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ESTABLISHING SCHEDULE QUALITY PARAMETERS FOR EFFECTIVE DELAY ANALYSIS IN CONSTRUCTION PROJECTS

Sneha Baskar[1], Murali Jagannathan[2], Dheeraj K Ubhayakar[3] and K. Hariharan[4]

ABSTRACT

The construction industry is vital to national development, yet it often faces inefficiencies due to time and cost overruns, largely stemming from a variety of factors. These delays lead to project disruptions, disputes, and claims. Various delay analysis methods—categorized as prospective and retrospective—are employed to manage and mitigate such delays. However, the success of these methods highly relies on the quality of the project schedule. While general schedule quality parameters exist, there has been limited focus on parameters specific to delay analysis. This study investigates preferred delay analysis approaches and identifies challenges in their application. A survey and focus group study involving real-time projects established key schedule quality parameters for delay analysis. These include: Sequencing of Activities, Inclusion of All Activities, Use of Lags, Use of Non-Finish-to-Start Relationships, Date Constraints, and Float Colour Coding. Among these, "Inclusion of All Activities" emerged as the most critical, while the "Use of Lags" was found to be the least sensitive parameter. By highlighting these parameters, the study provides valuable insights for practitioners to enhance schedule robustness. A well-structured schedule allows for accurate prospective delay analysis, helping mitigate potential time as well as cost overruns and improving overall project performance.

Keywords: *Delay Analysis; Prospective Delay Analysis; Schedule Quality Parameters; Sensitivity Analysis.*

1. INTRODUCTION

Frequent delays and cost overruns are prevalent challenges in the construction industry, often stemming from various factors that, if unaddressed, can escalate into significant project setbacks (Al-Momani, 2000). For instance, consider delays linked to alterations in design drawings during the construction phase (Bajjou & Chafi, 2020). There are two types of delay analysis: Retrospective and prospective (Bubshait & Cunningham, 1998). Retrospective delay analyses the root cause and ownership of delay at the end of the project completion (Doloi et al., 2012). Prospective delay analysis is performing delay analysis contemporaneously or predicting the delay before and mitigating it (Hossen et

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al., 2015). Irrespective of the approach (prospective or retrospective), a construction programme/schedule is a core requirement for delay analysis. Inadequate or inaccurate schedules impede the precise assessment of delays, underscoring the necessity for well-defined schedule quality parameters tailored to delay analysis. Yet, adherence to all these parameters can be challenging in practice. Effectively, this study addresses the research question: What are the schedule quality parameters to implement the industry preferred delay analysis, and how can they be prioritised?

2. LITERATURE REVIEW

2.1 SCHEDULE QUALITY AND DELAY ANALYSIS

A high-quality construction schedule is a crucial tool for effective delay analysis, providing a structured framework for tracking project progress and identifying deviations from the planned timeline (Hendradewa, 2019). It enables accurate delay assessments, ensuring that project managers can precisely pinpoint the causes and consequences of delays.

2.2 PARAMETERS TO DETERMINE THE SCHEDULE QUALITY

One of the fundamental schedule quality parameters is ensuring that all activities are captured in the schedule, providing a comprehensive breakdown of work packages, activity descriptions, and dependencies. Proper sequencing of activities and including the use of lags, leads, and logical constraints only in unavoidable circumstances ensures that the schedule reflects realistic project timelines (Marcinkowski & Krawczynska-Piechna, 2019). A well-structured schedule must also incorporate risk assessment measures, ensuring that potential disruptions are accounted for and mitigated effectively (Siddika & Lu, 2023). Real-time updates and periodic schedule reviews help maintain accuracy and adaptability in dynamic project environments. By defining and analyzing these key schedule quality parameters, construction projects can improve delay analysis, enhance project control, and support proactive risk management strategies. Establishing robust schedule quality parameters is critical to achieving efficient project execution and minimizing scheduling-related risk timelines (Marcinkowski & Krawczynska-Piechna, 2019). While there are many schedule quality guides available, like the Earned Value Management System (EVMS), Program Analysis Pamphlet (PAP) (Winter, 2009) and Planning and Scheduling Excellence Guide (Kavad et al., 2019), the parameters as per the (U.S. Government Accountability Office, 2015) were selected considering their agreement with standards like the Defence Contract Management Agency (DCMA) guidelines and their suitability for the assessment of construction project schedules (Srinath & Varghese, 2023). The differences between the retrospective and prospective delay analysis techniques are reviewed next.

3. RESEARCH GAP AND OBJECTIVES

Despite extensive research on delay analysis methodologies, a critical gap remains in the literature regarding the role of schedule quality in conducting reliable delay analysis. While the requirements for delay analysis may vary depending on the method chosen, the focus in this study is specifically on the most preferred delay analysis technique. Nevertheless, while numerous studies have examined both retrospective and prospective techniques (El-Sayegh, 2008), no research has specifically defined the schedule quality parameters necessary for conducting effective prospective delay analysis (Ajayi & Chinda, 2022) or retrospective delay analysis. Accordingly, the study's first objective is to determine which delay analysis industry professionals prefer (prospective or retrospective). The second objective is to arrive at schedule quality parameters for the most preferred delay analysis technique and conduct a sensitivity analysis to understand the most influential schedule quality parameters.

4. METHODOLOGY

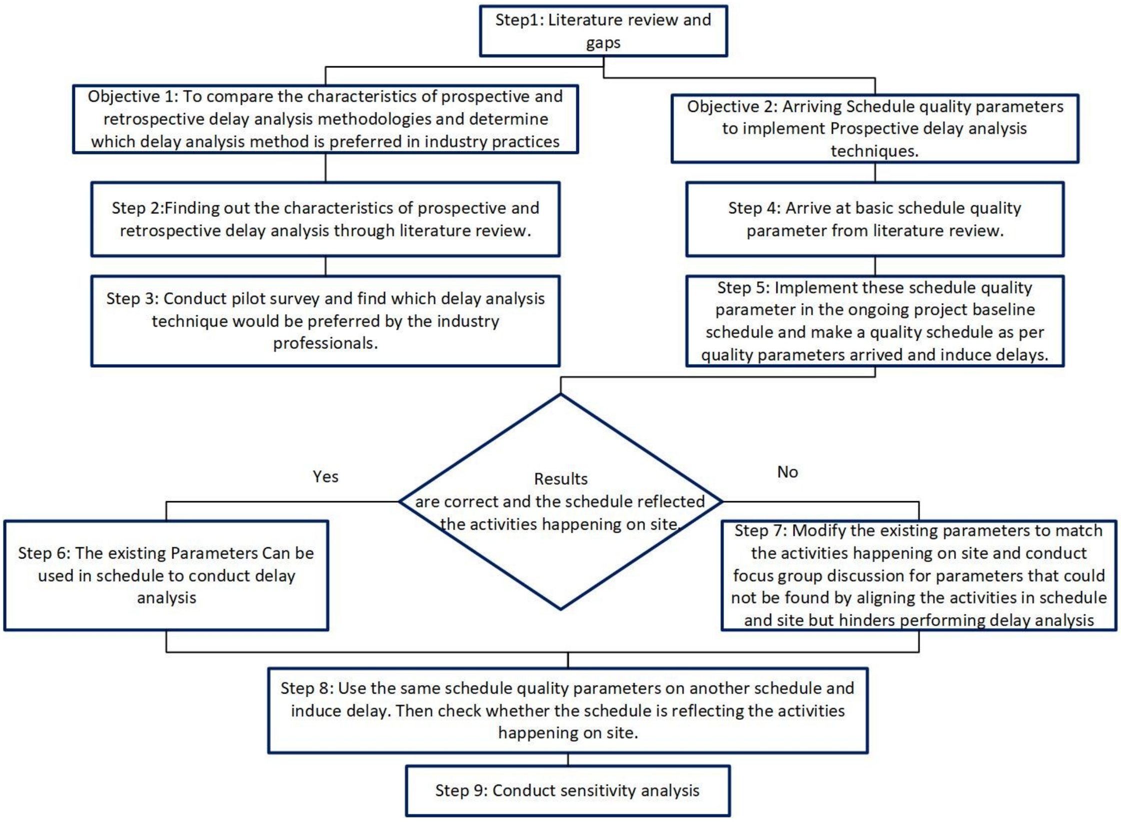

Figure 1: Methodology

As outlined in the methodology (Figure 1), a literature review (discussed earlier) was first conducted to identify the research gaps and assess the advantages and disadvantages of prospective and retrospective delay analysis techniques. However, the industry choice was not clear. Moreover, the link between a "quality" schedule and delay analysis had to be empirically established. Specifically, the absence of a "quality" schedule for successful delay analysis had to be verified through practitioners, especially the contractors who are often involved in the task of detailed schedule preparation. Therefore, a questionnaire survey form was developed. The survey form was used to collect primary data like working experience of the respondents, preferred delay analysis method, and reasons for delay analysis being a challenging task from industry professionals, including project managers, planners, and delay analysis experts, ensuring practical relevance. This primary data helps us understand which delay analysis is mostly preferred and why. And once the challenges while conducting delay analysis are known, it helps in the study to reduce those challenges. Of the 93 questionnaires distributed, 75 responses were received, yielding an 80% response rate. Respondents' experience levels were grouped in five-year intervals to study their influence on delay analysis practices. A Likert scale assessed the adoption of structured delay analysis methods, while a multiple-selection question identified reasons limiting the use of structured delay analysis techniques. The Likert scale responses were used to conduct a T-test to determine whether the mean significantly differs from the neutral value. In parallel, a project schedule was developed using Microsoft Project with established schedule quality parameters, and actual delays were introduced to evaluate their impact. Then the schedule with delay was compared with the actual site progress. However, the initial schedule failed to accurately mirror site progress, indicating gaps in existing parameters. To improve alignment, additional parameters were proposed and tested. A focus group comprising three professionals, each with over 15 years of experience in planning and contracts, evaluated the considered qualitative parameters. A revised schedule incorporating the modified parameters was tested on a different project. Iterative refinements were made until the schedule closely aligned with actual site progress, confirming the updated parameters' robustness. Sensitivity analysis was then used to assess each parameter's influence by intentionally degrading schedule quality and observing the resulting time shifts. More sensitive parameters led to larger deviations, highlighting their critical role. Subsequently, the schedule was improved in stages, beginning with the most sensitive parameters, to measure enhancement in accuracy. This structured approach provided insight into each parameter's contribution to reliable delay analysis and effective project control.

5. RESULTS

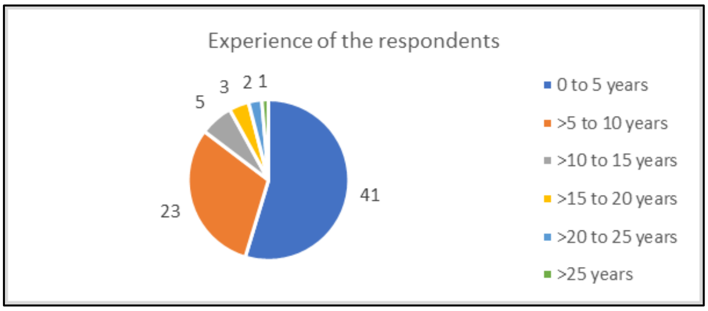

Figure 2: Experience of the respondents

It is evident from Figure 2 that most of the respondents have experience of 0 to 5 years, as the freshers are typically involved in initial planning. The next highest respondents, with 5 to 10 years of experience, were involved in delay analysis. The other questions asked to understand the delay analysis process among the industry professionals are tabulated in Table 1, with questions and the results of the T-test.

Table 1: T-test results

Statements	Null Hypothesis	Alternate Hypothesis	Mean Response	Is the p-value significant?	Result
Tools like Microsoft Project or Primavera are used for planning	The mean responses to Q1 are not significantly different from	Very frequently, MSP and Primavera are used for	2.533	Yes	Reject the null hypothesis and retain the

Statements	Null Hypothesis	Alternate Hypothesis	Mean Response	Is the p-value significant?	Result
project progress (Q1)	the neutral value	Project progress			alternative hypothesis
Schedules are used for monitoring and control (Q2).	The mean responses to Q2 are not significantly different from the neutral value	Very frequently, schedules are used to monitor and control	1.76	Yes	Same as above
Structured delay analysis technique is used to identify the impact of delays on the project completion (Q3)	The mean responses to Q3 are not significantly different from the neutral value	Very frequently, a structured delay analysis technique is used to identify the impact of the project	2.555	Yes	Same as above
Structured delay analysis technique (example: as-planned vs. as-built, time-slice analysis, etc.) helps to improve chances of success in delay-linked claims (like acceleration claims, disruption claims, etc) (Q4)	The mean responses to Q4 are not significantly different from the neutral value	It is fully agreed that structured delay analysis increases the success in delay-linked claims	1.453	Yes	Same as above
Structured Delay Analysis is a challenging task (Q5)	The mean responses to Q5 are not significantly different from the neutral value	It is fully agreed that delay analysis is a challenging task	1.653	Yes	Same as above
Mostly delay analysis method is prescribed in a contract document (Q6)	The mean responses to Q6 are not significantly different from the neutral value	Very frequently method of delay analysis is prescribed in the contract	2.708	No	Retain the null hypothesis

It is evident from Table 1 that the null hypothesis for most of the questions is retained, implying that structured analysis is important in effective claims management. However, structured delay analysis is a challenging task (Q5). The preference approach for the delay analysis (prospective) and the reasons why structured delay analysis is challenging are shown in Figures 3 and 4. The top reason for not adopting the structured delay analysis is “project schedules are not up to the mark”, which points to the schedule quality, establishing the relevance of the study and also justifying the need for the survey questionnaire and the subsequent analyses. More details are presented in the “Discussion” section.

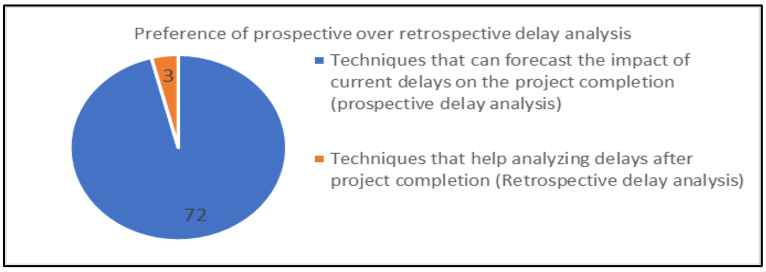

Figure 3: Graph showing preferences between prospective and retrospective delay analysis

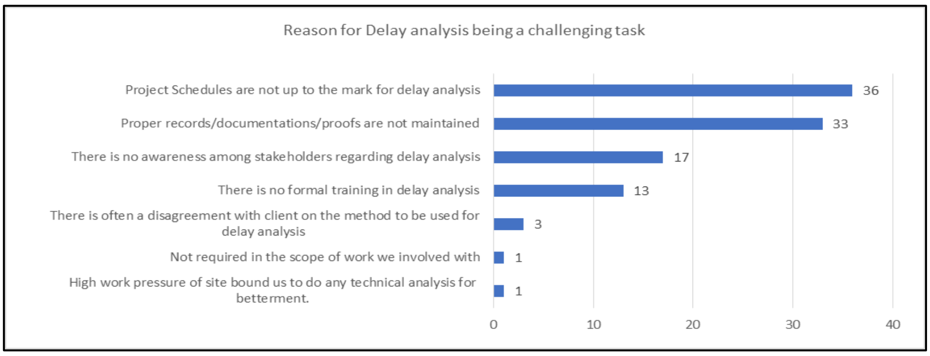

Figure 4: The reason for delay analysis being challenging

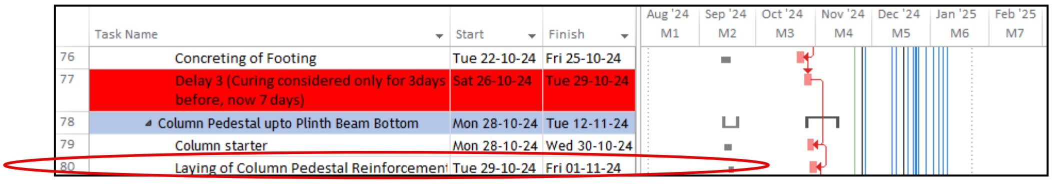

Figure 5: Schedule aligned with existing schedule quality parameters and induced delay events

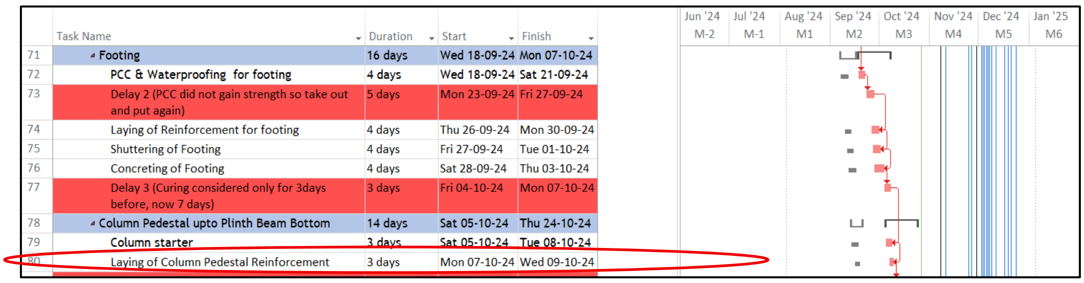

Figure 6: After inducing the delay events in the quality schedule, activity 80: Laying of column pedestal reinforcement starts on 07-10-24 and completes on 09-10-24

The schedule, refined following the existing schedule quality parameters, was updated to incorporate the identified delays. Delayed activities were visually distinguished in red, allowing for clear identification within the project timeline. Three distinct delay events were recorded and integrated into the schedule for further analysis. The scheduled start and completion dates for laying column pedestal reinforcement (Activity ID 80) were October 7, 2024, and October 9, 2024, respectively. However, based on actual site conditions, the activity commenced significantly later, on October 25, 2024. This discrepancy highlights a misalignment between the planned and actual project timelines, emphasizing the need for modified schedule quality parameters to ensure better synchronization between the schedule and on-site progress. When site activities are not carried out as per the schedule, a misalignment occurs between the planned schedule and actual site execution. This misalignment introduces an additional parameter: sequencing of activities. For instance, if the laying of plain cement concrete (PCC) had to be redone due to inadequate strength on the specified date, the procurement of materials had to be repeated. However, the successor activity for "Laying of PCC" was "Laying of reinforcement for footing," with no direct link to procurement. The absence of a field to track redoing as a delay resulted in inefficiencies. If an activity, "Testing of PCC," had been included and linked to "Procurement of Material," project tracking could have been more effective. This highlights the need for the parameter "Inclusion of all activities." The literature suggests that lags should be used only in unavoidable situations. However, in the Site 1 schedule, non-finish-start relationships were applied to activities such as column reinforcement, shuttering, and concreting. Since not all columns require full reinforcement before shuttering begins, a finish-to-finish relationship was used. During focus group discussions, industry professionals found non-finish-start relationships challenging to interpret. The site could be divided into sectors to address this, with activities named accordingly, such as "Sector 1 Column Concreting." This led to modifying the parameter to "Use of non-finish-start relationships. “The use of non-finish-start relationships inherently includes lags. To eliminate this dependency, the parameter "Use of lags" was modified from "Usage during unavoidable situations" to "No usage" for delay analysis. Similarly, the parameter "Date constraints" did not allow for a natural schedule flow. When delays were introduced, activities did not shift accordingly. Therefore, this parameter was also modified from "Usage during unavoidable situations" to "No usage. “Additionally, focus group discussions emphasized the importance of visualizing float ownership within the schedule. To enhance this, colour coding was introduced. As a result, the parameters "Sequencing of activities," "Inclusion of all activities," and "Float colour coding" were added, while "Use of lags," "Use of non-finish-start relationships," and "Date constraints" were modified.

Table 2: Identified schedule quality parameters

Parameter	Refinement for Improved Delay Analysis
Sequencing of Activities	All activities must have proper sequencing with clearly defined predecessors and successors, ensuring alignment with actual site progress.
Inclusion of All Activities	Every activity, including minor tasks like curing, must be included to represent the construction process comprehensively.
Use of Lags	Lags should be avoided; a dedicated activity name and duration should be assigned to maintain clarity in delay analysis.
Use of Non-Finish-Start Relationships	This relationship should not be avoided, as it complicates progress monitoring and delay tracking.

Parameter	Refinement for Improved Delay Analysis
Date Constraints	It should be completely removed to maintain transparency and ensure accurate representation of project delays.
Float Colour Coding	Float ownership should be clearly defined using distinct representations, such as colour coding, to improve accountability and tracking of delays.

To check the robustness of the arrived parameters, the modified schedule quality parameters were applied to a different project site, resulting in a schedule that accurately reflected the on-site activities. Once the as-planned schedule, following all the schedule quality parameters with delay induced, reflected the site progress for other projects as well, the arrived parameters were concluded to be a robust list of parameters. As there were many parameters, a sensitivity analysis was conducted. Plots were generated by plotting the number of days of variance on one axis against the percentage increase in non-compliance on the other, providing a visual representation of the relationship between schedule deviations and adherence to quality parameters. The initial 0.11% arrived when non-adherence was applied to one activity.

Table 3: Sensitivity analysis

Description (Independent Variable)	Count of activities in the schedule with description parameters	Total activities in the schedule	[(Count of activities in the schedule with description parameters/ Total activities in the schedule) x 100] = A	Difference between delay-induced and impact	[(Difference between delay induced and impact / Duration of project in days) x 100] = B	B/A	Ranking on the basis of B/A value
When "no lags" was not followed	1	914	0.11%	5	1.82%	16.68	1
When "no leads" was not followed	1	914	0.11%	5	1.82%	16.68	1
When "no dangling activity" was not followed	1	914	0.11%	13	4.74%	43.36	3
When "no linking to summary activity" was not followed	1	914	0.11%	9	3.28%	30.02	2

Description (Independent Variable)	Count of activities in the schedule with description parameters	Total activities in the schedule	[(Count of activities in the schedule with description parameters/ Total activities in the schedule) x 100] = A	Difference between delay-induced and impact	[(Difference between delay induced and impact / Duration of project in days) x 100] = B	B/A	Ranking on the basis of B/A value
When "no date constraints" was not followed	1	914	0.11%	15	5.47%	50.04	4
When "well sequencing of activities " was not followed	1	914	0.11%	18	6.57%	60.04	5
When "inclusion of all basic activities" was not followed	1	914	0.11%	25	9.12%	83.39	6

The analysis revealed the sensitivity of schedule quality parameters in ascending order, from least to most sensitive, as follows: Use of lags and Use of leads, Summary activities, Dangling activities, Proper sequencing of activities, Use of date constraints, and Inclusion of all basic activities. This same sensitivity analysis (considering the schedule parameters as independent variables and the delay impact as the dependent variable) was performed for seven projects with the same characteristics, revealing the same trend in the sensitivity of the parameters. To further validate these findings, a poorly structured schedule was selected and systematically refined, starting with the most sensitive parameter and progressing toward the least sensitive, ensuring a structured approach to improving schedule accuracy and alignment with on-site activities.

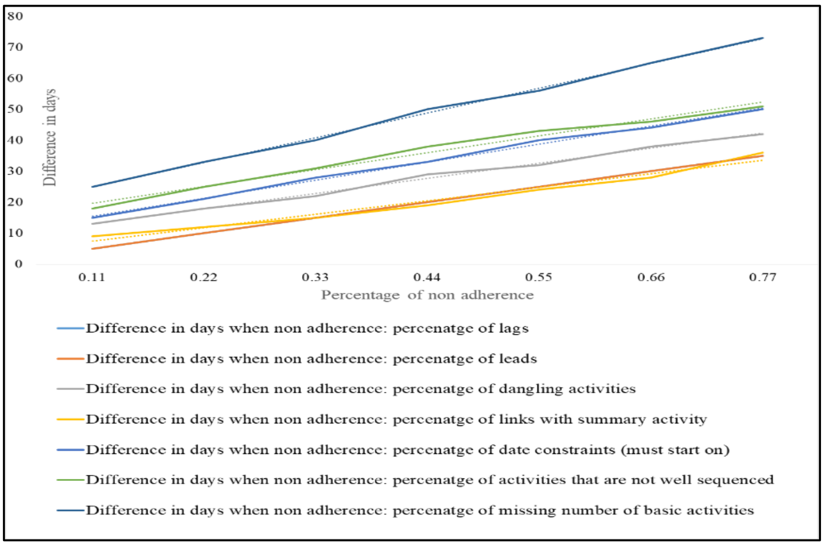

Figure 7: Plots showing sensitivity and linearity trend

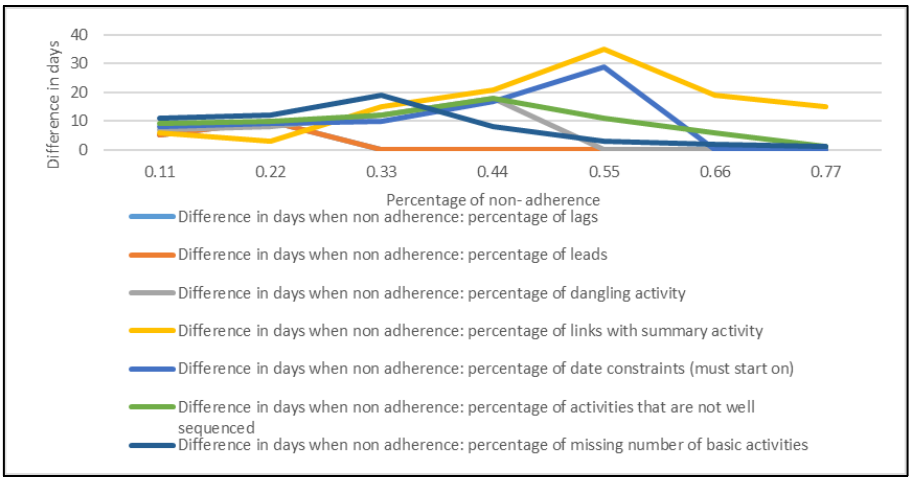

Figure 8: Plots showing a non-linear trend

6. DISCUSSION

As presented in Table 1, Microsoft Project and Primavera are among the most frequently used tools for tracking project progress. The data from Table 1 further reveals a consensus that delay analysis significantly improves the success rate of delay-related claims. However, practitioners also recognize that delay analysis remains a complex and challenging task. Notably, the specific delay analysis method is rarely stipulated in contractual documents. Although scheduling tools are widely adopted, effective delay analysis often proves difficult due to discrepancies between baseline schedules and actual site progress. Both prospective and retrospective delay analysis methods are available; however, survey results (Figure 3) indicate a preference for prospective techniques. These methods offer the advantage of forecasting delays, thereby facilitating the timely implementation of corrective measures. As illustrated in Figure 4, major delay analysis challenges include the substandard schedule quality and inadequate record-keeping, documentation, and proof. Addressing the issue of poor documentation, prospective delay analysis emerges as a viable solution, as it is performed contemporaneously and relies less on historical data. Nevertheless, enhancing the accuracy of schedules remains essential, particularly for effective delay analysis. While Table 1 outlines fundamental schedule quality parameters, initial attempts to align schedules with actual site progress using these parameters proved insufficient, as reflected in Figures 5 and 6. According to the literature, there were 23 schedule quality parameters, and through this study, specifically focusing on the quality parameters for delay analysis, three were revised and three were added, thereby developing schedule quality parameters for reliable prospective delay analysis. However, due to the extensive nature of these parameters and their potential to reduce scheduling flexibility, it may not be feasible for planning professionals to implement all of them in practice. Therefore, a sensitivity analysis was conducted (Table 3) to identify the most critical parameters, allowing planners to focus on those with the greatest influence on schedule reliability when full compliance is not feasible. The sensitivity analysis results (Figure 7) revealed a possible linear relationship between non-compliance with schedule quality parameters and the discrepancy (in days) between delay duration and actual delay impact. However, this linearity cannot be generalised as it is observed under certain specific conditions owing to the scheduling logic and treatment of delays. For example, an increase in the percentage of lags and leads showed a linear effect due to the uniform float consumption across an increasing number of activities, which may not always be the case. Further, focus group discussions highlighted that using lags and leads introduced errors. Leads, in particular, were found to be confusing, especially in finish-start relationships, because they could result in the premature start of successor activities before the completion of their predecessors. When delays occurred, these premature starts distorted the actual project timeline. The presence of lags, leads, dangling activities, and date constraints contributed to a linear impact pattern because the activity configurations ensured that impacting activities (on the non-critical path with uniform float) preceded impacted activities (on the critical path). Similarly, linking summary activities added complexity by introducing alternate paths, thereby influencing the impact of delay. Poor sequencing and improper inclusion of activities also exhibited linear behaviour due to consistent activity configurations across schedules, which may not always be the case. In summary, the linearity was caused by a) the presence of uniform float in similar activity, b) impacting and impacted activities are present in the same path, c) same date constraint (as soon as possible) in all activities and d) the same relationship (finish-start) in all activities e) the same duration of delay impacted and f) the induced delays not exceeding the float available in the non-critical activity. Therefore, the linearity cannot be generalised and is limited to a specific case. When the above conditions leading to linearity were not followed, the trend moves towards non-linearity as shown in Figure 8. The variation in delay impact associated with date constraints and dangling activities stemmed from the creation of additional dependency paths. These findings collectively underscore that each increment in schedule non-compliance proportionally degrades schedule reliability, reaffirming the importance of adhering to established schedule quality parameters. When poorly structured schedules were systematically corrected, the resulting improvement in schedule accuracy was observed. The rate of improvement varied across parameters, indicating that some factors had a greater effect on enhancing schedule quality than others. The difference between delay duration and delay impact, measured in days, effectively indicates each parameter's sensitivity. Among the parameters analyzed in the schedules considered in the study, "Inclusion of all activities" was found to be the most sensitive, while "Percentage of lags" was the least sensitive. This trend was consistently observed across all seven case studies, suggesting that the results are reasonably generalizable. However, it is crucial to note that the excluded activities in each case were uniformly assigned a duration of 15 days;

different durations might alter the sensitivity ranking. Additionally, the "must start on" constraint used in the analysis is hard, which magnified its adverse impact. A different type of constraint could yield different sensitivity outcomes. The linearity observed was also a product of how activities were selected and hence cannot be generalised; alternative configurations could result in non-linear relationships. By focusing on the most influential parameters, planners can enhance schedule accuracy and ensure that project timelines reflect actual construction progress more closely.

7. CONCLUSION

This study highlights critical schedule quality parameters for accurate prospective delay analysis and evaluates their sensitivity. Prioritizing sensitive parameters enhances schedule reliability, enabling timely mitigation. Despite challenges in full compliance, standardizing scheduling improves project control, reduces disputes and overruns, and supports effective delay analysis in construction project management.

8. LIMITATIONS AND FUTURE SCOPE

This research focused on a water supply and a hostel construction project, limiting its generalizability. Future studies should incorporate these project types to validate and refine schedule quality parameters for wider delay analysis relevance.

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