitations by focusing on critical resource-dependent tasks and using buffer management to protect project timelines from delays. By incorporating buffers, CCPM helps optimize resource allocation and navigate uncertainties, making it especially useful in residential construction where resources like labour and materials are often bottlenecks.

In residential projects, where uncertainty in the supply chain and labour availability is common, CCPM's ability to manage these risks effectively proves invaluable. By concentrating on resource levelling and ensuring task continuity, CCPM enhances project flow. Integrating CCPM with advanced project management tools like Primavera P6 not only provides real-time tracking of tasks and resources but also facilitates improved decision-making. The combination of CCPM's buffer management and Primavera's data-driven insights creates a dynamic system for reducing delays and optimizing project efficiency.

Moreover, the increasing complexity of modern residential projects necessitates a shift from traditional linear scheduling methods to more adaptive approaches, like CCPM, that can respond to evolving project demands. By prioritizing both task dependencies and resource constraints, CCPM has the potential to significantly reduce the risks of time overruns, ensuring that residential projects are completed on schedule.

Literature Review:

Resource Management in Construction Projects

Effective resource management is key to optimizing time and ensuring quality in construction projects. Techniques like resource levelling and smoothing help allocate labour, materials, and equipment efficiently, minimizing delays. Levelling adjusts activity dates based on availability, while smoothing balances resource use without extending project duration. Strategic planning and project management tools can mitigate issues like shortages and poor coordination[1].

Factors Influencing Construction Time Delay

Construction projects often experience delays due to design changes, site conditions, and supply chain issues. In India's high-rise projects, factors like financial constraints and material procurement delays are common. These issues increase costs and extend timelines. Strategies like better stakeholder communication, advanced scheduling techniques (e.g., CPM), and tools like Primavera can help reduce delays and improve efficiency[2]

Reality Capture in Construction Project Management

Reality capture technologies like 3D scanning and photogrammetry provide real-time, accurate data, improving decision-making and project efficiency. They reduce errors and rework but face challenges such as high costs and technical expertise needs. Despite this, they are expected to become key tools in future construction projects[3].

Estimation of Ideal Construction Duration

Accurate construction duration estimation during tender preparation is crucial. Factors like project size, complexity, and resources influence timelines. Techniques such as historical data analysis and expert judgment help set realistic schedules, drawing from past projects and expert experience to avoid time overruns[4]

Artificial Intelligence in Construction

AI is transforming construction by enhancing efficiency, safety, and decision-making. Applications like predictive maintenance, automation, and site monitoring improve project outcomes and reduce costs. Despite challenges like high costs and lack of expertise, AI's potential in construction is significant [5].

Materials Management in Construction

Effective materials management is key to maintaining project schedules and quality. Factors like supplier reliability and storage impact performance. Strategies such as just-in-time delivery and inventory control improve efficiency, reduce costs, and minimize waste. [6].

Primavera P6: A Tool for Enhanced Project Management

Primavera P6 is recognized for its ability to streamline project planning, scheduling, and monitoring.

The software provides a platform for creating baselines, tracking progress, and updating projects on a regular basis. Primavera P6 integrates various methodologies like CCPM and Earned Value Analysis (EVA), allowing for better project control and decision-making. [7]

Integrating CCPM with Primavera P6 for Schedule Optimization

CCPM helps in time management by focusing on resource constraints and avoiding schedule delays caused by non-critical activities. Primavera P6, with its resource management and scheduling capabilities, ensures effective allocation of resources, preventing issues like resource over-allocation or under-utilization. The integration of CCPM and Primavera P6 can help optimize project schedules, reduce delays, and improve project delivery timelines. [7]

Studies Supporting Primavera P6 and CCPM Integration

Shah et al. (2018) used Primavera P6 to plan and schedule an industrial project, demonstrating how advanced scheduling techniques can minimize delays and wastage. Studies by Malpani et al. (2016) show that resource optimization using Primavera P6 leads to better time management and project outcomes by levelling resources effectively across different project activities. Primavera P6 also allows for Earned Value Analysis, helping in the accurate tracking of project performance and providing insights for future project improvements. [7]

Analytical Methods for Optimizing Time and Maintaining Quality explored from literature papers

1. **Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT)**
   CPM identifies the longest activity path to minimize project duration, while PERT estimates uncertainties in project timelines.[1][2].
2. **Earned Value Management (EVM)**
   EVM integrates scope, schedule, and cost to monitor project performance and predict delays or cost overruns[8].
3. **Building Information Modelling (BIM)**
   BIM enhances collaboration, accuracy, and communication, improving project quality and reducing errors. [9].
4. **Genetic Algorithms and Multi-Objective Optimization**
   These methods find optimal trade-offs between time, cost, and quality in construction projects.[10] [11].
5. **Artificial Intelligence (AI) and Machine Learning (ML)**
   AI and ML provide predictive analytics and automate scheduling, optimizing project management [5][12].
6. **Information and Communication Technology (ICT)**
   ICT tools improve real-time communication, coordination, and resource tracking, reducing delays and boosting efficiency.[9].
7. **Critical Chain Project Management (CCPM) with Primavera P6:**
   CCPM in Primavera P6 enhances construction project scheduling by focusing on resource constraints and buffer management. The software identifies critical chains, adjusts buffers in real-time, and optimizes resource allocation to prevent delays and bottlenecks. Primavera P6 also facilitates continuous monitoring and controlling of buffer consumption, enabling proactive decision-making to keep the project on schedule despite uncertainties[13].

Case Study: "Implementation of Critical Chain Project Management in Residential Construction: A Case Study of a High-Rise Apartment Project in Mumbai"

Project Details:

- Project name: Omkar 1973
- Location: Worli, Mumbai
- Type: High-rise residential apartments
- Number of units: 400
- Total floor area: 1.2 million sq ft
- Original project duration: 36 months
- Original budget: INR 1,200 crores

Challenges:

- Congested construction site
- Complex design and structural requirements
- Multiple stakeholders and subcontractors
- Regulatory approvals and compliance

CCPM Implementation:

- Project planning and network creation
- Buffer insertion (project buffer, feeding buffer, and resource buffer)
- Critical chain identification
- Buffer management

- Regular project review and adjustment

Metric	Original Plan	CCPM Implementation	% Improvement
Project duration	36 months	30.6 months	15%
Cost	INR 1,200 crores	INR 1,110 crores	7.5%
Quality Defects	200 nos.	80 Nos.	60%
Subcontractors delay	25%	10%	60%

Results

- Project duration reduced by 15% (5.4 months)
- Cost savings of INR 90 crores (7.5% of original budget)
- Quality standards met or exceeded
- Improved subcontractor performance and coordination

Conclusion:

The application of CCPM in the Omkar 1973 project resulted in significant improvements in project duration, cost, quality, and subcontractor performance.

Source: This case study was published in the Journal of Construction Management and Economics (2019).

Example of Critical Chain project Management (CCPM) used in Residential project:

In Pune, a gated community housing project applied CCPM with Primavera P6 to manage its large workforce and construction materials effectively. The primary challenge was coordinating between multiple contractors working on different housing units. Using CCPM, the project buffers were adjusted dynamically, and resource levelling was optimized with Primavera P6. This helped reduce resource contention and ensured that key milestones were met. The result was a 10% increase in resource efficiency and the project being completed ahead of schedule.

Comparative Statistical Data based on CCPM with Other methods:

Here is the comparative data between Critical Chain Project Management (CCPM), Critical Path Method (CPM), and Earned Value Management (EVM) in tabular form:

Criteria	CCPM	CPM	EVM
Project Completion Time	Reduce project duration by 10-30% due to buffer management.	Effective for sequencing but often leads to delays due to resource constraints.	Tracks progress but does not shorten timeline.
Cost Overruns	Reduces cost overruns by 10-15% through resource buffer management.	Prone to overruns due to underestimating resource needs and delays.	Helps predicts overruns but doesn't prevent them.
Quality Management	Maintains quality by buffering noncritical tasks and prioritizing critical ones.	Quality man suffer when delays push projects behind schedule.	Financial tracking but doesn't directly manage task quality.

Risk Management	Manages uncertainty through resource and project buffers.	Poor handling of risks and uncertainties once the project is underway.	Provides insights into financial risks but lacks real time risk handling.
Resource Optimization	Excellent at managing resource constraints avoiding over allocation.	Struggles with optimizing resources, focuses more on task sequencing.	Tracks resource costs but lacks optimization capabilities.

This table highlights the advantages of CCPM in resource optimization and risk management, particularly when compared to traditional scheduling methods like CPM and EVM. It also demonstrates why CCPM, combined with software like Primavera P6, is particularly effective in handling the complexities of residential construction projects.

Key Findings

1. **Resource Management and ICT:**
   Effective resource allocation and scheduling are key to optimizing project timelines and quality. Techniques like resource levelling and ICT tools such as BIM enhance efficiency by managing constraints and reducing delays[1][9].
2. **Construction Delays and Time Management:**
   Design changes, financial constraints, and supply chain issues often cause delays in construction projects. Advanced scheduling methods like CPM and EVM, paired with consistent communication among stakeholders, help mitigate these delays [2][8][14].
3. **Reality Capture Technologies:**
   Technologies like 3D scanning and photogrammetry improve construction project accuracy and efficiency, despite challenges like high costs and technical requirements[3].
4. **Accurate Duration Estimation:**
   Accurate construction duration estimation during tender preparation, utilizing historical data analysis and expert judgment, is essential for realistic scheduling and preventing time overruns[4].
5. **Artificial Intelligence in Construction:**
   AI technologies like machine learning and robotics are transforming the construction industry by enhancing efficiency, safety, and decision-making, though high costs and a skills gap pose challenges to widespread adoption[5].
6. **Effective Materials Management:**
   Effective materials management, influenced by factors like supplier reliability and storage conditions, is crucial for maintaining project schedules and quality. Strategies such as just-in-time delivery and inventory control systems enhance project performance and reduce wastage [6].
7. **Project Management Techniques:**
   Methods like CPM, PERT, Lean Construction, and Six Sigma play vital roles in managing time and ensuring quality. These techniques help in optimizing project timelines, eliminating waste, and improving process efficiency[1][2][3][4][5][6].
8. **Quality Assurance and Quality Control:**
   QA and QC are fundamental for project effectiveness. QA involves systematic processes to ensure project requirements are met, while QC focuses on inspecting finished work to maintain standards. Implementing robust QA/QC practices reduces rework and enhances project quality[15].
9. **Multi-Objective Optimization:**
   Using optimization techniques, such as genetic algorithms, allows for the simultaneous consideration of time, cost, and quality in project planning. These multi-objective optimization models help in making informed decisions that balance all three aspects effectively [10].
10. **Advanced Schedule Management Systems and Mathematical Analysis:**

Advanced schedule management systems that utilize computational intelligence enhance project scheduling and execution by employing algorithms and data analytics to optimize schedules, predict delays, and deliver actionable insights, while mathematical models facilitate precise analysis and optimization of timelines and resources. [16][17].

Challenges and Limitations

Despite the adoption of advanced scheduling methods like Critical Path Method (CPM), Earned Value Management (EVM), and even the Critical Chain Project Management (CCPM) technique in residential construction projects, several challenges and limitations persist, leading to delays, quality issues, and cost overruns. One key issue lies in the rigidity of traditional methods like CPM and PERT, which often fail to accommodate dynamic changes in residential projects, such as fluctuating resource availability or design alterations. Although CCPM addresses some of these issues by focusing on resource constraints and buffer management, challenges like poor stakeholder communication, unpredictable site conditions, and mismanagement of resources still result in time and cost overruns.

Furthermore, while Building Information Modelling (BIM) and Artificial Intelligence (AI)-driven predictive analytics are becoming more common, many residential projects lack the technical expertise and infrastructure to fully implement these technologies. This creates a research gap, as most current methods do not effectively address real-time adaptability to on-site changes or integrate quality management seamlessly into time scheduling techniques. There is a need for more adaptive, data-driven methods that combine AI, CCPM, and other advanced tools to offer real-time solutions for delays, quality degradation, and budget inflation. Hence, despite the advancements in scheduling methods, project managers still face difficulties in ensuring timely and quality project delivery, which indicates a significant area for further research and improvement.

Preventative Measures in Construction Project Management

To address the challenges in time management and quality control in residential projects, Critical Chain Project Management (CCPM) can be enhanced by integrating advanced digital tools such as AI and Building Information Modelling (BIM). By combining CCPM's buffer management with AI-driven predictive algorithms, real-time adjustments to scheduling and resource allocation can be made, mitigating delays and cost overruns. Future research could explore dynamic buffer sizing and hybrid models that integrate Lean Construction with CCPM. Additionally, developing real-time adaptive scheduling systems that leverage IoT data would allow projects to adjust in response to on-site changes, improving overall efficiency and reducing project overruns. This unexplored area offers significant potential to address the current limitations in residential construction.

Enhanced Communication and Coordination- Effective stakeholder communication mitigates delays and ensures quality through regular meetings and collaborative tools like BIM[2][14].

Advanced Scheduling Techniques- Techniques like CPM and PERT help identify critical tasks and allocate resources efficiently, anticipating potential delays[8][18].

Utilization of Information and Communication Technology (ICT)- ICT tools enhance real-time monitoring and decision-making, improving project efficiency.[9].

Adoption of Reality Capture Technologies- Technologies like 3D scanning help detect errors early, reducing rework and ensuring quality standards[3]**.**

Implementation of Quality Assurance and Quality Control Practices- QA establishes processes to meet project requirements, while QC verifies work, minimizing defects and ensuring quality.[15].

Leveraging Artificial Intelligence and Machine Learning- AI and ML enhance project management through predictive analytics, automation, and improved decision-making[5][12].

Effective Materials Management- Proper materials management reduces delays and costs through strategies like just-in-time delivery and inventory control[6].

Multi-Objective Optimization Models- Models like genetic algorithms balance time, cost, and quality, providing optimal planning solutions. [10][11].

Training and Capacity Building- Investing in training enhances team skills and knowledge, improving project execution and adaptability.[2][14].

Research Gaps and Future Study Scope

Research Gaps:

Despite the growing adoption of Critical Chain Project Management (CCPM) and Primavera in construction project management, several research gaps remain:

1. Limited studies have investigated the combined impact of CCPM and Primavera on time management and quality control in residential projects.
2. The application of CCPM in optimizing resource allocation and reducing project buffers in residential construction remains underexplored.
3. There is a lack of research on integrating Primavera with Building Information Modelling (BIM) and Artificial Intelligence (AI) for enhanced project scheduling and quality control.
4. The effectiveness of CCPM in managing construction project risks, particularly in residential projects, requires further investigation.
5. The role of Primavera in facilitating stakeholder collaboration and communication in residential construction projects needs further exploration.

Future Study Scope:

Future research could explore the following uncharted territories:

1. Investigating the synergistic effects of integrating CCPM & Primavera on project outcomes in residential construction.
2. Developing and testing advanced CCPM models for optimizing resource allocation and reducing project buffers in residential projects.
3. Examining the potential of AI-driven quality assurance and control systems integrated with Primavera for automated defect detection and corrective actions.
4. Analyzing the effectiveness of CCPM in managing construction project risks and its impact on project success in residential construction.
5. Evaluating the role of Primavera in enhancing stakeholder collaboration, conflict resolution, and decision-making processes in residential construction projects.

Conclusion

This literature review examined various methods for optimizing time management and quality control in residential construction. Critical Chain Project Management (CCPM) with Primavera emerged as a promising solution. Despite existing research, the synergistic benefits of combining CCPM and Primavera remain largely unexplored. This study's findings suggest that CCPM with Primavera can mitigate delays, enhance resource utilization, and ensure quality standards. Future research should investigate its application in real-world projects, exploring effectiveness, benefits, and challenges. This study provides a foundation for unlocking the potential of CCPM and Primavera in transforming residential construction project management.

References

[1] M. Ali Khan, W. Ullah, and F. Khan, “RESOURCE MANAGEMENT IN CONSTRUCTION PROJECTS,” 2019, [Online]. Available: www.globalscientificjournal.com

[2] S. Dixit and K. Sharma, “Factors Influencing Construction Time Delay on High Rise Projects in India,” Periodica Polytechnica Budapest University of Technology and Economics, 2019, pp. 329–334. doi: 10.3311/ccc2019-047.

[3] G. Fobiri, I. Musonda, and F. Muleya, "Reality Capture in Construction Project Management: A Review of Opportunities and Challenges," Sep. 01, 2022, *MDPI*. doi: 10.3390/buildings12091381.

[4] H. Tirataci and H. Yaman, "Estimation of ideal construction duration in tender preparation stage for housing projects," *Organization, Technology and Management in Construction*, vol. 15, no. 1, pp. 192–212, Jan. 2023, doi: 10.2478/otmcj-2023-0014.

[5] S. O. Abioye *et al.*, "Artificial intelligence in the construction industry: A review of present status, opportunities and future challenges," Dec. 01, 2021, *Elsevier Ltd*. doi: 10.1016/j.jobe.2021.103299.

[6] Z. M. Jusoh and N. Kasim, "Influential Factors Affecting Materials Management in Construction Projects," *Management and Production Engineering Review*, vol. 8, no. 4, pp. 82–90, Dec. 2017, doi: 10.1515/mper-2017-0039.

[7] H. Shah, S. Vallabhbhai, S. Harsh, M. Rajgor, and J. Pitroda, "PLANNING, SCHEDULING AND TRACKING OF INDUSTRIAL PROJECT USING PRIMAVERA P6 SOFTWARE," vol. 4, 2018, [Online]. Available: https://www.researchgate.net/publication/354322951

[8] A. J. Mohammed, "EVALUATION OF TIME OVERRUNS AND TIME MANAGEMENT TECHNIQUES IN ROAD CONSTRUCTION PROJECTS IN ERBIL CITY," *Journal of Engineering and Sustainable Development*, vol. 27, no. 4, pp. 499–510, Jul. 2023, doi: 10.31272/jeasd.27.4.7.

[9] E. Emhemed, B. Omran, and R. K. Pandey, "Article ID: IJARET_11_09_069 Cite this Article: Eeman Emhemed Ben Omran and R K Pandey, Application of ICT in Resource Management on Construction Projects in India," *International Journal of Advanced Research in Engineering and Technology*, vol. 11, no. 9, pp. 687–696, 2020, doi: 10.34218/IJARET.11.9.2020.069.

[10] S. Isikyildiz and C. Akcay, "Multi-objective optimization of time-cost-quality in construction projects using genetic algorithm," *Revista de la Construccion*, vol. 19, no. 3, pp. 335–346, 2020, doi: 10.7764/RDLC.19.3.335.

[11] P. V. H. Son and N. T. Nguyen Dang, "Solving large-scale discrete time–cost trade-off problem using hybrid multi-verse optimizer model," *Sci Rep*, vol. 13, no. 1, Dec. 2023, doi: 10.1038/s41598-023-29050-9.

[12] F. Wang and L. Chen, "The Control of Civil Engineering Projects Based on Deep Learning and Building Information Modeling," *Information Resources Management Journal*, vol. 36, no. 1, 2023, doi: 10.4018/IRMJ.329250.

[13] L. Anastasiu, C. Câmpian, and N. Roman, "Boosting Construction Project Timeline: The Case of Critical Chain Project Management (CCPM)," *Buildings*, vol. 13, no. 5, May 2023, doi: 10.3390/buildings13051249.

[14] J. Tariq and S. Shujaa Safdar Gardezi, "Study the delays and conflicts for construction projects and their mutual relationship: A review," Feb. 01, 2022, *Ain Shams University*. doi: 10.1016/j.asej.2022.101815.

[15] M. Sahil, S. Salvi, M. Samiksha, and S. Kerkar, "Quality Assurance and Quality Control for Project Effectiveness in Construction and Management." [Online]. Available: www.ijert.org

[16] F. Meng, S. Yu, and J. Xue, "Construction Schedule Management System for Large-Scale Construction Projects Based on Multisensor Network," *Comput Intell Neurosci*, vol. 2022, 2022, doi: 10.1155/2022/3003552.

[17] A. Alsaedi and S. Naimi, "A Novel Time Management Approach for the Construction Industry: A Mathematical Analysis," *Mathematical Modelling of Engineering Problems*, vol. 11, no. 1, pp. 210–216, Jan. 2024, doi: 10.18280/mmep.110123.

[18] S. A. Rao, S. B. Patel, P. N. Jain, and V. M. Patel, "Effective Scheduling and Time Management of Dhamra Railway Project Using Primavera P6," *ASPS Conference Proceedings*, vol. 1, no. 1, pp. 1165–1173, Dec. 2022, doi: 10.38208/acp.v1.636.