A Sustainable Approach to Construction Delay Analysis Using Window Method and Primavera P6

Qudsia Fatima[1], Dr. Gugulothu Vikas[2]
[1]*Student, ME, Department of Civil Engineering with Specialization in Construction Management*
[2]*Assistant Professor -Civil Engineering, Lords Institute of Engineering and Technology Himayat Sagar 500091, Telangana*

Abstract- Delays in construction projects significantly impact costs, schedules, and stakeholder confidence. This study critically examines the causes, impacts, and analysis methods of delays, using literature review, stakeholder surveys, and forensic tools. The Window Analysis Method with Primavera P6 was applied to assess critical path shifts and delay responsibilities in a luxury golf and leisure project. Key delay factors included late drawings, permit issues, and BIM discrepancies. Findings reveal that over 70% of delays were avoidable through better coordination and planning. The study promotes best practices like early risk detection and digital project tracking, aligning with SDG 9 and SDG 11 by supporting resilient infrastructure and sustainable urban development.

Keywords: Window Analysis, Primavera P6, forensic delay analysis, time impact analysis, extension of time (EOT), critical path method, SDG 9& 11, sustainable infrastructure, delay mitigation strategies.

1.OBJECTIVES

1. To identify and analyze the key causes of delays in construction projects using both primary data (interviews, questionnaires) and secondary data (literature and project records), with emphasis on schedule disruptions and their root sources.
2. To evaluate the impact of delays on project performance parameters such as time, cost, and resource efficiency, through the application of forensic delay analysis techniques like Window Analysis and Time Impact Analysis (TIA) using Primavera P6.
3. To assess the entitlement of Extension of Time (EOT) claims through structured delay attribution, responsibility analysis, and quantification of delay impacts on critical milestones in a real-time case project.
4. To propose sustainable delay mitigation strategies that enhance construction project delivery and stakeholder coordination, thereby contributing to SDG 9 (Industry, Innovation & Infrastructure) and SDG 11 (Sustainable Cities and Communities) by promoting resilient infrastructure and timely urban development.

Literature Review

Durdyev et al. (2017): Delays in construction projects can be attributed to a variety of factors, including poor planning, lack of communication among stakeholders, and unpredictable environmental conditions. These delays not only affect the project timeline but also have substantial financial repercussions, which, in turn, can lead to cost overruns and diminished quality. Their research emphasizes the importance of understanding these contributing factors early in the project life cycle to mitigate their effects through effective scheduling and risk management strategies.

Kaliba et al., 2009 and Doloi et al., 2012: a combination of effective planning, communication, and risk management is necessary to prevent delays from affecting the project's success. Their findings emphasize that managing the project schedule effectively and anticipating potential challenges before they arise can significantly mitigate the risks of delay and improve project outcomes.

Assaf and Al-Hejji (2006): identify both internal and external causes of delays, categorizing them into several key areas. According to their research, poor project planning, insufficient resources, lack of coordination among stakeholders, and changes in project scope are among the most common internal causes of delays in construction. They emphasize that a lack of detailed scheduling and poor resource

allocation often lead to significant delays in the construction process.

Sambasivan, M., & Soon, Y. W. (2007): conducted an influential study on the causes and effects of delays in the Malaysian construction industry. The study identified a range of factors that contribute to delays in construction projects, with poor project management being one of the most significant causes. Other critical factors included labor shortages, material supply issues, changes in project scope, and financial problems faced by contractors. These delays often lead to increased project costs, reduced quality, and strained relationships between project stakeholders.

Al-Kharashi, A., & Skitmore, M. (2009): aimed to investigate the causes of delays in construction projects specifically in Saudi Arabia. This study highlights the local context while identifying common issues that affect construction projects globally.

Faridi and El- Sayegh (2006): aimed to identify the significant factors that contribute to delays in construction projects in the United Arab Emirates (UAE). Their goal was to prioritize these factors and examine how they impact the construction process in the region.

Gaps Identified from Literature

Despite extensive research on construction delays, several gaps remain, especially in the areas of sustainable construction, software-based delay analysis, and practical case applications:

1. Limited Adoption of Advanced Delay Techniques:

Most studies rely on basic qualitative or statistical methods, with few employing forensic tools like Window Analysis or Time Impact Analysis using software such as Primavera P6.

2. Lack of Integration with SDGs:

Existing research rarely links delay analysis to sustainable development goals—particularly SDG 9 and SDG 11—despite their relevance to infrastructure and urban development.

3. Few Real-Time, Data-Driven Case Studies:

There is a scarcity of practical case studies demonstrating delay attribution using actual project data and scheduling tools.

4. Inadequate Allocation of Delay Responsibility:

While causes are discussed, detailed attribution of responsibility (e.g., client, contractor, external agencies) using documented evidence is often missing, which is critical for EOT claims.

5. Generic Delay Factors without Project Context:

Literature often overlooks project-specific issues such as design conflicts (e.g., BIM clashes), provisional sums, or permit delays, which are crucial in complex, mixed-use developments.

This study addresses these gaps by integrating advanced tools, real-time project analysis, and sustainability alignment, contributing a practical framework that bridges academia and industry

1.1. What is the Significance?

The outcomes of this research are anticipated to support a diverse group of stakeholders, such as project managers, contractors, consultants, and policymakers. By uncovering the underlying causes of delays and offering practical solutions, this study seeks to:

- Improving Planning: Helps optimize scheduling to reduce delays.
- Informed Decisions: Provides data for better resource and budget management.
- Cost Reduction: Minimizes financial impacts of delays.
- Better Risk Management: Identifies key causes of delays and mitigates risks.
- Enhanced Collaboration: Promotes better communication among stakeholders.
- Legal Clarity: Provides insights into managing contractual and legal issues.
- Industry Improvement: Recommends practices to reduce delays and boost efficiency.

1.2. Software Used – Primavera P6

- Primavera P6 was chosen for this research due to its advanced scheduling features and widespread use in construction. It was used to create the baseline schedule, track project progress, and conduct delay analysis using the Window Analysis Method.
- By segmenting the schedule into time windows and inserting delay fragments, the study identified changes in float and critical path shifts.
- Primavera's capabilities in float calculation, Gantt chart generation, and Time Impact Analysis (TIA) enabled clear visualization of project deviations and supported evaluation of Extension of Time

(EOT) claims.

- Its integration of scheduling, resource management, and forensic analysis ensured a transparent and accurate delay assessment, making it essential to the study.

2.METHODOLOGY

This research uses a mixed-method, case study approach combining stakeholder insights with forensic delay analysis. Qualitative data from interviews and observations captured on-site challenges, while quantitative analysis using the Window Analysis Method and Primavera P6 identified, mapped, and assessed delay events across the project timeline. This integrated strategy linked specific delays to project phases, distinguished delay types, and evaluated critical path impacts, providing a comprehensive understanding of delay causation and offering practical mitigation strategies.

1.1. Data Collection:

Key sources included baseline schedules, progress reports, delay logs, contracts, correspondence, BIM issue logs, and relevant literature. These enabled accurate mapping of delay events, classification of delay types, and assessment of critical path impacts.

2.2 Delay Analysis Technique – Window Analysis:

Window Analysis is a forensic delay analysis method that breaks down a project's duration into sequential time segments or "windows" to assess delays incrementally. In each window, actual progress is compared with the baseline schedule to identify disruptions, their timing, and their impact on the critical path. This systematic, time-phased approach allows for detailed tracing of delay events, critical path changes, float shifts, and re-sequencing of work.

2.3 Step-by-Step Delay Evaluation Process:

- Collection of Baseline Schedule
- Division of the Timeline into Analysis Windows
- Updating Schedule Progress in Each Window
- Insertion of Delay Fragnets in Primavera P6
- Recalculation of Critical Path
- Quantification of Delay Impact (Extension of Time - EOT)
- Mitigation Assessment

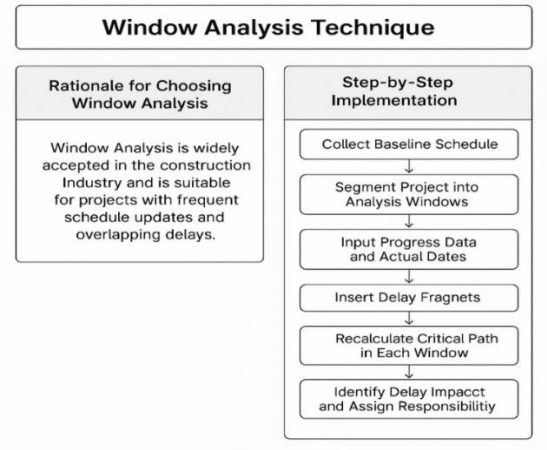

Figure 1: Window Analysis Technique

2. Data Analysis Using Primavera P6:

3.1 Window Analysis of Window 01:

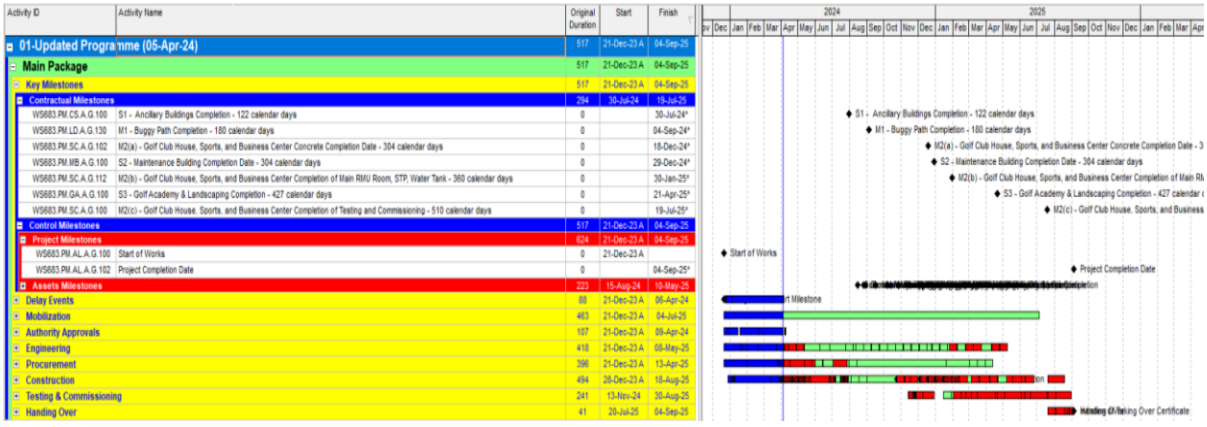

Figure 2: Window 01 – Updated Programme.

The projected completion date for each contractual milestone in the impacted updated programme with updates on the delay fragnets, as shown in the above figure after the schedule run on Data Date 05 Apr 2024.

3.2 Window Analysis of Window 02:

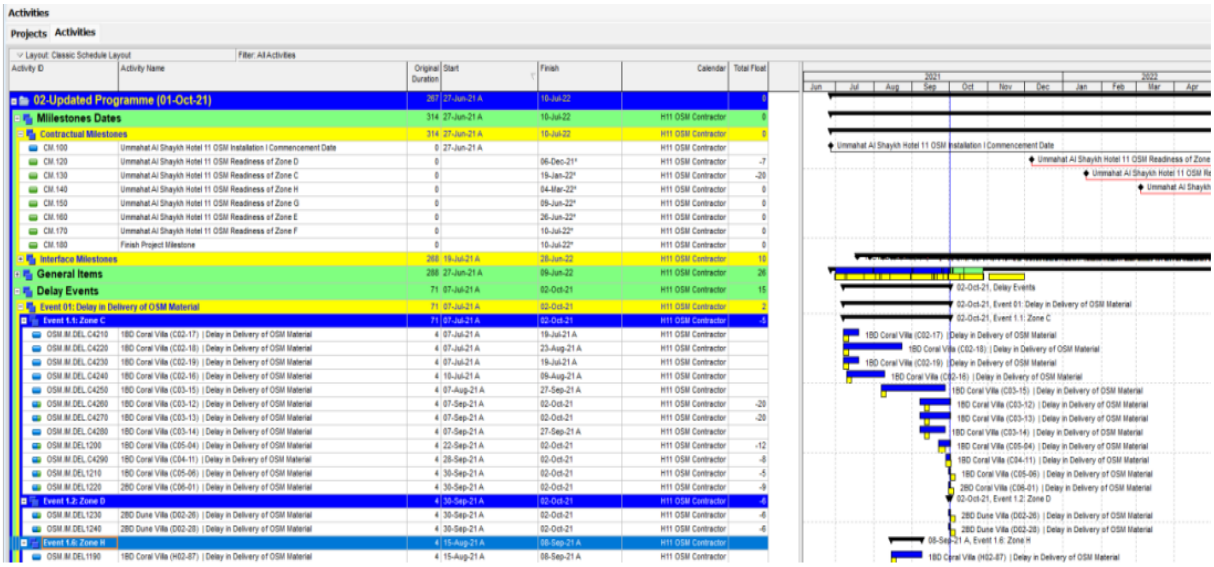

Figure 3: Window 02 – Updated Programme.

The projected completion date for each contractual milestone in the updated programme with delays, as shown in the above figure after the schedule run on Data Date 03 May 2024.

3.3 Window Analysis:

Window no.	*Window Start*	*Window Finish*	*Milestone*	*Contractual Finish Date*	*Finish Date of The Base Programme used for this Window*	*Expected Finish Impacted* at Window Start date	*Expected Finish Updated* at Window Finish date	*Employer Delay / Impact (Employer)*	*Contractor Delay / Mitigation after Impact (Contractor)*	*Net Impact (EOT) within the Window*	*Cum. Employer Delay*	*Revised Date as per EOT*
1	21-Dec-23	5-Apr-24	S1	21-Apr-24	21-Apr-24	24-Jul-24	30-Jul-24	94	6	94	94	24-Jul-24
			M1	16-Jun-24	16-Jun-24	16-Jun-24	4-Sep-24	0	80	0	0	16-Jun-24
			S2	20-Oct-24	20-Oct-24	30-Jan-25	29-Dec-24	102	-32	70	70	29-Dec-24
			M2(a)	20-Oct-24	20-Oct-24	21-Jan-25	18-Dec-24	93	-34	59	59	18-Dec-24
			M2(b)	15-Dec-24	15-Dec-24	27-Mar-25	30-Jan-25	102	-56	46	46	30-Jan-25
			S3	20-Feb-25	20-Feb-25	9-Jun-25	21-Apr-25	109	-49	60	60	21-Apr-25
			M2(c)	14-May-25	14-May-25	24-Aug-25	19-Jul-25	102	-36	66	66	19-Jul-25
			PCD	5-Jul-25	5-Jul-25	13-Oct-25	4-Sep-25	100	-39	61	61	4-Sep-25
2	5-Apr-24	3-May-24	S1	21-Apr-24	30-Jul-24	3-Aug-24	19-Aug-24	4	16	4	98	28-Jul-24
			M1	16-Jun-24	4-Sep-24	4-Sep-24	27-Aug-24	0	-8	0	0	16-Jun-24
			S2	20-Oct-24	29-Dec-24	12-Jan-25	29-Jan-25	14	17	14	84	12-Jan-25
			M2(a)	20-Oct-24	18-Dec-24	29-Dec-24	9-Jan-25	11	11	11	70	29-Dec-24
			M2(b)	15-Dec-24	30-Jan-25	15-Feb-25	24-Feb-25	16	9	16	62	15-Feb-25
			S3	20-Feb-25	21-Apr-25	27-Apr-25	3-May-25	6	6	6	66	27-Apr-25
			M2(c)	14-May-25	19-Jul-25	27-Jul-25	11-Aug-25	8	15	8	74	27-Jul-25
			PCD	5-Jul-25	4-Sep-25	13-Sep-25	29-Sep-25	9	16	9	70	13-Sep-25

Table 1: Contractor's Efforts Across Multiple Disciplines

The mitigation durations shown in the table above are the result of the Contractor's efforts across multiple disciplines, including, among others, issues such as the lack of permits, out-of-sequence activities, and engineering works. The majority of the mitigated measures undertaken by the Contractor were at its own risk, with the aim of benefiting the project and all stakeholders. The resulting PCD is September 13, 2025. The extended completion dates for the remaining Milestones and Sections are as shown in the table above.

Contractual Milestone	*Milestone Date*	*Cum. Employer Delay*	*Revised Date as per EOT #01*
S1: Ancillary Buildings Completion	21-Apr-24	98	28-Jul-24
M1: Buggy Path Completion	16-Jun-24	0	16-Jun-24
S2: Maintenance Building Completion Date	20-Oct-24	84	12-Jan-25
M2(a): Golf Club House, Sports, and Business Center Concrete Completion Date	20-Oct-24	70	29-Dec-24
M2(b): Golf Club House, Sports, and Business Center Completion of Main RMU Room, STP, Water Tank	15-Dec-24	62	15-Feb-25
S3: Golf Academy & Landscaping Completion	20-Feb-25	66	27-Apr-25
M2(c): Golf Club House, Sports, and Business Center Completion of T&C	14-May-25	74	27-Jul-25
PCD: Project Completion Date	5-Jul-25	70	13-Sep-25

Table 2: Contractual Milestones

3. RESULTS AND DISCUSSION

3.1. Key Findings from Delay Analysis:

The detailed forensic analysis conducted using Window Analysis Method and Primavera P6 revealed several critical findings regarding the nature, extent, and responsibility of delays encountered in the RDGC project. These findings offer valuable insights into the actual impact of delays on project milestones and the contractor's entitlement to extensions.

- Multiple Delay Events Significantly Affected the Project Schedule
- Delays Were Concentrated in Early and Mid-Project Phases
- Critical Path Shifted Across Multiple Work Zones
- Client-Related Issues Accounted for the Largest Share of Delays
- Contractor-Related and External Delays Were Also Significant
- Overall Project Completion Was Delayed by 70 Calendar Days
- Contractor Demonstrated Mitigation Efforts
- Delay Analysis Supported Extension of Time (EOT) Claims

3.2. Revised Project Milestones:

Milestone/Section	Original Completion Date	Revised Completion Date	Delay (Calendar Days)
Milestone 01 – Buggy Path Completion	16-Jun-2024	16-Jun-2024	0
Milestone 02a – Clubhouse, Sports & Business Centre Structure	20-Oct-2024	29-Dec-2024	70
Milestone 02b – Completion of RMU Room, STP, Water Tank	15-Dec-2024	15-Feb-2025	62
Milestone 02c – Testing and Commissioning	14-May-2025	27-Jul-2025	74
Section 01 – Ancillary Buildings & Signage	21-Apr-2024	28-Jul-2024	98
Section 02 – Maintenance Building & Landscaping	20-Oct-2024	12-Jan-2025	84
Section 03 – Golf Academy & Landscaping	20-Feb-2025	27-Apr-2025	66
Section 04 – Golf Clubhouse, Sports & Business Centre (Overall)	05-Jul-2025	13-Sep-2025	70
Whole of the Works	05-Jul-2025	13-Sep-2025	70

Table 3: Contractual Vs. Revised Milestone Dates

- The most affected section was Section 01 (Ancillary Buildings), delayed by 98 days, primarily due to late handover and incomplete works from preceding contractors.
- The overall project completion date was extended by 70 calendar days, substantiating the need for a justified Extension of Time (EOT).
- Mitigation measures implemented by the contractor reduced further delays that could have

occurred due to drawing conflicts and permitting delays.

This milestone revision reflects the true time impact of all events analyzed and provides a clear reference point for contract administrators and project controls professionals in assessing progress deviations.

3.3. Critical Delay Events Identified:

- Late Handover of Ancillary Buildings (Section 01)
- Delayed Issuance of IFC Drawings and Design Packages
- Construction Permit Delays for Superstructure Works
- Activation Delays of Provisional Sums
- IFC/BIM Coordination Issues and Model Clashes
- Vendor Response Delays and Submittal Backlogs

These events cumulatively resulted in a 70-day delay to overall project completion, with specific milestones (M2a, M2b, M2c) impacted by 62–98 days. The contractor's entitlement to Extension of Time (EOT) is substantiated through these event-based delay attributions and their linkage to the critical path, as demonstrated in Primavera P6.

3.4. Stakeholder Responsibilities:

1. Client / Employer

Responsibility Share: ~35%

Key Delay Events Attributed:

- Late issuance of IFC drawings and design packages
- Delayed activation of Provisional Sums
- Construction permit approvals not provided on time

Observations:

The client was primarily responsible for administrative and approval-related delays. These delays affected early procurement, shop drawing preparation, and work commencement, especially in the Clubhouse and Ancillary Buildings. Their delayed decisions directly impacted the project's critical path.

2. Contractor (Joint Venture – PC Constructions & G R Infra Projects)

Responsibility Share: ~30%

Key Delay Events Attributed:

- Initial mobilization inefficiencies
- Delayed preparation of shop drawings
- Lack of proactive follow-up in some areas (e.g., BIM coordination)

Observations:

While the contractor made efforts to mitigate delays, some issues such as slow internal coordination and late mobilization contributed to delays in early-stage tasks. However, the contractor also proceeded at risk in several areas to minimize impact, indicating a proactive intent.

3. Design Consultants and Third Parties

Responsibility Share: ~20%

Key Delay Events Attributed:

- Inconsistent or incomplete BIM/IFC models
- Late responses to design clarifications
- Unresolved clashes between architectural and structural packages

Observations:

Design consultants were a key cause of execution uncertainty due to inconsistent documentation. Their coordination issues created repeated rework cycles, delaying shop drawing approvals and service installations.

4. Nominated Vendors and Subcontractors

Responsibility Share: ~15%

Key Delay Events Attributed:

- Delayed technical submittals and material approvals
- Slow responses during procurement stage
- Inefficiencies in OS&E and signage package coordination

Observations:

Subcontractors and suppliers contributed to secondary delays, particularly in the finishing stages. While not always critical path activities initially, the accumulation of float erosion turned some into critical path concerns later in the timeline.

4. CONCLUSIONS:

- The project experienced multiple delay events, primarily due to late issuance of IFC drawings, delayed permits, BIM coordination issues, and activation delays of Provisional Sums, which collectively contributed to time overruns.
- Through detailed scheduling simulations, it was found that the critical path shifted across multiple zones, with milestones such as M2a, M2b, and M2c being delayed by 62 to 98 calendar days. The overall project completion was extended by 70 days, from 05-Jul-2025 to 13-Sep-2025.
- Stakeholder responsibility was distributed across the client (35%), contractor (30%), external consultants (20%), and vendors/subcontractors (15%). These responsibilities were substantiated through documentary evidence and critical path shifts observed in Primavera P6.
- The contractor demonstrated proactive mitigation measures, including re-sequencing activities, proceeding with partial works in advance of approvals, and early preparation of shop drawings. These efforts helped in minimizing further delays.
- The structured delay analysis supported a valid Extension of Time (EOT) claim, as the identified delays were mostly beyond the contractor's control and had clear impacts on the critical path.
- The research also established a strong link between effective delay management and sustainable construction practices, aligning with SDG 9 (Industry, Innovation and Infrastructure) and SDG 11 (Sustainable Cities and Communities) by promoting efficient, resilient, and well-managed project delivery.

This study contributes to both academic research and practical construction management by offering a robust framework for delay identification, attribution, and mitigation using advanced scheduling tools.

4.1. Future Scope for Study:

- Multi-Project and Cross-Sector Delay Analysis
- Integration of Cost and Delay Claims
- Application of Artificial Intelligence (AI) and Machine Learning
- Real-Time Delay Monitoring Using IoT and Automation
- Delay Impact on Sustainability Metrics
- Legal and Contractual Dispute Resolution Models
- Simulation and Scenario-Based Delay Modeling

REFERENCES

[1] Aibinu, A. A., & Jagboro, G. O. (2002). The effects of construction delays on project delivery in Nigerian construction industry. International Journal of Project Management, 20(8), 593–599. https://doi.org/10.1016/S0263-7863(02)00028-5

[2] Alaghbari, W., Kadir, M. R. A., Salim, A., & Ernawati. (2007). The significant factors causing delay of building construction projects in Malaysia. Engineering, Construction and Architectural Management, 14(2), 192–206. https://doi.org/10.1108/09699980710731308

[3] Assaf, S. A., & Al-Hejji, S. (2006). Causes of delay in large construction projects. International Journal of Project Management, 24(4), 349–357. https://doi.org/10.1016/j.ijproman.2005.11.010

[4] Mubarak, S. A. (2015). Construction Project Scheduling and Control (3rd ed.). Wiley.

[5] Alwi, S., Hampson, K., & Mohamed, S. (2002). Non value-adding activities in Australian construction projects: A preliminary model for waste reduction. Proceedings of the 10th International Group for Lean Construction Conference.

[6] Braimah, N. (2013). Construction delay analysis techniques—A review. International Journal of Project Management, 31(5), 394–404. https://doi.org/10.1016/j.ijproman.2012.08.003

[7] Marzouk, M., & El-Rasas, T. (2014). Analyzing delay causes in Egyptian construction projects. Journal of Advanced Research, 5(1), 49–55. https://doi.org/10.1016/j.jare.2012.11.005

[8] Zack, J. G. (2001). Schedule delay analysis. Cost Engineering, 43(6), 13–17.

[9] Amorin, R., & de Oliveira, M. A. (2020). Application of Primavera P6 in Delay Analysis: A Case Study. Journal of Construction Engineering

and Project Management, 10(3), 27–34.

[10] Project Management Institute (PMI). (2017). A Guide to the Project Management Body of Knowledge (PMBOK® Guide) (6th ed.). Project Management Institute.

[11] Amoah, K. B. O., Okere, G., & Deshpande, A. (2024). Construction delay analysis: Causes, impacts, and mitigation strategies. *Journal of Civil Engineering Research, 14*(1), 1–9. academia.edu+10ascelibrary.com+10sciencedirect.com+10researchgate.net+1article.sapub.org+1

[12] Kowsalya, D., & Abdu Rahoof, B. (2023). Time delay analysis of construction projects: Review. *International Journal of Engineering Research & Technology, 12*(03), –. ijert.org

[13] Singh, G., & Singh, J. (2024). A case study of schedule delay analysis in building construction project. *African Journal of Biological Sciences, 6*(5), 9920–9936. researchgate.net

[14] Meta-analysis of critical causes of project delay using Spearman's correlation (2020). *Canadian Journal of Civil Engineering.* researchgate.net+15cdnsciencepub.com+15researchgate.net+15

[15] Akbulut, A., & Çalık, T. (2021). Delay analysis in construction project using Primavera & SPSS. *Dissertation.* researchgate.net+6sciencedirect.com+6researchgate.net+6

[16] Irjet Team (Date N/A). Schedule delay analysis in construction using Primavera P6. *IRJET.* irjet.net+2irjet.net+2ascelibrary.com+2

[17] MDPI Review (2021). An overarching review on delay analyses in construction projects. *Buildings, 11*(3), 109. linkedin.com+15mdpi.com+15researchgate.net+15

[18] Quollnet (2025). Delay analysis in construction: Methods, legal claims, EOT tools. *Online article.* quollnet.com

[19] PlanAcademy (2024). Project delay analysis: Best methods and limitations. *Online article.* planacademy.com

[20] ScienceDirect (2024). Delay analysis selection model for a construction project. *Journal article.* sciencedirect.com

[21] ASCE Journal of Legal Affairs (Year N/A). Delay analysis in construction contracts: Assessing claims and extensions. ascelibrary.com

[22] ResearchGate (200?) Daily windows delay analysis. *Conference paper.* researchgate.net+3researchgate.net+3academia.edu+3

[23] Academia.edu (2001). Construction delay analysis using daily windows technique. *Tech paper.* academia.edu

[24] SCImago (2022). Study the delays and conflicts for construction projects and their impact. *ScienceDirect article.* academia.edu+15sciencedirect.com+15mdpi.com+15

[25] IAARC (2010). Evaluation of delay analysis methodologies on lost productivity in construction. *Proceedings.* sciencedirect.com+3iaarc.org+3ascelibrary.com+3