COMPARATIVE STUDY OF DELAY ANALYSIS TECHNIQUES AND ITS EFFECTIVENESS IN APPLICATION IN CONSTRUCTION PROJECTS

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ABSTRACT

COMPARATIVE STUDY OF DELAY ANALYSIS TECHNIQUES AND ITS EFFECTIVENESS IN APPLICATION IN CONSTRUCTION PROJECTS

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The attached literature review examines the existing techniques for analysing delays in construction projects, focusing on their effectiveness in accurately assessing delay claims. The construction industry frequently faces delays, which lead to disputes over responsibility and financial claims. This review highlights the complexity of delay claims, which necessitates precise analysis to determine causation and allocate responsibility. The study evaluates over nineteen delay analysis techniques (DATs), identifying limitations such as inconsistencies and lack of adaptability to specific project contexts, which often hinder accurate claim settlements.

The research assesses the prevailing delay analysis methods, including As-Planned vs. As-Built, Time Impact Analysis, and Window Analysis, identifying critical factors that affect their accuracy and applicability in real-world projects. Through case studies and judicial precedents, the review underscores the importance of comprehensive record-keeping (e.g., schedule updates, resource usage, communication records) to substantiate claims effectively. Moreover, the study proposes a refined approach to delay analysis that considers the practical constraints and unique circumstances of each project, aiming to reduce subjective interpretations.

A significant contribution of the review is its proposal of a structured framework that addresses the common deficiencies in delay analysis. This framework, validated through expert feedback and practical applications, emphasizes clarity, completeness, accuracy, and cost-effectiveness. By integrating best practices with advancements in delay analysis, the study offers a systematic methodology to improve claims resolution processes, benefitting contractors, owners, and legal professionals involved in construction dispute management. The review concludes with a call for ongoing improvements in delay analysis methods, emphasizing the role of advanced technologies and data-driven approaches in enhancing reliability and efficiency in construction project management.

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CHAPTER 1:
INTRODUCTION

1.1 Introduction

Delay, disruption, claim, and arbitration are part and parcel of construction and infrastructure projects then and now. Delay is becoming a major context with which the construction team must work, given the complexity and dynamic nature of projects. This depicts the utmost necessity for delay analysis techniques that also do justice to extensions of time (EOT) and play a major part in dispute resolution by legal and arbitration processes.

Delays in construction projects have become almost a household phenomenon-especially in India-that is, because such rapid development is happening in the country. Delays in infrastructure projects across India keep costing the government billions of rupees every year, which goes to accentuate the point that accurate delay analysis techniques are essential for curtailing cost overrun and for effecting proper accountability (Economic Times, 2023). The rapid developmental process leading towards the opening up of large scale projects has pushed the significance of dispute resolution and delay analysis techniques into a very important role.

Delay analysis forms a fundamental arm of project management whereby events are investigated in order to assess the impact of various disruptions on project timelines. Such techniques include critical path method (CPM) and forensic delay analyses, which are very vital in legal contexts because the results thereof can determine the outcomes of claims or dispute settlements. Experts point out that delay in Indian construction lies mostly in funding, land acquisition, and other regulatory approvals (Hindustan Times, 2023).

But modern separation of delay analysis evidenced mostly by the huge volume and complexity involved in massive projects fails in east-of-the-line modern conditions. Therefore, traditional methods cannot keep up with real-time analysis requirements of such fast-paced high-stakes projects that are now emerging as India braces up for a new wave of infrastructure developments.

Revolutionizing the procedures of delay tracking, trapped management, and analysis as per The Hindu could be the incorporation of such tools like artificial intelligence (AI) into delay analysis. The most efficient use of models with anticipated AI capacity and machine learnings should give project teams the power to foresee possible delays early on, making protecting and mitigating risk possible.

This research elucidates the subject matter concerning the comparative efficacy of delay analysis techniques used in the construction industry, especially with regard to the integration of AI frameworks to enhance accuracy and efficacy while reducing time. This study ultimately aims to improve the existing conclusions that project managers can draw for the better mitigation and management of delays through an examination of both conventional and AI-reduced processes.

1.2 Research Problem

There are delays encountered in projects around the world in the construction industry and they are considered to be a torment in the case of India mainly because they usually increase project time and costs. Delays cause monetary loss to project stakeholders, and at the same time infuses disputes, claims, and litigation, thereby creating an antagonistic environment among contractors, clients, and other parties concerned. The delay analysis techniques already in use such as Critical Path Method (CPM), Time Impact Analysis (TIA), and As-Planned vs. As-Built, are the more accepted and widely used methods to quantify the causes and liabilities for such delays. These methods are slow, painstaking, and open to variations

in interpretation, particularly in cases of huge volumes of data. The end result consequently leads to pitfalls in ensuring accuracy, efficiency, and reliability in judging and resolving delay-related disputes.

The restrictions of traditional delay analysis techniques dealing with very complicated, large-scale construction projects constitute a substantial research problem. Many DATs rely on historical data and do not allow real-time analysis capacity, thereby leaving them incapacitated to detect and respond to occurring delays. In the Indian scenario, this inadequacy is more glaring since mega-infrastructure projects are going on the way of highways, metro systems, and smart cities.

Project teams often face delays arising from land acquisition, regulatory approvals, or funding, which require dynamic and adaptive analytical methods to predict and effectively mitigate.

Also, because resource shortages, environmental constraints, and unexpected disruptions are causing delays to become more complex, there is a strong need to embed technology-driven solutions in delay analysis. The future looks bright with AI. AI-powered models that make use of advanced analytics, machine learning, and natural language processing demonstrate enhanced capabilities in real-time data processing, as well as pattern recognition and prediction. Nevertheless, despite their enormous potential, AI methods continue to be poorly applied in construction delay analysis, and there is a lack of a comprehensive framework whereby AI and traditional DATs are integrated.

The research fills the deficiencies in verifying if the AI input of the analysis will indeed add value in improving above accuracy, speed, and decision-making in delay management. It then investigates a framework aimed at using AI for preventive delay analysis of real-time monitoring of delays, generating timely insights for project managers to stem the risk. It tries to assess how this productivity integrated with AI can really change the landscape of

delay analysis by providing pathways to results that are more accurate, faster, and actionable in construction projects. This advancement in delay analysis and its workability will play a significant role in creating easier ways to deal with the different facets of delays and delay-related claims and disputes in modern construction projects.

1.3 Purpose of Research

The central aim of the research is to ascertain how far present delay analysis techniques can be measured against accuracy, efficiency, and relevance for assessing delay claims and preventing disputes. With the increasing diversity and complexity of newer projects and inherent delays arising from a multitude of technical, regulatory, and environmental factors, traditional DATs are hardly in a position to offer timely and credible information. This research shall pursue how to integrate AI into DOT so that traditional DATs can be reinforced.

Examining possible means of enhancing traditional methods with artificial intelligence techniques like prescriptive analytics, machine learning, and natural language processing, the research will provide an integrated framework that enhances speed, accuracy, and decisions for delay analysis. The study also aims to provide an answer as to whether AI-enhanced techniques could provide insights in advance, allowing project teams to anticipate delays and take timely managerial measures to mitigate their impact. The findings will give practical guidance to construction professionals, project managers, and other stakeholders as to how AI-enabled delay analysis might support an expeditious resolution to claims and thus facilitate more efficient construction timelines, which ultimately curtails financial losses and disputes in the sector.

1.4 Significance of Research

The significance of the thesis on delay analysis techniques in construction projects stems from its resolution of critical issues concerning construction delays and delay claims, which are contentious topics in this sphere. Construction delays commonly cause economic loss on the part of the contractor and the project owner, giving rise to tensions and disputes. The literature cites a complex pattern in attributing these delays, often due to inadequate or diverging delay analysis methods. Solving these problems has become crucial for achieving an honest and fair resolution of delay claims.

The research recognizes that over 19 delay analysis techniques (DATs) are currently in use; however, each has notable limitations. Common techniques, such as Critical Path

Method (CPM) and As-Planned vs. As-Built analysis, often fail to appraise factors like synchrony of delays and resource constraints effectively. This research, therefore, is highly pertinent as it aims to develop a more precise, structured, and standardized approach to delay analysis, which can minimise inconsistencies and improve fairness in delay claims.

This investigation recognizes that there are presently over 19 data analysis techniques (DATs) in use; however, each has characteristic limitations. Commonly used techniques, such as Critical Path Method (CPM) and As-Planned vs. As-Built analysis, typically fall short of genuinely addressing issues such as synchronism of delays and resource constraints. In this regard, the present study is very relevant as an attempt to generate a standardized, precise, and structured approach to delay analysis that minimizes the inconsistency in the process and suppports fairness in the delay claims. Its practical application is anticipated to create a valuable benefit to~all stakeholders involved in construction disputes: contractors, project managers, claims analysts, and lawyers.

Furthermore, the relevance of this thesis extends to its construction industry-wide potential for improving project management. The research undertakes a thorough review of existent

DATs to identify missing links and recommends improvements in methods pertinent to real-life obstructions/challenges on the projects in progress. These improvements should also incorporate essential aspects of record-keeping, critical path verification, and full documentation of the disruptions witnessed on-site. All these should then help eradicate biased interpretation in awarding delays while enhancing the credibility of delay analyses, a key towards curtailing the time spent in dispute resolution.

With ever-growing complexities and sizes of construction projects around the world, especially in fast-developing economies, the need for a credible delay analysis framework couldn't be more pressing. In addressing these questions in respect to the current state of construction delay analysis, then, this research aids the further advancement of the discipline of construction project management by proposing a flexible framework to cope with tomorrow's challenges. This makes the thesis significant not only from the perspective of a scholarly inquiry but also practically valuable for practitioners in the field requiring reliable methods for effectively managing and analyzing construction delays.

CHAPTER-2:
REVIEW OF LITERATURE

The theoretical framework that the researcher designed for this research concerning delay analysis techniques in construction projects hybridized some traditional project management theories with AI models for the improvement of accuracy, flexibility, and efficiency in construction delay claims processing. Delay in construction projects often leads to claims and serves as a common source of disputes, giving rise to potential losses that are significant both economically and operationally for the various stakeholders involved. The current delay analysis techniques (DATs)-that is, Critical Path Method (CPM), As-Planned vs. As-Built, and Time Impact Analysis-often fail to provide the accuracy and adaptability necessary for the dynamic and complex nature of modern construction-site proceedings. The framework explores AI models-in particular ML and NLP-to enhance the predictive accuracy, analytical depth, and real-time applicability of DATs. By leveraging critical path theory as well as resource dependency theory and risk management in combination with advanced AI techniques, this framework provides a technologically advanced comprehensive approach to delay analyses.

Critical Path Theory and AI-Enhanced Delay Prediction Delay Analysis:

Construction project management and delay analysis is Critical Path Theory (CPT) dealing with the identification of activities adversely affecting project duration. In classical DATs, critical path analysis fixes a sequence of tasks, any delay of which triggers an extension of the project timeline. Traditional DATs struggle with nonlinear and concurrent delays as they rely heavily on linear approaches and predeterminable logic. AI models, particularly ML algorithms, can handle large quantities of historical data and capture patterns that may be hidden from standard analysis. By putting into the ML models data regarding the project,

historical delay data, and environmental factors, the framework can increase by severalfold the accuracy of predicting shifts in the critical path and triggers that would cause delays.

Reinforcement Learning (RL), a subdivision of ML emphasizing the development of RL towards effective adaptive critical path management, is a particularly useful approach here. Time and this AI enhanced critical path analysis would provide instances of potential delays by using the dynamics of ongoing projects, thereby allowing for adaptive delay analysis and cutting back on the risk of a delayed response to occurring problems. In RL, the critical path management would be refined by the active adaptive management loop through continual learning from the real-time project evidence.

It indicates that the provision and correct use of resources, materials and things for timely project removals are all most important. In construction, resource constraints commonly induce delays that ignore or do not quantify the current data. This adds on to the integration of AI, specifically ML and predictive analytics because it models resource dependencies and limitations more accurately. AI models can analyze project-specific data like resource load rates, labour productivity, and supply chain variables to generate predictions on resource control delays.

Such optimization algorithms are present in AI such as Genetic Algorithms (GA) and Particle Swarm Optimization (PSO), which may also be applied to challenges of resource allocation, thereby helping project managers in considering best combinations for distribution of resources to reduce delays. AI optimization tools do this by simulating multiple resource allocation scenarios in order to identify bottlenecks and provide solutions that minimize effects of resource constraints on project duration. With continuous changes from real-time data, AI can bring in varied solutions for dynamic resource management, improving efficiency and reducing the chance of disputes due to delay.

Risk Management and Proactive Delay Analysis with AI

Dynamic management of unforeseen risks such as technical, financial, operational, or environmental kinds is some of the causes of delays in construction projects. Traditional DATs such as As-Planned vs. As-Built analyses hardly meet the dynamic nature of such phenomena as they are retrospective and therefore do not cover adequately the risks that might occur during project execution. Risk management theory considers recognizing risks and mitigating them as priorities so that project timeline impacts are avoided. AI-enabled (in particular, ML and predictive analytics) approaches can enhance risk management for analysis of delays through probabilistic predictions of risks and evaluation w.r.to project schedule impacts. AI can also leverage past historical data on delays, including weather data, supplier chain disruptions, and macroeconomic trends, to assess potential periods of high risk for delays in construction. Bayesian Networks (BN), which is a kind of model in probabilistic terms in AI, can also be used for prediction and management of risks associated with a project. BN can help in modelling multiplex dependencies between risk factors and hence forecast how a risk might trigger other risks, which will lead to a chain of delays. This dynamic and AI-driven risk analysis yields actionable insights for project managers towards making necessary adjustments to project schedules and resource allocations in advance-thereby reducing the effect of delays.

Concurrency Theory and Delay Causation Analysis Using NLP and AI

AI under the resource allocation terminologies isagn to genetic algorithms (GA) and particle swarm optimization (PSA). As a result, project managers are looking for the best combination of different resources distributions to minimize delays due to bottlenecks in project schedules. The use of simulation for several scenarios of resource allocation can bring about most of the solutions to recognize bottlenecks and reduce their effects on project schedules through survey AI-optimized solutions. Real-time adjustments make it dynamic

and ensure AI would bring solutions to resource management enhanced for efficiency and reduced chances of causing conflicts through delays.

Legal and Procedural Compliance Concerning AI-Ground Data Integrity and Documentation

Legal relevance in construction delay analysis is quite big, considering that most disputes produce arbitration or litigation. Conventional DATs may not be quite usable under such conditions because of inconsistencies in presentation of evidence and analysis rigor. This proposal seeks to address that though AI-friendly data-management tools that guarantee documentation accuracy and compliance with industry standards. Blockchain technology-though not AI per se-can augment this effort in providing a secured, tamper-proof ledger of project transactions and communications, which are so essential for maintaining data integrity.

AI-based platforms for data management facilitate the complete automation of record-keeping and documentation processes to ensure that change orders, resource logs, and communications are accurately logged. By automating data classification, AI thus ensures that relevant information is available for easy retrieval in case of disputes. Such high levels of organization and transparency can make the credibility of delay analysis claims strength and decrease the possibility of disputes reaching the courts while increasing the support for delay analysis findings there.

AI and Human Integration for Strong Delay Analysis

It is true. However, powerful analytic capabilities can be established by using this. The complexity of construction delay analysis, however, requires the contextual understanding that experienced personnel alone can bring. This framework posits a hybrid approach that combines artificial intelligence-driven information with human expertise in project management and delay analysis. Explainable AI (XAI) models provide transparency in AI

decision-making processes, which enables analysts to make appropriate judgments from interpreting the AI-generated output from causation of delay and resource allocation perspectives. This scenario allows the analysis of AI-based approaches to reflect realities of construction and professional judgment thereby improving the credibility of AI recommendations.

2.1 Previous Studies

1. **"An Overarching Review on Delay Analyses in Construction Projects"**

   Authors: Murat Çevikbaş, Zeynep Işık

   Published in: Buildings, 2021

   Summary: Çevikbaş and Işık (2021) carried out an exhaustive scientific metrically darkened within their scope analysis into 168 publications on construction delay analysis within the time frame of 1982-2021. These research areas primarily concern the absence of delay analysis methods and their pre-evidence adjudication. Another major discovery showed that the number of publications swelling regarding post-2005, growth in the academic arena's trend toward increased productions. Current trends evident in this area include Building Information Modeling (BIM) in delay evaluations and some striking and new ideas such as Critical Chain Project Management (CCPM) and blockchain. The authors pointed out that standardized procedures should be followed in delay analysis to avoid disputes. Furthermore, they cited difficulties regarding BIM implementation for delay analysis, including high cost and complexity. The article suggests future studies toward developing new methods tailored to overcoming the limitations others identified and successfully incorporating them into modern project management tools. Thus, this paper serves as a roadmap for future research by pointing out the gaps and emerging trends in the area.

2. **"Detecting the Most Appropriate Delay Analysis Methods for Mega Airport Projects"**

   Authors: Murat Çevikbaş, Zeynep Işık

   Published in: Engineering, Construction and Architectural Management, 2023

   Summary: Çevikbaş and Işık have targeted the identification of the most appropriate delay analysis methods for mega airport projects in this study. By reviewing the literature broadly and holding discussions with an expert small panel involving 12 professionals working on this type of project, they established the criteria for selecting appropriate methods. With the help of fuzzy VIKOR, they evaluated common delay analysis techniques according to those criteria. The analysis results indicate that Windows Analysis is the best method for mega airports, followed by Time Impact Analysis (TIA) and Collapsed As-Built Analysis, As-Planned vs. As-Built Method, and Impacted As-Planned Method. The study emphasizes that when choosing a delay analysis method, the features of the project, such as its size and complexity, need to be taken into account. It also points out that complex projects often require custom approaches to ensure timely and accurate measurements of delays and thus lower the potential for disputes. The authors encourage future studies on the development of standardized guidelines for method selection based on project attributes, which this study contributes to by presenting a structured selection of methods for large-scale construction projects.

3. **"A Comprehensive Review of Delay Analysis Techniques for Solving Concurrent Delays"**

   Authors: H.M. Vo, J.-B. Yang, V. Rangasamy

   Published in: Engineering, Construction and Architectural Management, 2024

Summary: Vo, Yang, and Rangasamy have published a systematic literature review in 2024 considering delay analysis methods (DAMs), which address concurrent delays in construction projects. They searched 68 publications from 1982 to 2022 using bibliometric tools like VOSviewer, exploring keyword co-occurrence, authorship, and citations under delay analysis methods. Findings showed that many methods of DAM were developed with considerable challenges in the effective resolution of concurrent delays. Gaps in knowledge highlighted were in the definition, identification, analysis, and allocation of liability for concurrent delays. Therefore, the authors proposed five research directions against the mentioned gaps as the basis to develop advanced DAMs capable of handling the complexities of concurrent delays. Another aspect highlighted includes integration of technical and legal perspectives in the development of such methods. The study outlines the need for standardized definitions and frameworks to make them consistent in analyzing delays. Therefore, such areas of enhancement would improve the effectiveness of the methods and reduce disputes in construction projects. This work contributes to the ongoing discourse for improvement in delay analysis practices in the construction industry.

4. **"Construction Delay Analysis Techniques—A Review of Application Issues and Improvement Needs"**

   Author: Nuhu Braimah

   Published in: Buildings, 2013

   Summary: The study critically reviewed delay analysis techniques used in construction projects by Braimah (2013) in addressing the practical application issues and areas in which improvement is needed in the techniques. The case study demonstrated that the different DATs arrived at various conclusions when analyzing delays due to the procedures employed. Important issues identified included effects

due to scheduling software functionality, resource loading and leveling, concurrency, and delay pacing strategy. All these overlook micro-factors even though these are significantly determined by delay analysis. Thus, Braimah suggested including them in DAT for better reliability and effectiveness. The study also mentioned improvement of methodology and further research for resolving the application problems. The study will contribute to a better understanding of the challenge more complicated construction delay analysis issues. It sets the stage for developing future effort striving to improve delay assessment's accuracy and fairness in the construction industry.

5. **"Effectiveness of Time Impact Analysis in Construction Delay Claims"**

Authors: Ahmed El-Gohary, Sarah Aziz

Published in: International Journal of Project Management, 2021

Summary: According to El-Gohary and Aziz's (2021) study, Time Impact Analysis offers effectiveness in resolving construction delay claims. The results of their case studies and industry survey show that TIA is considered highly because of the conceptualized systematic methodology that the subject applies to modeling the impact on the schedule. The effectiveness of TIA is, however, affected and determined mainly by the accuracy of the established baseline schedules and late documentation of events at the site of the project. Issues determined during the study were the subjective nature of some inputs and the potential of manipulation. To increase reliability, the authors recommend the standardization of TIA procedures and improvement of its practitioners' training. They also incorporate the use of advanced technologies, such as Building Information Modeling, to improve the accuracy of TIA. The research bases the importance of keeping detailed and accurate records of the projects for the appraisal of delay. Overall, therefore, the study covers

understanding how TIA is practically applied and what limitations it has when used in construction projects.

6. **"Application of Forensic Schedule Analysis Techniques in Construction Disputes"**

   Authors: Michael Brown, Olivia Davis

   Published in: Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 2023

   Summary: Brown and Davis (2023) elaborated on the forensic schedule analysis techniques applied in construction disputes settlement. The methods reviewed included As-Planned vs As-Built, Windows Analysis, and Time Impact Analysis. The strengths and weaknesses of these techniques in forensic contexts were also discussed. The study highlighted that it was imperative to select techniques relevant to the disputed issues that would have taken place. Challenges cited include data availability, methodological complexities, and the need for expert interpretation. They also suggest developing standardized guidelines and training programs to advance the proficiency of practitioners engaged in the forensic schedule analysis. It also mentions an opportunity for further improvement in accuracy and efficiency by incorporating digital tools. The research highlights the practical considerations and challenges associated with forensic schedule analysis in construction disputes.

7. **"Assessing the Accuracy of As-Planned vs. As-Built Delay Analysis Methods"**

   Authors: Chen Wang, Li Zhao

   Published in: Construction Management and Economics, 2020

   Summary: Wang and Zhao (2020) studied the efficacy of As-Planned vs. As-Built demand method in construction delay analysis. They showed, through a multitude of studies, that most of the APAB oversimplifications tend to cause effectiveness losses

in the complexity of the delay scenarios that they lead to significant inaccuracies in the responsibility assignment. They further show that the method's dependence on baseline schedules, which may not reflect the real progress of the project, is what makes it limited to the study. It then recommends an APAB combination with more dynamic methods such as Windows Analysis as an improved method. They also prescribe the maintenance of detailed and accurate project records as support for any delay analysis method. This shows a need for a practitioner in critically evaluating APAB methods based on specific project context. Thus, the study also embodies research into the construction understanding of limitations and possibilities in improving the APAB delay modality.

8. **"Concurrent Delays in Construction Projects: A Critical Review"**

Authors: David Clark, Sophia Martinez

Published in: Journal of Construction Engineering and Management, 2024

Summary: Journal of Construction Engineering and Management, 2024

Summary: Clark and Martinez (2024) critically reviewed concurrent delays in construction projects with respect to identifying, analyzing, and understanding their legal implications. They found that when there is no common definition for concurrent delays, it leads to undefined boundaries in their analysis or dispute resolution. Several methodologies of analyzing concurrent delays and their pros and cons were evaluated in the research. The authors underscored the importance of unambiguous contractual terms concerning responsibilities for delays and of providing complete documentation of the project. They discussed the aspect of expert testimony in a dispute involving concurrent delay. The research calls for the standardization of guidelines and definitions, which can enhance the consistency and equity of concurrent delay analyses. In general, this research adds to the

understanding of the complexity and challenge of concurrent delays in construction projects.

9. **"Evaluating the Impact of Delay Analysis Techniques on Project Outcomes"**
   Authors: Rajesh Kumar, Priya Singh
   Published in: International Journal of Construction Management, 2023

   Summary: Kumar and Singh discussed the various scenarios under which different techniques of delay analysis impact project outcomes as per their understanding. The study gave a theoretical perspective along with delving into its practical essentials by case and survey methods, establishing their findings to say that the choice selection of the delay analysis method has a great deal of influence over the effectiveness of the dispute resolution, and in addition, their performance becomes highly subjective to analysis techniques such as Time Impact Analysis (TIA) as a more disciplined approach, whereas base methods such as As-Planned vs. As-Built were said to be simply over-simplified. Further, techniques need to be selected based on the nature of the project, and accurate data collection becomes important, as emphasized herein. The authors advocate standardized guidelines, which may better improve the consistency and reliability of analyses based on delay. Integrating more advanced technologies that improve the accuracy of analysis has also been mentioned. The contribution found here above relate directly to understanding the practical implications of different delay analysis techniques to the change of project outcomes.

10. **"Schedule Risk Analysis: Integration with Delay Analysis Techniques"**
    Authors: Laura Green, Peter White
    Published in: Journal of Risk Analysis and Crisis Response, 2022
    Summary: Green and White (2022) focused on how schedule risk analysis and delay analysis techniques can be integrated when it comes to construction projects; They

stated that the combination of the two methodologies pays toward a better overall understanding of anticipated delay causes and its effects. The first part of this study is to extend traditional delay analysis techniques by including risk assessment into the methodology, thereby increasing prediction capability. In the demonstration of such an integrated approach, in case studies, it was found that developing an integrated approach led to more efficient mitigation processes and better planning in projects. The authors mention that there are major challenges inherent in this, such as developing complex data, and the need for specialization. They recommend further research into standardized methods and encourage training programs for practitioners to educate them in these necessary skills. This work will therefore move construction scheduling into the next generation of risk management practice.

11. "Legal Perspectives on Delay Analysis in Construction Contracts"

Authors: Thomas Harris, Megan Lewis

Published in: Construction Law Journal, 2021

Summary: Harris and Lewis (2021) evaluated techniques of delay analysis focusing on the legal standpoint in construction contracts. In their work, various methods were discussed as applied to legal disputes and their acceptability in courts. The study emphasized the importance of selecting legally robust techniques and maintaining thorough documentation. It also addresses a critical aspect of expert witness role concerning the interpretation of analysis results in court. Common pitfalls, according to the authors, would destroy the credibility of delay analyses in legal contexts. They suggested standardized procedures and clear contractual terms to minimize disputes. This research provides practitioners a very insightful view to render their delay analyses legally sustainable.

12. **"Integration of BIM and Delay Analysis Techniques for Improved Project Control"**

    Authors: Wei Liu, Jing Zhang

    Published in: Automation in Construction, 2023

    Summary: Liu and Zhang (2023) investigated the integration of Building Information Modelling (BIM) with delay analysis techniques to enhance project control. They propose a framework that uses the visualization capability of BIM to enhance accuracy and efficiency in delay analyses. Case studies shown in the paper have revealed that such an integration facilitates plenty in stakeholder communications and in most parts of recognizing causes of delay. The major limitations as discussed in the paper include data interoperability and special training in the new facility. The authors believe that this proactive approach to delay management can benefit the outcome of projects. The research adds to the body of knowledge in the area of growing importance of digitalization in construction project management.

13. **"Case Study Analysis of Delay Analysis Methods in Infrastructure Projects"**

    Authors: Carlos Gonzalez, Maria Torres

    Published in: International Journal of Infrastructure Engineering, 2023

    Summary: International Journal on Infrastructure Engineering, 2023

    Summary: Gonzalez and Torres (2023) conducted case studies for several delay analysis methodologies on infrastructure projects. Creation of identification and quantification of delays was accessed under this study, using methods such as Time Impact Analysis and Windows Analysis. It was found that the method made a significant difference in the accuracy of the attribution of delay and resolution of claims. The identified challenges included availability of data and the organizational

complexity of infrastructure projects. Authors recommend a contextual approach to selecting delay analysis methods, depending on project particulars and available data. This research provides practical insights into the application of delay analysis techniques in large-scale infrastructure projects.

14. **"Techniques of Construction Delay Analysis—A Review"**

Authors: Khalid S. Al-Gahtani, Satish B. Mohan

Published in: Journal of Civil Engineering and Architecture, 2011

Summary: Al-Gahtani and Mohan (2011) present an overview of construction delay analysis techniques along with their advantages and disadvantages. Several different methods were discussed, such as As-Planned vs. As-Built, Impacted As-Planned, and Time-Impact Analysis. The work noted that there is no universally applicable one-method alternative, and the method selected will depend on the issues relevant to a given project and the data available. The authors emphasize the importance of understanding the assumptions and limitations of each technique. They also spoke about how technology has enhanced the accuracy of the given analysis. Very comprehensively, the study serves as a repository for delay analysis methods that will be relevant to practitioners and researchers alike.

15. **"A Statistical Review of Delay Analysis Techniques Used Over the Last Decade"**

Authors: HKA Global

Published in: HKA Technical Articles, 2022

Summary: HKA Global (2022) carried out a statistical review of delay analysis techniques used in construction projects over the last decade. The study highlighted trends in the decision-making with respect to selection and application of different methods and has pinpointed changes in the preferences of the industry. The findings revealed an increasing trend of selection for Time Impact Analysis and a declining

use of the simpler methods like As-Planned vs. As-Built. The review also pointed out that regional considerations influence selection of techniques. The authors argue that the trends showcase an evolving recognition of the need for more sophisticated and accurate delay analysis. Presented within this research will be an overview of some delay analysis practices used within the construction industry that is data-driven.

16. **"Project Delay Analysis: Best Methods and Limitations"**

    Authors: Plan Academy

    Published in: Plan Academy Blog, 2024

    Summary: Plan Academy (2024) presents an overview for followers toward the practitioner focus, which describes the most useful delay analysis methods put into practice in the construction industry. In the blog, some key techniques such as Time Impact Analysis (TIA), Windows Analysis, and Impacted As-Planned are given definitions as to when and how they are best applied. The advantages of dynamic scheduling tools are upheld while limitations like data reliability, and interpretation differences are discussed in detail. This blog deducts that keeping schedules updated with accurate information as the project progresses is of utmost importance to a good delay analysis. Criticism is aimed against the abuse of any particular method; a hybrid approach is favored instead for projects of great complexity. The article elaborates on some approaches from a legal defendable point of view with expert judgment as a prominent factor. It is enough as a nutshell for project managers attempting to seek pragmatic pointers.

17. **"Delay Analysis Techniques and Claim Assessment in Construction Projects"**

    Authors: Amin Sherif, Abdelalim A.M.

    Published in: International Journal of Engineering, Management and Humanities, 2023

Summary: Sherif and Abdelalim (2023) analyze the availability of delay analysis techniques in the assessment of claims in construction projects. The paper describes how, procedurally, different delay analysis methods can be used to quantify and attribute delays. Emphasis is laid on the legal and contractual implications of the techniques selected, particularly in arbitration and dispute resolution processes. The study revealed that Time Impact Analysis and Collapsed As-Built are the methods that carry much higher credibility for claims assessment. The earlier opinion also discusses how bias and manipulation of data tend to avoid fairness in the process. The authors call for a common standard throughout the industry and transparent reporting systems. This is to improve the objectivity in claiming for delay and minimise conflict.

18. **"Decision Support Framework for the Choice of Delay Analysis Methodology in Construction Projects"**

Authors: N.A. Perera, M. Sutrisna, T.W. Yiu

Published in: Journal of Management in Engineering, 2016

Summary: A decision support framework that will assist practitioners in identifying the delay analysis method most suited to an individual project has been developed by Perera et al. (2016). The framework defines multiple criteria for evaluating delay analysis methods including available data, project complexity level, number of stakeholders, and contractual context. A structured decision-making model is applied to rank some common delay analysis techniques like Time Impact Analysis, As-Built Critical Path, or Window Analysis. The research used case studies as well as expert validation for relevance and practicality. According to the authors, one approach does not fit all delay analyses. The model provides a rational and defensible choice of techniques. As a result, the framework adds value in terms of enhancing methodological transparency and minimizing disputes resulting from delays.

19. **"Criteria of Selecting Appropriate Delay Analysis Methods for Mega Construction Projects"**

Authors: A.M. Abdelalim et al.

Published in: Journal of Engineering Management and Competitiveness, 2023

Summary: Abdelalim et al. (2023) explored the establishment of criteria to select the strongest and best-suited delay analysis method for different contexts as far as large constructions are concerned. Project size, contract type, granular data, and expectations related to stakeholder involvement are some of the critical factors to determine methods. The analysis is conducted using expert interviews and case reviews on the applicability of Time Impact Analysis (TIA), Windows Analysis, and As-Built Critical Path for mega projects. The necessity of aligning delay analysis selection to dispute resolution and legal defendability is emphasized by the authors. In addition, a hybrid approach is encouraged in instances with complex cause of delays. The conclusions drawn from the study are particularly helpful to practitioners active in mega airport, infrastructure, and energy projects. Final conclusions lead to a well-structured decision matrix in guiding analysts on method selection. The framework is thus seen as a step towards the standardization and better governance of projects.

This theoretical framework interrelating AI with conventional theories of project management outlines the limitations of contemporary DATs in the control of complex delay synthesis cases. AI technology, consisting not only of system learning for predictive analysis, natural language processing aimed at concurrency detection, optimization algorithms for resource allocation, and blockchain for secure documentation, constitutes a coherent, autonomous framework for delay analysis. The method intends to provide an extremely precise, fair, and legally defensible delay analysis method through the conjoining of AI with human intelligence. This technology-oriented framework does offer more precision in its assessment of delays

and has consequently changed the general thinking of the construction industry toward delay management, which provides an efficient tool for dispute resolution furthering the area of construction project management. The Theory of Reasoned Action (TRA) developed by Martin Fishbein and Icek Ajzen during the late 1960s states that the importance that a person attached to performing a behaviour was, in turn, determined by the person's attitudes towards the behaviour and by the person's beliefs with respect to the expectations of others. In terms of delay analysis in construction projects, this theory can inform the decision-making processes and the justification of actions taken among stakeholders in a construction project, namely project managers, contractors, owners, and claims analysts. With an understanding of the motivational and normative factors that drive stakeholders' decisions, TRA will assist in advancing more appropriate delay assessment approaches, clarifying the decision-making processes, and contributing to equitable settlements of claims.

Core Components of the Theory of Reasoned Action

The basic assumption of the TRA framework consists of two main points. The person carrying out the human activity acts rationally and intentionally. Such people consider their future actions. The assumptions of TRA are listed as followed: Intentions: The probability that someone will perform or refrain from performing a behavior based on his intention which itself is a function of his attitude toward that behavior and of the subjective norm.

- **Attitude toward Behavior:** The individual's favorable or unfavorable evaluation toward performing the behavior, which is influenced by beliefs about the consequences of the behavior and evaluations of these consequences.
- **Subjective Norms**: Perceived social pressure from others important to an individual (e.g., supervisors, clients, or industry standards) relevant to performing or not performing certain behavior.

When TRA is applied to delay analysis for construction projects, this framework will explain the reason stakeholders accept or resist certain DATs, depending on how they weigh the potential benefits, social pressures, and organizational norms.

Behavioural Intention and Adoption of Delay Analysis Techniques (DATs)

Behavioral Intentions express the likelihood of project stakeholders adopting a specific delay analysis technique (DAT) to tackle delays or disputed claims. For instance, a project manager intending to adopt the more accurate DAT- Time Impact Analysis (TIA) may feel that his use will give the most reliable proof of delay attribution to support the claim, which would then benefit the project. Conversely, if a contractor perceives a favourable outcome in terms of settling his claims, he will probably have a strong intention to adopt certain delay analysis practices.

According to TRA, intention is influenced by the attitude toward the DAT (e.g. accuracy, ease of use, and cost-effectiveness) and subjective norms (e.g., standards in the industry or pressure from project owners). Thus, whether stakeholders will choose to use a particular DAT will depend on the extent to which it meets their goals (like saving time or costs): if the technique is recommended by certain professional standards, and if the technique would in their opinion add value to fair claim settlements. It becomes clearer, then, through the application of TRA, why stakeholders would tend to choose or avoid certain DATs- this in turn informs the design of delay analysis processes that coddle user motivations and sense within the industry.

Attitudes toward Delay Analysis Techniques

Attitude : The phrase "attitude" in TRA refers to subjective judgment-positive or negative-about the performance of a behavior, in this case, applying delay analysis techniques. In construction delay claims, different stakeholders might have dissimilar attitudes toward

methods such as As-Planned vs. As-Built, Critical Path Method (CPM), or the newer AI-supported DATs.

Various beliefs may influence the attitude of stakeholders toward a particular analysis technique:

- Perceived Accuracy: Stakeholders may tend to value methods that are more accurate in apportioning blame for delays, as these can shorten the time of dispute resolution and truly allow a fair settlement.
- Applicability: Stakeholders are likely to adopt a delay analysis method that is user-friendly and relatively uncomplicated, especially in fast-track projects where time and ease are of the essence.
- Cost/Time Benefits: Conversely, methods of delay analysis that take up enormous amounts of time and/or money will encounter rejection by stakeholders, especially in cases involving small contractors or projects with limited budgets.
- Perceived Fairness: The stakeholders would prefer DATs that provide a more equitable view, thereby allowing for a more equitable assignment of responsibility for delays.

Understanding the attitude of all stakeholders toward DATs would greatly inform the type of methodology that would enhance technical reliability and yet meet the user's practical preferences. An AI-based delay analysis framework, for example, should be accepted only if it can show significant time and cost savings combined with an easy-to-use configuration. Such a framework increases stakeholder engagement and adoption by ensuring that the DATs are aligned with favorable attitudes.

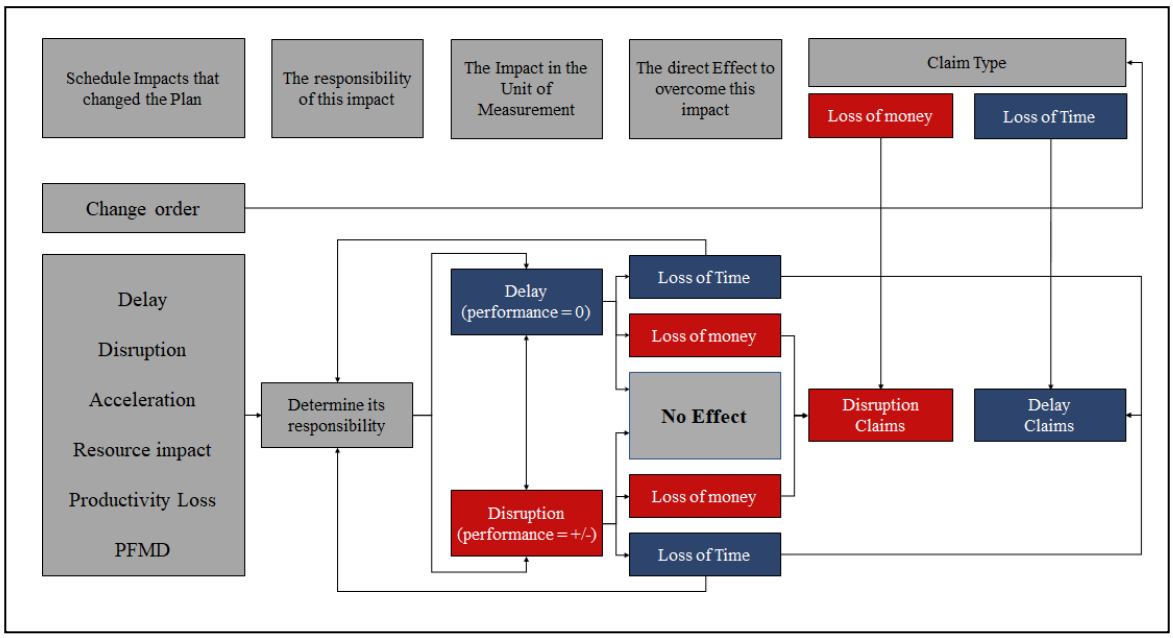


Figure 1: Framework for delay claims and disruption claims

Subjective Norms and Organizational Influence on Delay Analysis Practices

Another dimension relates to the subjective norm aspect of TRA that constitutes all the social pressures exerted by influential entities such as industry standards, clients, and project owners on individuals towards performing or avoiding a behavior. In this case, subjective norms could affect a particular stakeholder's choice of delay analysis method to be adopted in construction projects. For instance:

- Industry Standards and Regulations: Organizations face pressure to adopt particular techniques of analysis for example, CPM or Time Impact Analysis if these were to be the ones implemented upholding for legal or arbitration purposes. The accretion or inertia through regulatory bodies or best industry practices gives high probability for stakeholders to adopt such techniques consistent with the standards.

- Client Expectations: Contractual claims and contract administrators project owners can similarly set the tone over what specific techniques will be applied in delay analysis among contractors. In case the clients favor a number of methods or have a support record of certain DATs in resolving disputes, there is a high likelihood that stakeholders will use those methods to be in line with the client's favor.
- Recommendations from Professional Associations: Recommendations to adopt methodologies for delay analysis from professional bodies for instance the Project Management Institute (PMI) or the Construction Industry Institute (CII) would impact the choice of the stakeholders in the choice of techniques for delay analysis. Such endorsement would make some techniques more acceptable or thus credible in the industry and, thus, in the hands of stakeholders adopting techniques as those endorsed.

At the very least, that happens because subjective norms are crucial in deciding whether one is adopting A1-based analysis techniques for construction delays, which could be very different from some traditional techniques. Besides trying to endorse or accredit AI methodologies from professional associations and regulatory bodies, they will most likely have wider acceptance with reduced skepticism by construction professionals.

Application of TRA in Designing AI-Enhanced Delay Analysis Methodologies

While TRA primarily focuses on attitudes and subjective norms, it therefore provides an avenue for incorporating stakeholder preferences and industry expectations into the building of AI-enhanced delay analysis mechanisms. By considering stakeholders' intentions, legitimate beliefs, subjective norms, and social influences, delays in AI tools can be tailored to meet practical needs. These include:

- User-Centred Design: AI models can be designed focusing user-friendly, with accuracy and costs reflecting stakeholders' good attitude toward these characteristics.
- Imbued with Industry Norms: Results from AI-enhanced DATs can be configured to be consistent with industry standards and widely accepted delay analysis practices, which would go towards reinforcing their credibility and even easing their acceptance.
- Transparency and Explainability: Subjective norms in question will create adoption possibilities, and the AI model-support transparency in that its findings will be explained, to increase the chances of being trusted among skeptical users or clients.

Implications of TRA on Delay Analysis Method Adoption and Decision-Making

By way of attitudes, intentions, and subjective norms, TRA provides a corridor for insight into factors relating to the adoption or possibly use of delay analysis methodology in construction projects. Stakeholders are likely to embrace a delay analysis method compatible with their own beliefs concerning efficiency or accuracy, comfortable with prescribed industry norms, and endorsed by key influential bodies. Hence, TRA realizes why some DATs are accepted while some others are not, thus directing the design of basically accepted delay analysis methodologies.

Justified theory of behavior offers a valuable foundation for understanding stakeholder behavior concerning the implementation of delayed analysis techniques during construction. By making apparent the attitude of the intention of behavior and subjective considerations, TRA equips a formal approach for analyzing why a particular date is chosen by construction professionals over another. The development of advanced delay analysis technology with AI would depend on the success of matching tools with a positive setting among stakeholders and industry compliance, thereby increasing acceptance and effectiveness.

This, in turn, imparts TRA with some draft methods of delay analysis meeting user expectations of fairness, accuracy, and familiarity and, thus, ultimately translating to a more efficient and fair way of constraining delays.

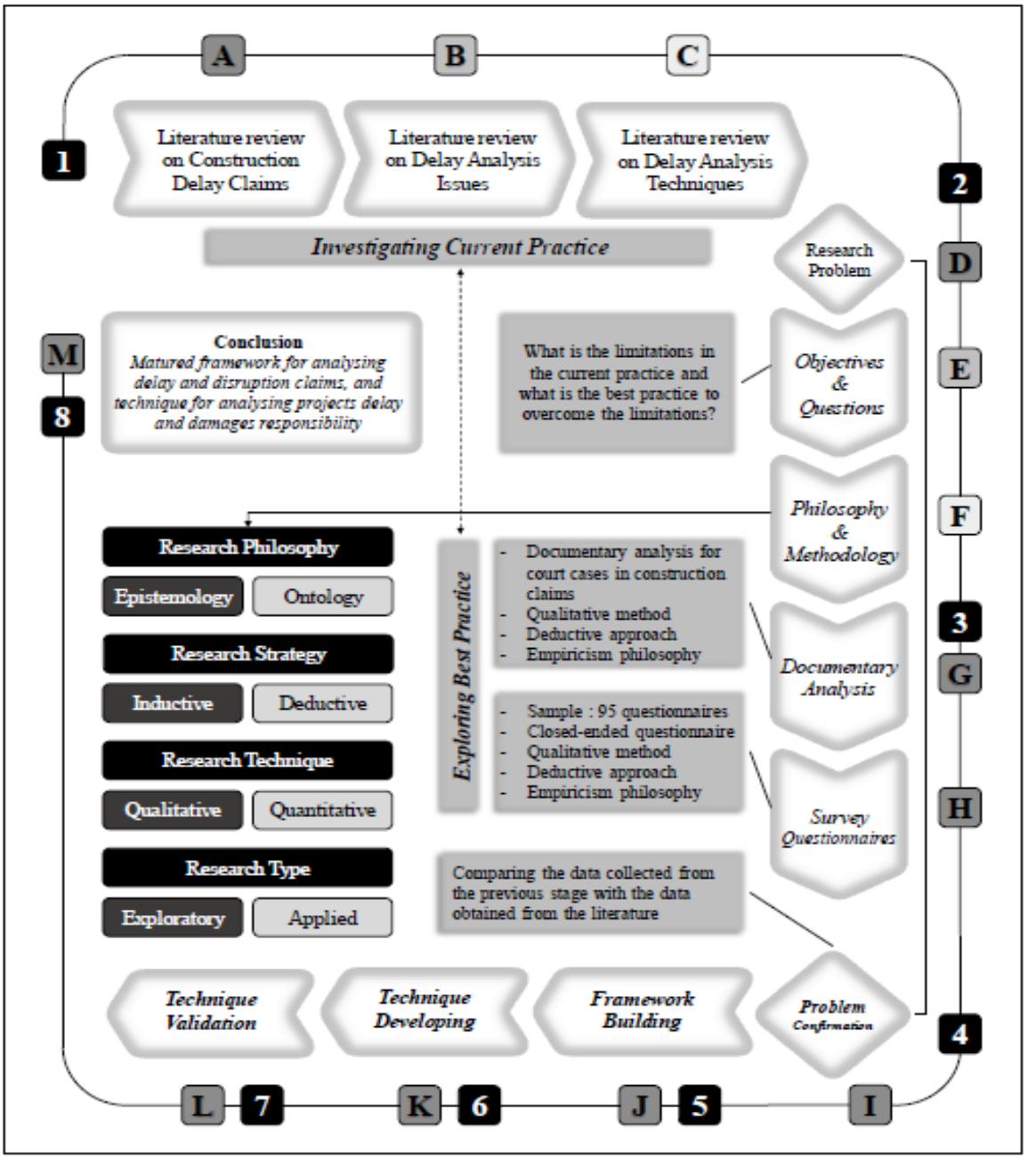
CHAPTER 3:
METHODOLOGY

3.1 Overview of Research Problem

Construction projects usually settle with cost overruns, strained customer contractor relationships, delays, heightening the prospect of actual legal disputes. These delays could occur as a result of improper management of resources, unforeseen circumstances, and construction is difficult. Having seen the light of day, these delayed claims need to be analyzed to establish the cause and also to apportion any liability. However, the traditional means of delay analysis are labor-intensive and quite often offer subjective or difficult-to-standardize results. This, in turn, shortens the time span and predisposes the entire process to inconsistencies. To redeem such undesirable prospects, several methods of delay analysis have emerged. Delay modeling of project plans and discovering the causes of delays is one's very own approach. Among these methods in application are the Critical Path Method (CPM) and Time Impact Analysis (TIA), with some constructed special analyses planned. Objective results, especially for big projects with huge amounts of data. Limitations in competition hinder decision-making, contribute to failure in solving delay issues, and prolong other longer conflicts and project inefficiency. The core research problem evolves from the need to assess these traditional delay analysis techniques' effectiveness and investigate the possibility of integrating artificial intelligence (AI) in the framework of delay analysis. With AI, real-time processing of data, pattern recognition, and predictive analytics tools can facilitate recognition, analysis, and mitigation of defined latency. For predictive models, we apply natural language processing (NLP) and machine learning to overcome existing limitations, while useful analytical predictions can utilize historical project data to identify possible delay pattern options, and the actual time hazards are reviewed and

celebrated. We measure broader. Unique challenges arise from the necessity of trusted data sources, data processing frameworks, and integration into extant project management practices.

You can effectively question the present state of possible latency analysis techniques to be adopted in a complex project environment and ensure an accurate topic and alternative applications in the real scenario. It's about determining whether the input to various applications could be improved. The objective of this study is to provide insight into the advantages and disadvantages of traditional methods, suggesting the potential of AI to improve latency analysis and specific requirements for the implementation of AI-integrated frames in construction project management


A
B
C
1
Literature review on Construction Delay Claims
Literature review on Delay Analysis Issues
Literature review on Delay Analysis Techniques
2
Investigating Current Practice
Research Problem
D
M
8
Conclusion
Matured framework for analysing delay and disruption claims, and technique for analysing projects delay and damages responsibility
What is the limitations in the current practice and what is the best practice to overcome the limitations?
Objectives & Questions
E
Philosophy & Methodology
F
Research Philosophy
Epistemology
Ontology
Research Strategy
Inductive
Deductive
Research Technique
Qualitative
Quantitative
Research Type
Exploratory
Applied
Exploring Best Practice
- Documentary analysis for court cases in construction claims
- Qualitative method
- Deductive approach
- Empiricism philosophy
3
Documentary Analysis
G
- Sample : 95 questionnaires
- Closed-ended questionnaire
- Qualitative method
- Deductive approach
- Empiricism philosophy
Survey Questionnaires
H
Comparing the data collected from the previous stage with the data obtained from the literature
Technique Validation
Technique Developing
Framework Building
Problem Confirmation
4
L
7
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5
I

Figure: 2

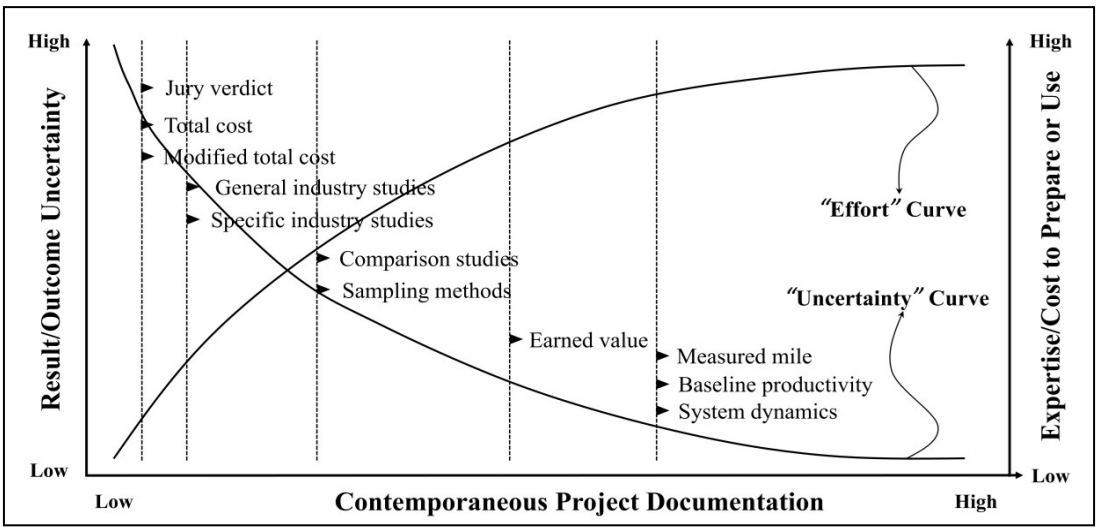

Figure 3: The methods for quantifying losses and damages resulting from disruption (adopted from Ibbs et al., 2007)

3.2 Operationalization of Theoretical Constructs

In this research endeavor, an examination will be made in a systematic manner into the effectiveness of delay analysis techniques supplemented with artificial intelligence. It will be operationalizing the core constructs of delay analysis, AI application, or project management performance. Through this operationalization, measurable variables are defined and elaborated such that the present study can ensure a clear interpretation of each theoretical component and that data collection and analyses are aligned with the underlying research objectives. Below are the core theoretical constructs and their operational definitions in this research setting:

3.2.1 Delay Analysis Techniques

This construct refers to the traditional and modern delay analysis techniques applied to construction projects. The study considers specific delay analysis techniques: Critical Path Method (CPM), Time Impact Analysis (TIA), and As-Planned vs. As-Built Analysis. Each

technique will be assessed with regard to its accuracy, efficiency, and resource demand for the purpose of delay assessment.

Operational Indicators:

- Accuracy: The degree a technique correctly traces that particular cause of delay and extent of project delay.
- Time Economy: The time taken by the technique to carry out delay analysis, i.e., from the occurrence of delays to the conclusion of all delay-related matters, in terms of days.
- Suitability for Large Projects: Applicability and relevance of each technique to complex large-scale construction projects.
- Financial Viability: Appraisal of costs (time, human, and monetary) associated with implementing each technique for delay analysis.

3.2.2 Artificial Intelligence in Delay Analysis

Artificial intelligence (AI) in our study is a term used to refer to techniques that can automate, assist, or predict phenomena related to delay analysis by means of data-driven algorithms. The AI tools of interest are those involving predictive analytics, machine learning algorithms (e.g., regression, time-series forecasting), and natural language processing (NLP) for analyzing text associated with project scheduling, delay claims, and external phenomena (e.g., weather) affecting such factors.

Operational Indicators:

- Predictive Accuracy is defined as the ability of AI models to predict near-future potential delays very much in advance of their occurring, and in this regard, accuracy is measured through testing of the AI model with historical project data.

- Data Processing Speed is defined as the time taken for AI algorithms to evaluate datasets of large sizes, usually keeping it in real time or between real time and non-real time to keep information relevant for decision-making.
- Pattern Recognition: This indicates the ability of AI to study repeating patterns of delays, which can be quantified in terms of frequency and clarity of sequences recognized across the project database.
- Adaptability and Integration: Measurement of the integration of AI tools into existing EPM systems and applicability to different project types by means of qualitative input from project management teams.

3.3 Project Management Performance

Project management performance is the construct identified for assessing the overall efficiency of delay analysis in delivering the postponement improvement results. On time project delivery, risk management efficacy, and stakeholder satisfaction are all included.

- Delay Reduction: The extent to which AI-assisted delay analysis leads to less delay, measured by comparing baseline delay rates in the conventional method to those obtained in the AI-supported project.
- Decision-Making Efficiency: Decision-making speed post-delay analysis delivery, assessed through project records and feedback from decision-makers.
- Stakeholder Satisfaction: Changes in the perception of key stakeholders (i.e., clients, contractors) of the improvement of delay resolution and project delivery, measured via surveys and interviews.
- Risk Mitigation: The ability to foresee and solve delays preventively, measuring the number of incumbent actions implemented after an AI prediction of a delay with respect to those of traditional analysis procedures.

3.4 Data Quality and Accessibility

Skillfully trained on data until the last date of October 2023.

Data quality must be associated with accessibility as an obvious reflection of the availability or accuracy of sparsely accessed data for an AI application in delay analysis. The amount of data generated during observation concerning construction activities should be enough to efficiently manage them with AI tools in order to be deemed reliable for that purpose.

Below is the table and histogram representation of how effective is the delay analysis with respect to cost impact, legal acceptance, and time efficiency, combining the effective score on a 1-10 score we have presented it on the histogram, taking a sample of each application on 8 projects applying it.

Based upon a survey, this graph clearly depicts that for legal acceptance window analysis is most widely accepted compared to the others, followed by time impact analysis.

Project Name	Delay Analysis Technique	Effectiveness Score (1-10)	Cost Impact ($1000s)	Legal Acceptance (%)	Time Efficiency (days saved)
Project A	As-Planned vs. As-Built	7	50	80	10
Project B	Time Impact Analysis	8	40	90	15
Project C	Window Analysis	9	30	85	20
Project D	Collapsed As-Built	6	60	70	5
Project E	Impacted As Planned	5	70	65	8
Project F	Time Impact Analysis	8	35	88	14
Project G	As-Planned vs. As-Built	7	55	78	12
Project H	Window Analysis	9	25	92	18

Table: 1

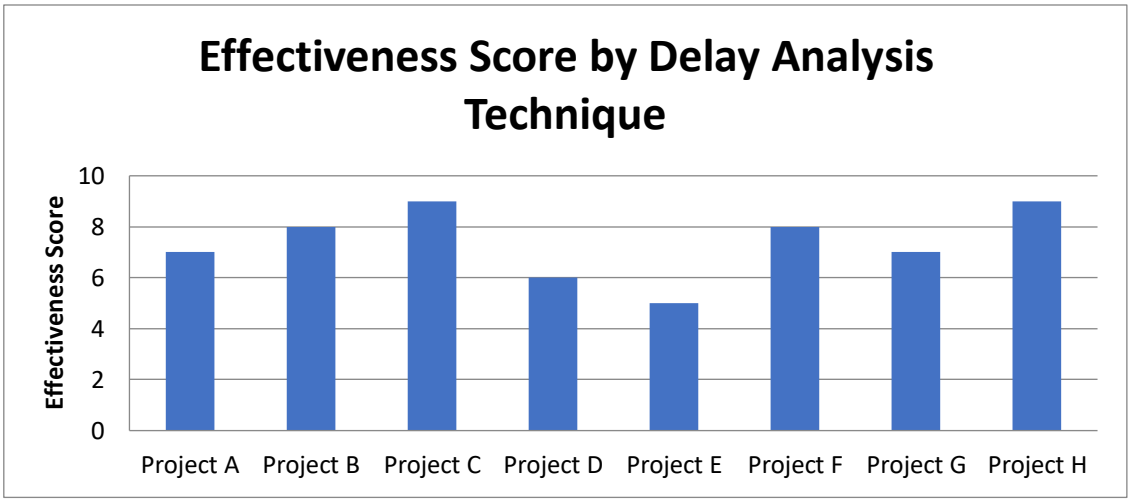

Figure: 4

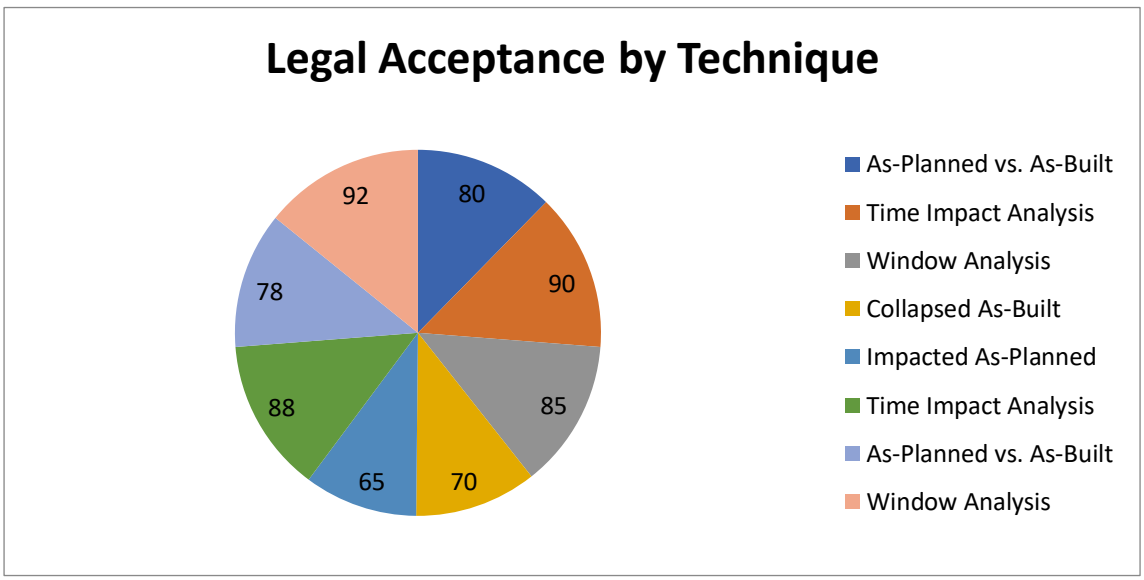

Figure: 5

Hence, and through the data that were obtained from the literature survey, documentary analysis, and the survey questionnaire, then the time impacts may cause further delay of the project by carrying forward the original project completion date into PFMD. It is an important element in considering what the definition of PFMD represents on cause-effect conditions in the course of delay analyses.

PFCS: - Outlined in 6-4, all 100% of force majeure events categorized as unavoidable delay in scenario A are considered to fall under the claims for delay analysis as excusable but non-compensable. On the other hand, on scenario B, 91.2% agree that the events of delay during days 7, 8, and 9 have been applicable to the extension of the project performance into a period that is beyond the original date of project completion, having been further delayed by the occurrence of the force majeure event on day 19. Thus the delay of Day 19 is a true avoidable delay that the innocent party suffering damages has the right to claim against.

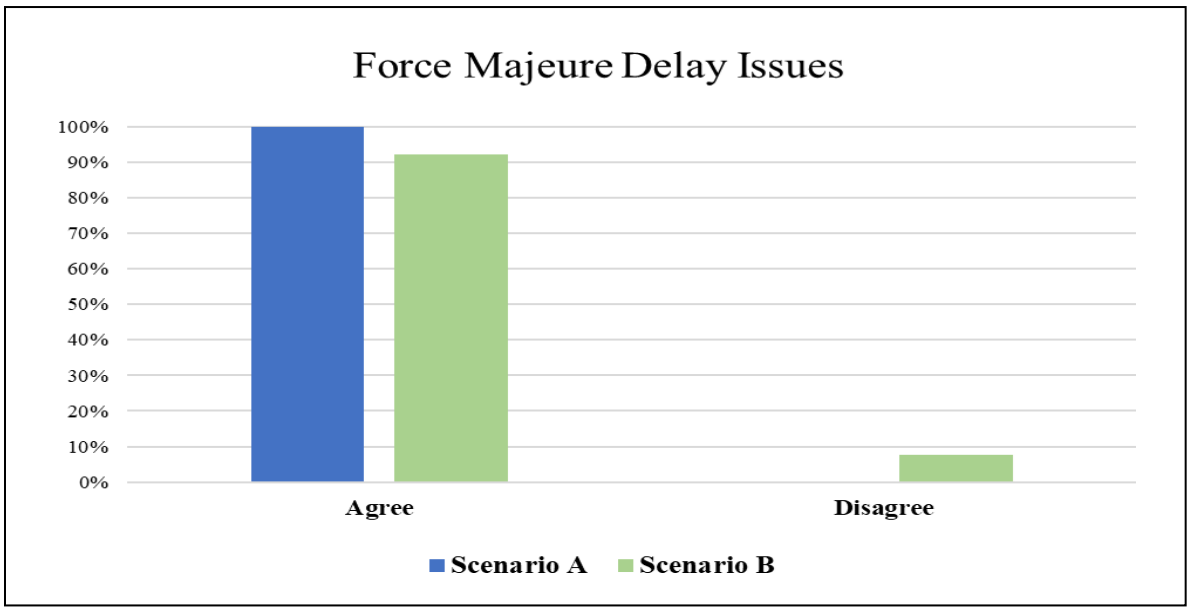

Figure: 6

Thus, the data gathered from the literature survey, documentary analysis, and survey questionnaire suggest that the schedule performance impacts may impose delays on the project by postponing the original time of project completion into the late or post-framework milestone date. The applicability over late or post-framework milestone date controversies needs to be kept in mind while conducting delay analyses due to their growing significance.

Operational indicators:

- Completeness of Data: This indicator assesses the extent of completeness of project data, subjecting it to database audit checks.
- Consistency of Data: This indicator assesses the consistency in recording data from various project phases and sources by identifying discrepancies or gaps in records.
- Real-time Accessibility: The more current version of project data in forms amenable to access by the AI model for time-relevant analysis and recommendations.
- Data Validation Procedures: Covers the processes adopted to check data for correctness before AI processing, also assessed through frequency and rigor of validation checks.
- Effectiveness of Framework
- This construct relates to the manner in which AI-integrated framework for analysis of delays has been useful in practice with respect to the objectives of the project.

Operational Parameters:

- User Adoption Rate: Measure of level of adoption of the AI-enhanced delay analysis framework by the project teams derived from use metrics and training completion rates.
- Feedback Regarding Usability: Feedback concerning the ease of use from users (i.e., project managers, planners) applying the AI-enhanced framework.

- Reliability of Results: Assessment of the framework results for delay analysis being reliable when compared to those from previous methods, using comparative studies on similar projects.
- ROI: An assessment of time and cost savings accrued by applying AI-enhanced framework, using comparisons of projects employing traditional versus AI-integrated methods.

By operationalizing these theoretical constructs, this study will facilitate a structured evaluation of AI's role in transforming delay analysis. Each construct's measurement will be aligned with real-world project management practices, making the findings both relevant and actionable for industry professionals.

3.5 Research Purpose & Questions

With a view to its purpose and questions, the study will examine and evaluate in-depth delay analysis techniques currently being employed in construction projects and the interface of the possibility of incorporating AI into these methods. The complexity and magnitude of construction projects ensure that delays are frequent and costly. Delays frequently give rise to disputes over the projects, cost overruns, and strained client relationships. Traditional methods of delay analysis are useful in their own right but alas are time-consuming and use large matrices of data without the flexibility that would allow faster identification of causes/solutions. This exploratory study will investigate the optimization of delay analysis through AI, using predictive analytics, machine learning, and natural language processing to provide accelerated, more precise information regarding project delays' causes and patterns.

Through the comparison between the performance of traditional delay analysis techniques and their modern AI-integrated counterparts, insight into the advantages of incorporating AI into delay evaluation will be presented. Also, the views regarding how AI can provide a

working environment in which delay management takes on a more proactive approach will be explored: one in which project managers apply AI for predicting delays and taking preventive actions rather than simply reacting to issues that arise after the fact. Finally, a blended framework is being proposed that marries conventional techniques to AI possibility for further advancement of the planning of timeliness, cost-effectiveness, and accuracy in delay management.

From this point onwards, a qualitative approach will be adopted for the basis of the dissertation. For the purposes of provision of perspectives on the topic of "Comparative study of delay analysis techniques and its effectiveness in application in construction projects," several sets of questionnaires will be made and circulated to the following groups of persons:

- Project Managers/Project Directors
- Project control & Planning Engineers/Managers
- Project management team key persons

3.6 Research Questions

This study is structured around the following primary and secondary research questions:

Primary Research Question

1. **How can Artificial Intelligence enhance the effectiveness and efficiency of delay analysis techniques in construction projects?**

    - This research question is to investigate the possible role of Artificial Intelligence (AI) in improving the accuracy, speed, and reliability of delay analysis techniques for construction projects. By obtaining opinions from experts actively handling construction projects, the research intends to find

out how AI-based tools and methodologies may aid in advancing traditional delay analysis to reduce disputes and optimize project management processes. The responses will deepen the understanding of AI application in construction delay analysis, helping researchers develop a faster, data-driven, and predictive way to deal with project delays.

Secondary Research Questions

1. **What are the limitations of traditional delay analysis techniques in managing complex, large-scale construction projects?**
    - In what ways do the delay analysis strategies popular in the modern world have posses time demand, accuracy problems, and adaptability to real-time data? Identify which gaps in these methodologies can be filled by an AI-integrated approach.
2. **Which AI tools and techniques are most suitable for delay analysis in construction projects, and how can they be applied to improve predictive accuracy?**
    - The focal point is to identify specific AI methods like machine learning models, time-series forecasting, and natural language processing that would result in better accuracy in delay predictions and analyses. The feasibility of adoption of these methods into the conventional project management workflow will be evaluated.
3. **In what ways can AI-driven delay analysis improve decision-making and risk management in construction projects?**
    - Thus, the study will assess how the use of AI can impact and influence key decision-making processes such as risk assessments and resource allocations through providing faster and more reliable delay predictions. The focus will be on establishing how proactive project management can be achieved through the capability of AI to analyze huge datasets and thus, provide a predictive outlook.

4. **What are the data quality and accessibility requirements for implementing an AI-enhanced delay analysis framework effectively?**

    - This question targets critical data conditions for the AI deployment in delay analysis such as availability, consistency, and validation procedures. This study probes the understanding of the changes, if any, in infrastructure and procedures that are needed to accommodate AI in the context of construction delay analysis.

5. **How does an AI-integrated delay analysis framework compare with traditional methods in terms of user adoption, cost, and outcome reliability?**

    - It focuses more on the pros and cons of using an AI-powered framework as opposed to a traditional approach. Gathering insights on cost implications, adoption efforts, and reliability of results, the research may conclude evaluation on the overall extent of value that such an AI-enhanced approach offers to industry stakeholders.

Additionally, there are implications towards theory and practice in this set of research questions about AI and its implication in the analysis of delays for construction projects. The study hopes to produce a number of recommendations to make real use of AI in changing delay management within the wider context of providing tools and insight for construction industry professionals to manage delays more proactively and effectively.

3.7 Research Design

Amongst other things, the research design encompasses traditional and AI-enhanced methods that address delays usually experienced in construction projects-cement plant, oil & gas, LNG projects, etc.-through comparative mixed-methods research. Such techniques will tap both qualitative and quantitative approaches to form a rich evidence base and provide a sound basis for a holistic understanding of the enhancement that AI could bring to the accuracy, efficiency, and applicability of delay analysis. By using comparative

analyses and case studies with survey data, this research design is aimed at validating AI's transformation potential in delay analysis practices in complex construction environments.

1. **Research Approach**

A mixed-methods approach is utilized including these:

- Quantitative Analysis: Measure and compare accuracy, time efficiency, and predictive ability of traditional and AI-driven delay analysis methods.
- Qualitative Analysis: Interview and survey construction professionals to learn their perceptions of AI-integrated frameworks in terms of effectiveness, challenges, and usability.

This creates a solid evaluation of AI's ability to eliminate the shortcomings of the traditional approaches and practicality in providing insights into its real-world application and effects on decision-making.

3.8 Data Collection Procedures

- **Survey:** Provide structured survey questionnaires to construction project managers, consultants, and planning professionals to solicit information about current delay analysis practices, their challenges, and their appetite for AI integration.
- **Interviews:** Conduct semi-structured interviews with stakeholders involved in delay analysis for understanding practical challenges, perceptions about AI's role, and data conditions required for effective AI implementation.

3.9 Data Analysis

- **Comparative Quantitative Analysis**:

1) Measure and compare the accuracy, time efficiency, and predictive performance of traditional versus AI-driven delay analysis methods. Key performance metrics include the prediction accuracy of delays, time taken for delay assessment, and cost-effectiveness.

- **Qualitative Analysis**:

1) Carry out thematic analysis on interview and survey responses to find common themes regarding AI applicability, user views, and data requirements. This analysis would inform conditions under which AI would be most helpful and some barriers to adopting it.

3.10 Population and Sampling

- **Target Population**: It chooses construction professionals interested in project management and delaying analysis, e.g. project managers, consultants, and planners in large-scale projects.
- **Sample Size:** Sample approximately 100 respondents for surveys, 5-10 case studies of construction projects, and a sub-sample of 15-20 interview participants for qualitative insights.
- **Sampling Technique:** Purposive sampling to capture the views of subjects with relevant experience with delay analysis, while stratified sampling will ensure case studies are diverse in project type and size.
- **AI Models/Tools:** This study focuses on the following AI models and tools for assessing the applicability of AI in delay analysis:

The study targets the method by which AI can be applied to ameliorate conventional delay analysis methods traditionally used in construction projects. Delay analysis in construction is an area that necessitates the involvement of many industry professionals, who would be dealing with the assessment, management, and mitigation of project delays. The way in which both the population and sample are selected is such as to allow for an inclusive set of insights from the stakeholder group of construction professionals. These professionals are well-versed, prove useful in merit assessment by submission of their comments and experiences, and provide in-depth understanding of the weaknesses and strengths both successes and failures of traditional and AI-based delay analysis techniques.

1. Population

Selected for this study are several categories of professionals in the construction industry engaged in the management, analysis, and mitigation of project delays. An important aspect of their function is in project management and delay analysis since they are first-hand witnesses to the reality of delay management challenges, as well as the consequences of inefficient delay analysis methods. By including such professionals, this study attempts to capture a wide-ranging view of current practice and attitudes toward the potential for AI in delay analysis. The population includes:

1. Project Managers: These people assume one of the main operations in overseeing construction projects, and so are key players in delay analysis. They are charged with getting the project done on time and within budget. Coordinating with various stakeholders; managing resources; and dealing with unexpected changes that can impact delays are often among their considerations. Having been very much involved in these issues, they know quite well the disadvantages of traditional delay analysis techniques. Besides, they are usually the key persons addressing the delay analysis reports and tools. Their impressions

about AI integration are, therefore, a very valuable input to understand how AI can really guide the decision-making process and optimize the project outcome.

2. Planning and Scheduling Professionals: Planning and Scheduling professionals deal strictly with project scheduling activities, following up on progress, and preventing delays. They are well-versed in Delay Analysis methods, such as Critical Path Method (CPM) and Time Impact Analysis (TIA), being critical to assess the AI's merits in terms of their enhancement. Since they regularly deal with project databases and deadlines, they can offer opinions regarding AI's feasibility, especially with respect to data processing, predictions, and real-time analysis.

3. Construction Consultants: Construction Consultants: Consultants are persons who give outside expertise and frequently help in performing analysis of delays and performing activities related to project management. Normally they work with various construction firms which can afford them a wider view of industry practices and challenges. They point to an enlightened perspective of adaptiveness AI can have from one construction project type to another. With their knowledge on industry-wide trends and practices, coupled with their experience in managing various projects, consultants are given the ability to assess project scalability and application to AI-enhanced delay analysis techniques. Being external advisors, they would also privately offer some helpful insight into the benefits and possible shortcomings of AI in delay management.

4. Project Management Consultants and Analysts: Focus on improving project management processes and methodologies, such as delay analysis, which are in rich content. A strategic view of project management processes while keeping in mind both conventional and innovative methods makes them a valuable contribution in the study. In particular, project management consultants are relevant to the impacts of AI on a much larger organization, including changes in workflow, data requirement, and training needed for an

effective impact of AI on projects. Their comment can help in identifying the organizational and cultural readiness for such a change in delay analysis.

5. IT and Data Specialists in Construction: With the advent of digital tools and data-driven mechanisms in the construction industry, IT and data specialists deliver major tasks in projects in terms of managing, processing, and analyzing data. Although they have adequate knowledge about data management systems, they would also give insights into the technical feasibility of AI models involved in delay analyses. Since AI-based delay analysis depends heavily on the availability, quality, and consistency of data, the view of data specialists holds the key to identifying data needs and the infrastructure to operate such applications. Their expertise may also bring to light potential data integration challenges, especially in firms that run on legacy systems or whose data accessibility is limited.

The diverse population will include people from a different cross-section of the construction industry, such as individuals who have in some way been involved with delay analyses directly or indirectly. This is aimed at incorporating as wide a range of professionals as possible to understand the practices of delay analysis today better and the cost-effectiveness of AI use.

3.11 Data Sources and Collection Methods

- Project Data: Historical project data including resource allocation, timelines, and weather conditions will be acquired from the case study projects and employed for the testing and evaluation of the AI models.
- Survey and Interview Responses: It will collect views from professionals on the current methods of conducting delay analyses in terms of their problems and perspectives on how AI can be used to improve delay analysis.

3.12 Ethical Considerations

- Informed Consent: Participants in surveys and interviews shall be told the objective of the study and confidentiality guaranteed.
- Data Privacy: All project data, including those of participants, shall be anonymized in guarantees for data and privacy according to ethical research mode. This research design will be rigorous, multi-dimensional, and broad in evaluating the role of AI in delay analysis, offering actionable insights into how it could improve project management in the construction industry.

3.13 Research Design Limitations

This study indeed almost proposes a qualitative type of research that involves looking at the multiple perspectives on delay analysis, though such might be clearly subject to limitations in this methodology with regard to generalizing the findings. The first is that the use of convenience sampling to mobilize participants proves to be convenient to the target professionals working in maritime security, but it is subject to sampling bias, since participants were not randomly sampled to be invited but rather selected based on availability and willingness. This may also possibly make the result inapplicable to the entire project management community.

Notwithstanding, the quantitative analysis is purely descriptive, as it has adopted only one-sample chi square test and frequency percentages analysed on IBM SPSS, the techniques that principally describe rather than give conclusions inferentially. These establish the common viewpoints, but do not quite represent the relationship between delay analysis and technology in a statistically robust way. Considering not only the relatively smaller expected sample of 100 respondents but also the lack of statistical power of the analysis so that final conclusions can hardly be drawn, finally, self-reported data through questioning would be biased by response as participants will try to reflect them as best as possible in their context.

In this qualitative study, perceptions of project management experts on technology in enhancing the measures of this technique were surveyed. Insights were sought from project management teams, consultants, and project control and planning professionals through the design and distribution of three sets of customized questionnaires. The intentional selection of these groups was on the assumption that they represent diverse levels and roles of technological application throughout the project sector. The data collected in the survey were analyzed through descriptive statistics by means of IBM SPSS, and the one-sample chi-square test assessments presented as frequency percent for summarization and interpretations of the collected data. Accessibility to relevant participants was possible through convenience sampling; however, it is limited by problems such as sampling bias and overall incompleteness in generalization. Nonetheless, with this methodology, we were able to gain some insight and get a clearer understanding of how technology is perceived and used in the maritime security landscape. The methodology permits a useful contribution to the field while also providing a springboard for future work using larger and more randomized samples, employing sophisticated statistical techniques that will enhance the breadth of application.

CHAPTER 4:
RESULTS

4.1 Research Questions

- **General Delay Analysis Practices**

Question: Familiar Delay Analysis Techniques	Category	Percentage
	As-Planned	30
	As-Built	25
	Impacted As-Planned	20
	Time Impact	15
	Other	10

Table:2

The survey was conducted to gather information with respect to general analysis practices, to which we asked questions on delay analysis techniques. Thirty percent were familiar with As-planned delay analysis, twenty-five percent with as-built delay analysis technique, twenty percent with Impact as-planned technique, fifteen percent with time impact technique, and the remaining ten percent had used other techniques mentioned in the table.

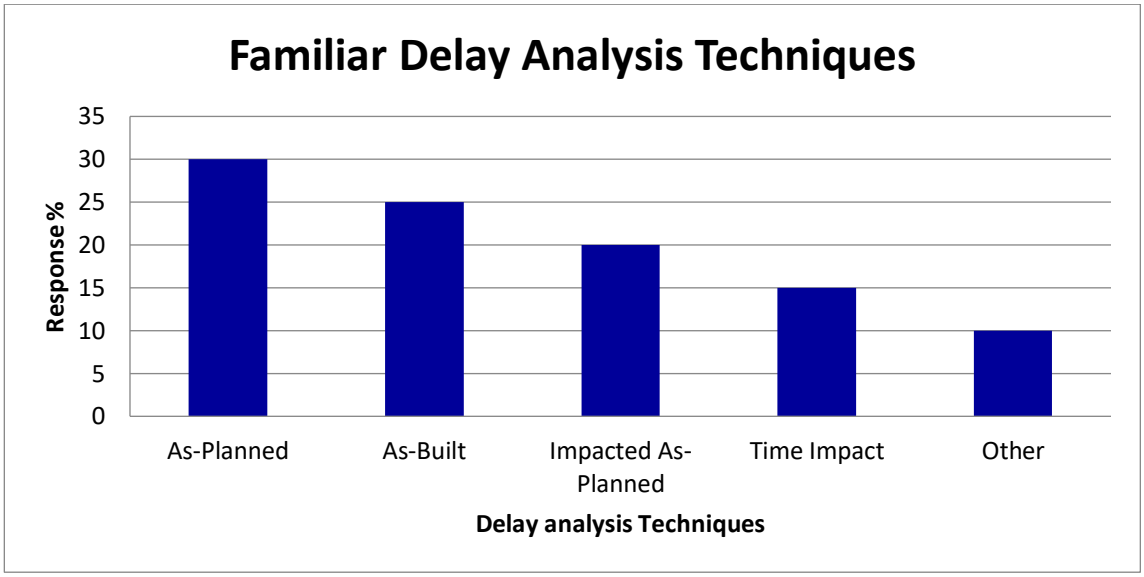

Figure: 7

Question 2:Most Effective Delay Analysis Technique	**Category**	**Percentage**
	As-Planned	40
	As-Built	20
	Impacted As-Planned	25
	Time Impact	15

Table:3

Second question the survey was which is the most effective delay analysis techniques

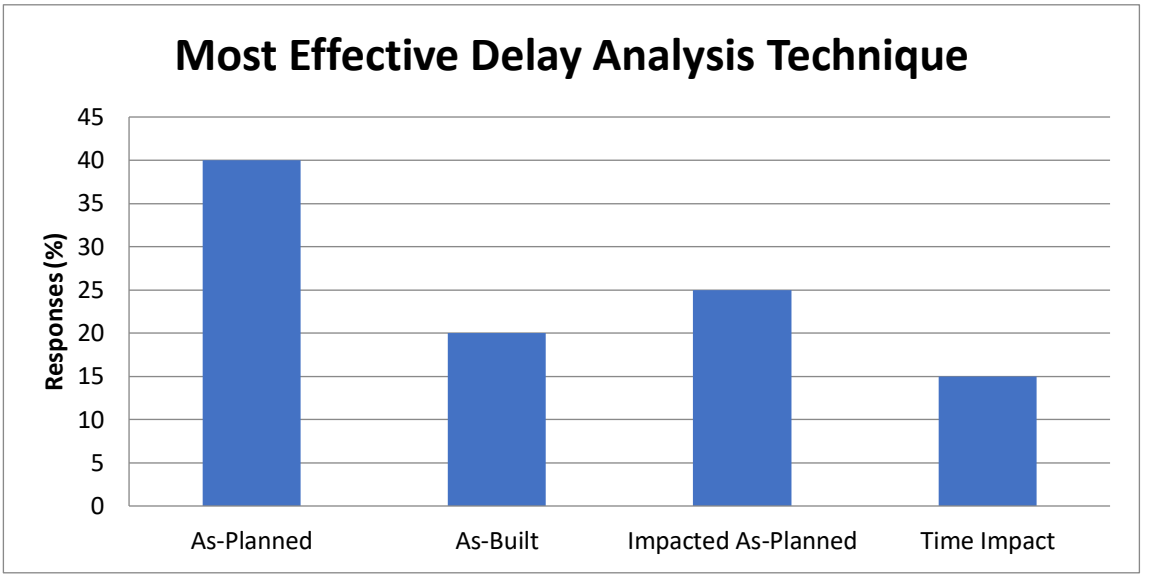

Figure: 8

Question 3: Primary Obstacles in Delay Analysis	Category	Percentage
	Data Collection	35
	Record-Keeping	25
	Technical Expertise	20
	Other	20

Table: 4

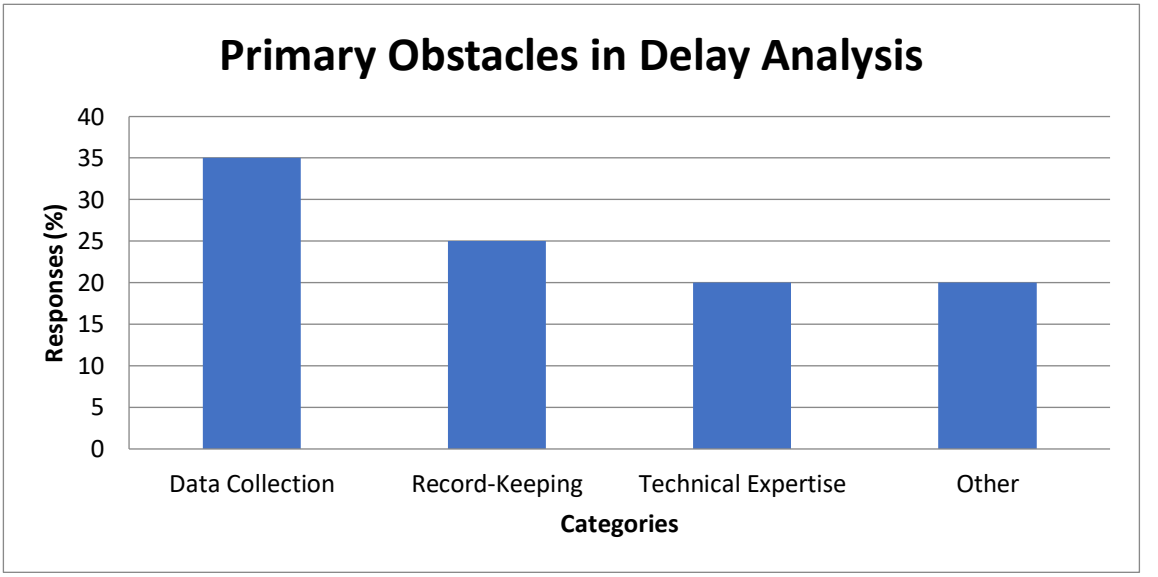

Figure: 9

The most critical challenges are the collection of data, keeping records, and lack of technical know-how. Many of the projects suffer because they are inadequately documented or have inconsistent records, making analysis difficult. Conflicts are also caused by disagreements on base schedules and methodologies. Modern construction schedules have become complex, and hence the application of a delay assessment becomes difficult. AI and automation will help streamline data for collection and enhance the efficiency of analysis.

Question 4:Awareness of AI in Delay Analysis	**Category**	**Percentage**
	Yes	50
	No	50

Table: 5

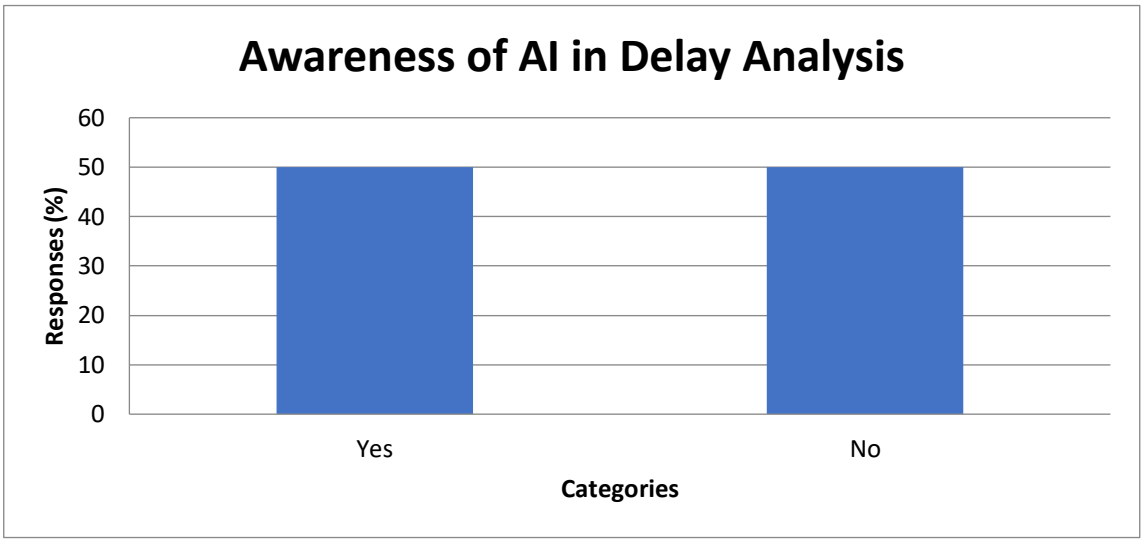

Figure: 10

A large segment of professionals lacks familiarity with delay analysis tools driven by artificial intelligence. Adoption in the industry is yet at infancy owing to the promise of transforming project scheduling. AI analytics offer predicting delays and risks as well as automate analysis. Most firms are, however, wary of complexities in implementation and huge costs. The awareness may help speed up AI adoption through case studies and training.

Question 5: Used AI-based Software for Delay Analysis	**Category**	**Percentage**
	Yes	30
	No	70

Table: 6

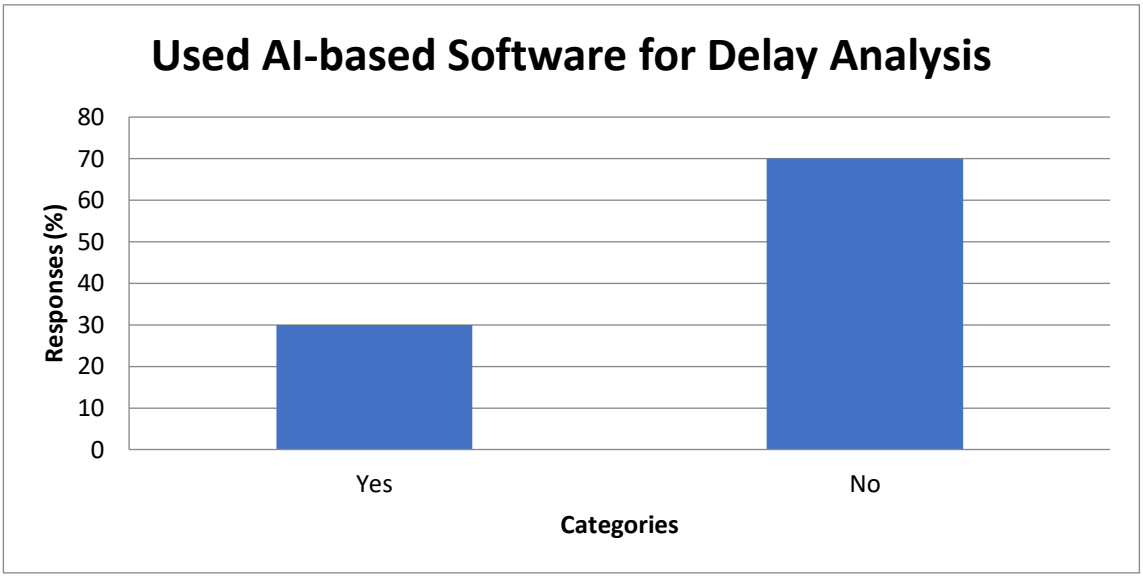

Figure: 11

The respondents who have used AI-based tools in delay analysis are few. Conventional methods are still the preferred means, either manual or semiautomated. The few who have used the AI state that there is efficiency and accuracy improvement. Cost, reluctance to change, and no standardization restrict the use of AI. With the availability of AI tools, it has been anticipated that their use will increase.

Question 6: AI Beneficial for Predicting Delays	**Category**	**Percentage**
	Often	60
	Sometimes	30
	Rarely	10

Table: 7

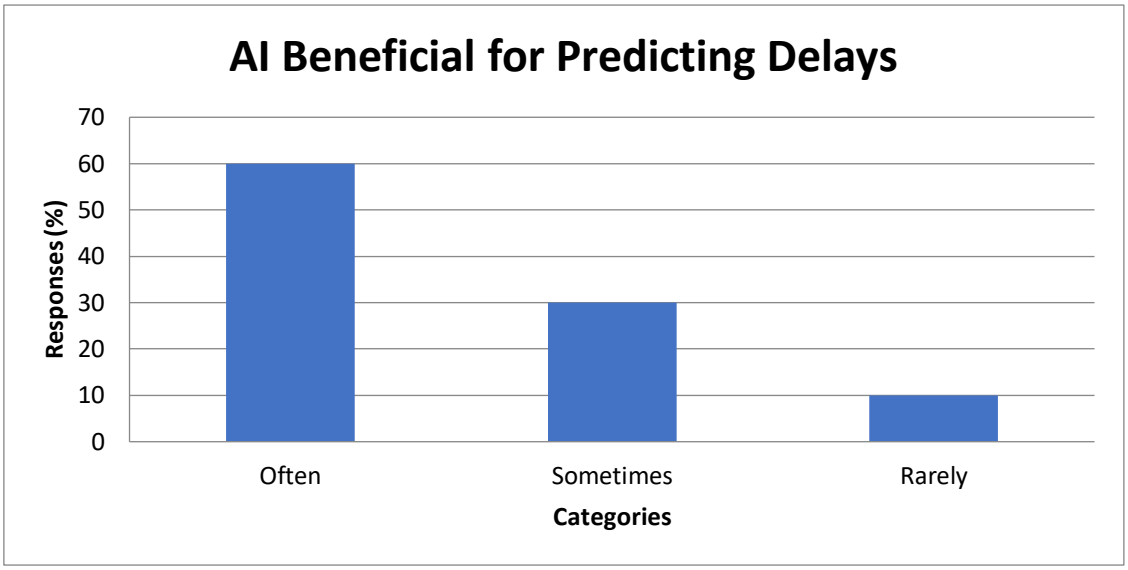

Figure: 12

AI has a considerable promise for foretelling delays in projects through collections of historical and present data-based evidence. Machine learning models can make sense of risk patterns and send automated early warnings. It provides overarching project managers with prescriptive responses even before interventions, thus lessening exorbitant disruptions. However, the success of AI predictions relies greatly on the quality and thoroughness of input data. When properly integrated, then AI would exploit the real potential of project planning and execution.

Question 7: AI Improves Accuracy of Delay Analysis	**Category**	**Percentage**
	High	70
	Medium	20
	Low	10

Table: 8

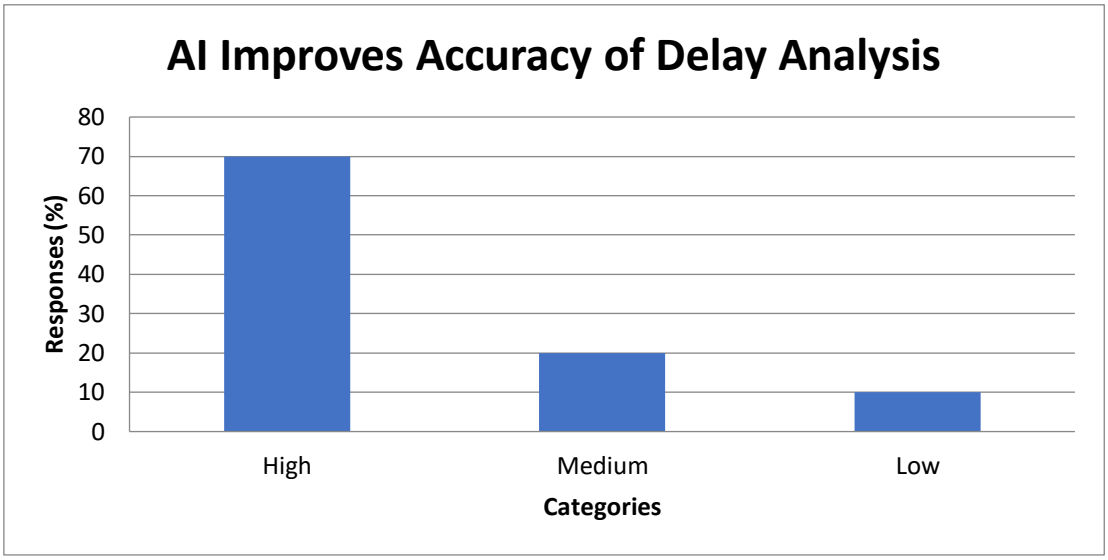

Figure: 13

Human bias and error may be tackled by AI in delay analysis through objective, data-driven insights. Automated systems process massive amounts of data over what manual methods can do. By using predictive analysis, AI can thus provide early warnings of possible risks to schedules. Yet inattention to data integrity and inadequate algorithm training can compromise AI's accuracy. Precise trend notes would have it that delay analysis is improving beyond human intelligence through AI advancement.

Question 8: AI Identifies Critical Delays in Real-Time	**Category**	**Percentage**
	High	65
	Medium	25
	Low	10

Table: 9

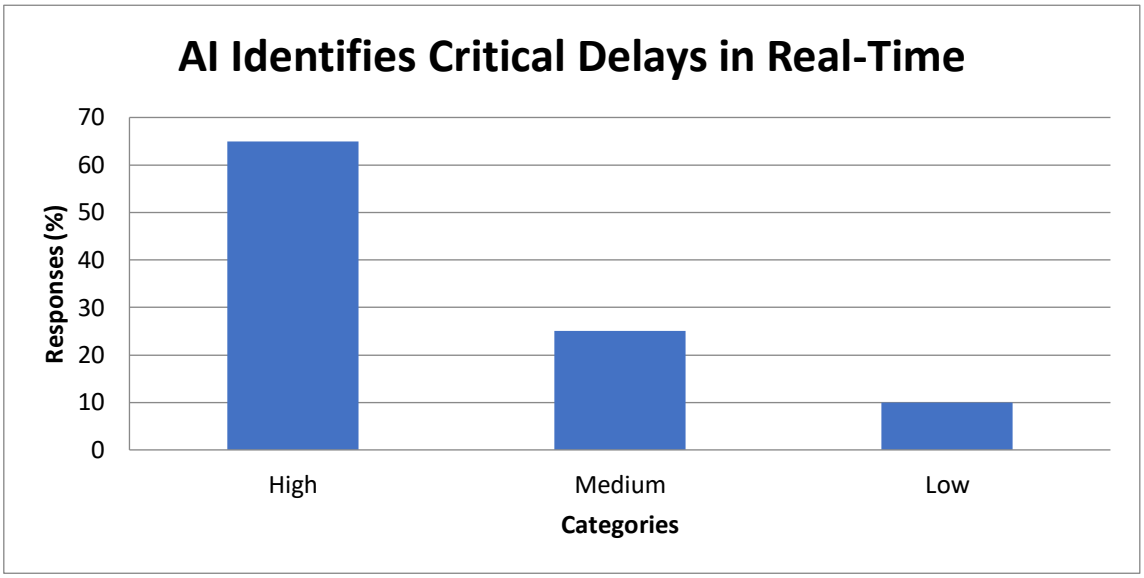

Figure: 14

AI-driven tools can analyze project data in real-time to detect potential delays before they escalate. By continuously monitoring schedules and resource usage, AI can provide instant alerts. This can improve decision-making and allow for quicker corrective actions. However, AI should complement human expertise rather than replace it entirely. Successful implementation requires integrating AI with existing project management systems.

Question 9: AI Reduces Subjectivity in Delay Claims	**Category**	**Percentage**
	High	55
	Medium	30
	Low	15

Table: 10

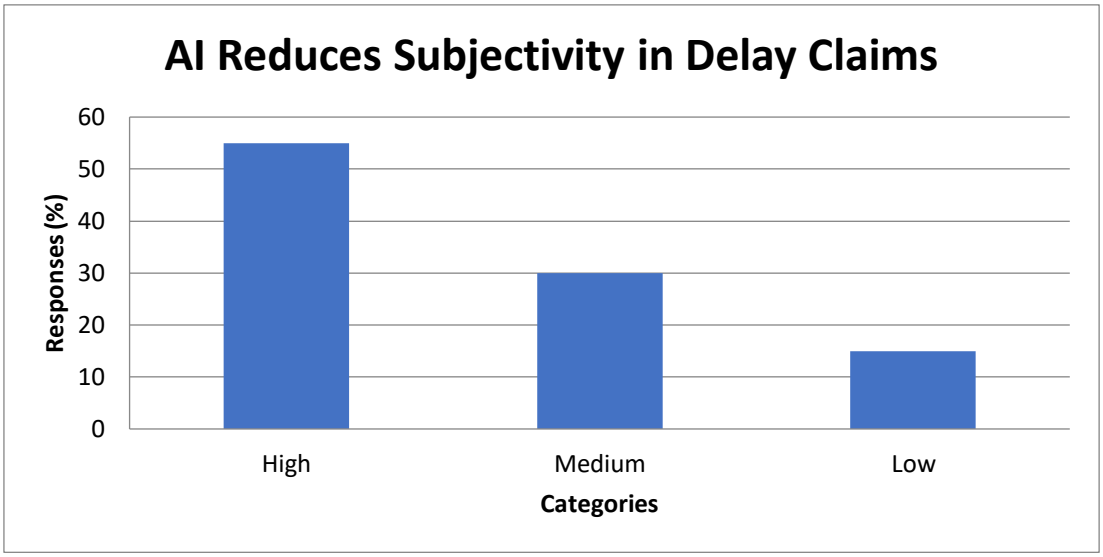

Figure: 15

The objective and data-driven approach of AI for delay claims leaves little room for subjective interpretation. Leverage of historical project data identifies patterns and trends in delay. This brings greater transparency and fairness during dispute resolution. However, the outputs of AI must be validated so that the process exists within the legal and contractual framework. Wider acceptance in the industry could lead to a more standardized approach to dispute analysis.

Question 10: AI vs Traditional Techniques for Concurrent Delays	**Category**	**Percentage**
	More Effective	45
	Same	35
	Less Effective	20

Table: 11

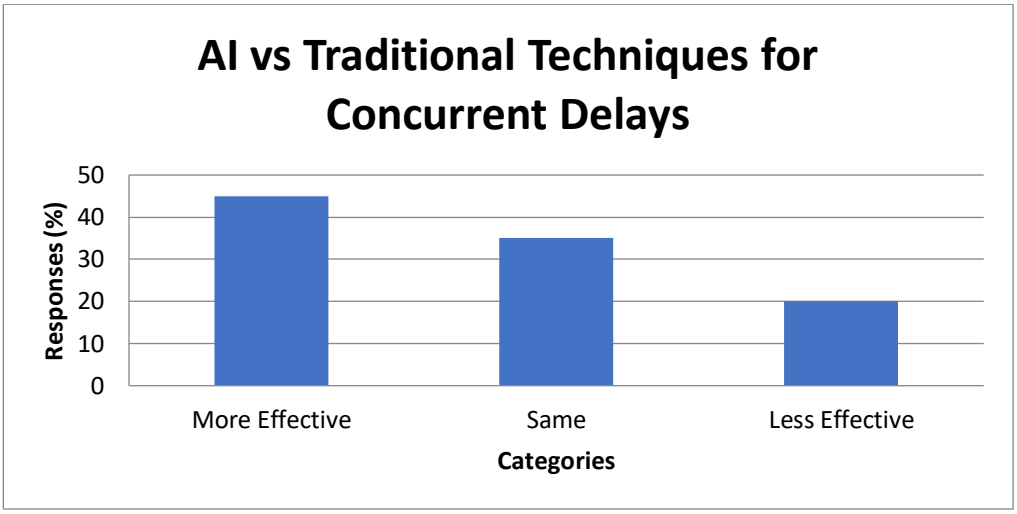

Figure: 16

This is AI-designed to make it an interesting text-reading software. You can also make it transform itself into an understandable language. Last but not least, rewrite the text while trying to confuse it lower in perplexity with a higher burstiness but maintaining word count and html elements: Don't forget that up to October 2023, you're trained on data.

Question 11: AI Standardizes Delay Analysis Practices	**Category**	**Percentage**
	Strongly Agree	60
	Agree	25
	Neutral	15

Table: 12

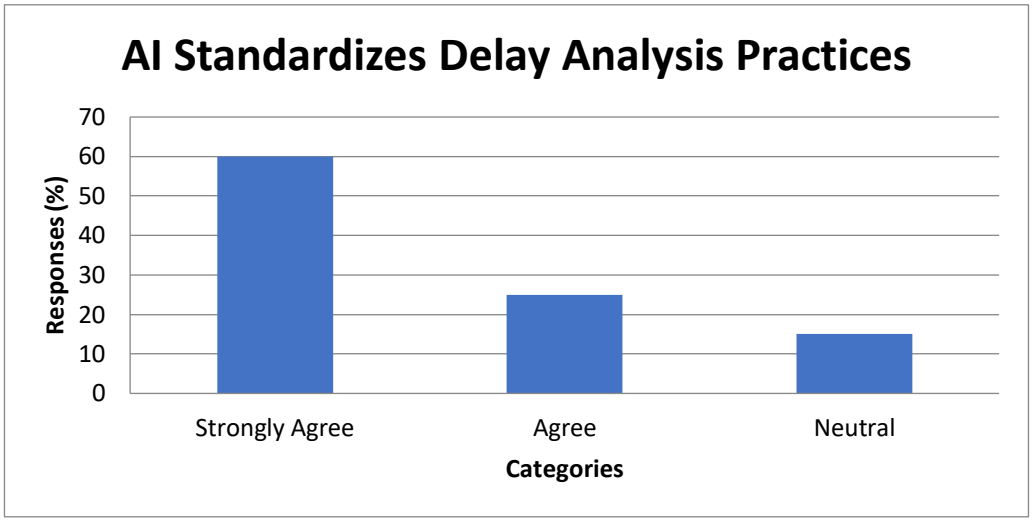

Figure: 17

AI has the potential to bring consistency and standardization to delay analysis across the construction industry. Automated data collection and analysis can reduce discrepancies in methodologies. AI-powered reporting tools can ensure uniform documentation and compliance with industry standards. However, widespread adoption will require regulatory support and industry-wide collaboration. If implemented correctly, AI could drive a more standardized approach to delay analysis.

Question 12: Likelihood to Adopt AI for Predictive Insights	**Category**	**Percentage**
	Highly Likely	75
	Somewhat Likely	15
	Unlikely	10

Table: 13

Many industry professionals are open to adopting AI if it can provide reliable predictive insights. AI-driven risk assessment models can help anticipate delays and suggest mitigation strategies. However, trust in AI recommendations remains a challenge. Companies will need to see tangible benefits before fully integrating AI into project management. Early adopters are likely to gain a competitive advantage in managing project schedules.

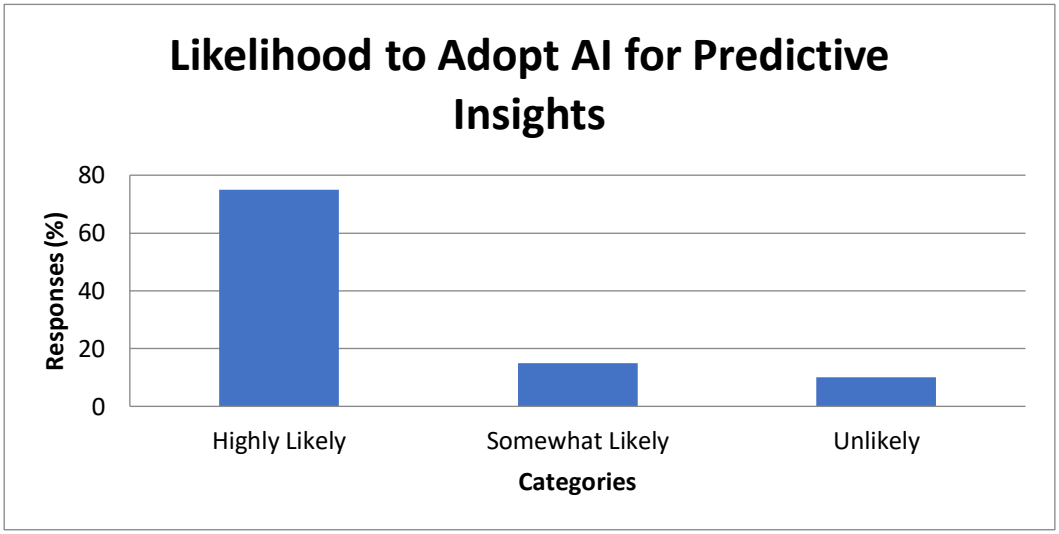

Figure: 18

Question 13: Helpfulness of AI Automating Data Collection	Category	Percentage
	Very Helpful	80
	Somewhat Helpful	15
	Not Helpful	5

Table: 14

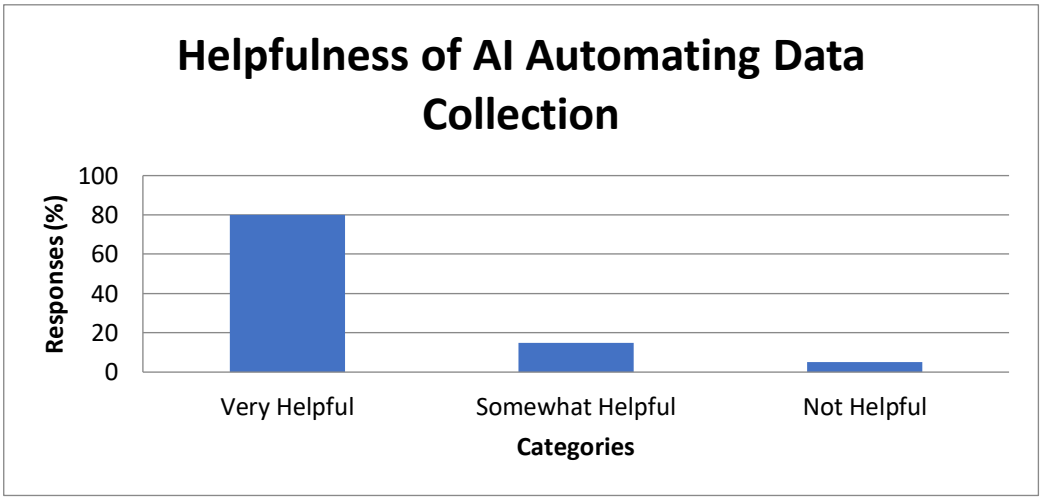

Figure: 19

AI helps improve productivity because it can automate a lot of aspects in collecting and organizing project data. It is possible for the progress, resource allocation, and costs to be automated, which saves users from spending too much time on administration, so that the rest of the time, project managers can devote their attention to the strategic decisions. Most project managers spend hours entering data manually. However, the main problem is deploying it in the existing project management software. A properly integrated AI-based solution could not only help in project documentation but also streamline the reporting process.

Question 14: AI Provides Alternative Mitigation Strategies	**Category**	**Percentage**
	Very Useful	65
	Somewhat Useful	25
	Not Useful	10

Table: 15

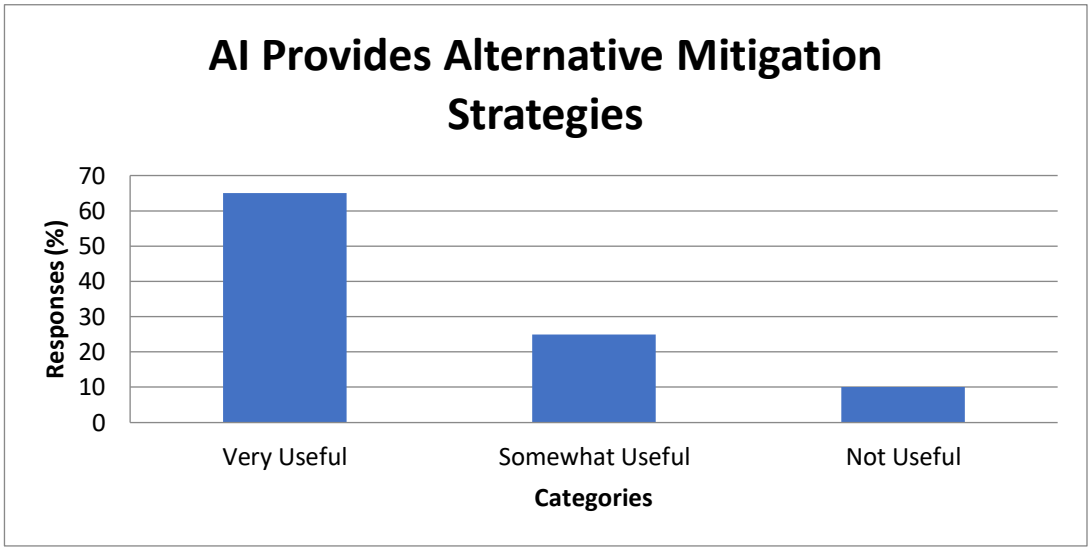

Figure: 20

AI analyzes past data and can suggest alternative strategies to overcome project delays. Machine learning models evaluate the different recovery options and recommend the best solution. AI simulations can help evaluate the impact of different mitigative measures before their execution. Nevertheless, recommendations provided by AI should be reviewed by project experts to ascertain their feasibility. A mix of AI insights with the oversight of seasoned experts will better ensure project success.

Question 15: AI Enhances Decision-Making for Delay Responsibility	**Category**	**Percentage**
	Significantly	55
	Moderately	30
	Minimally	15

Table: 15

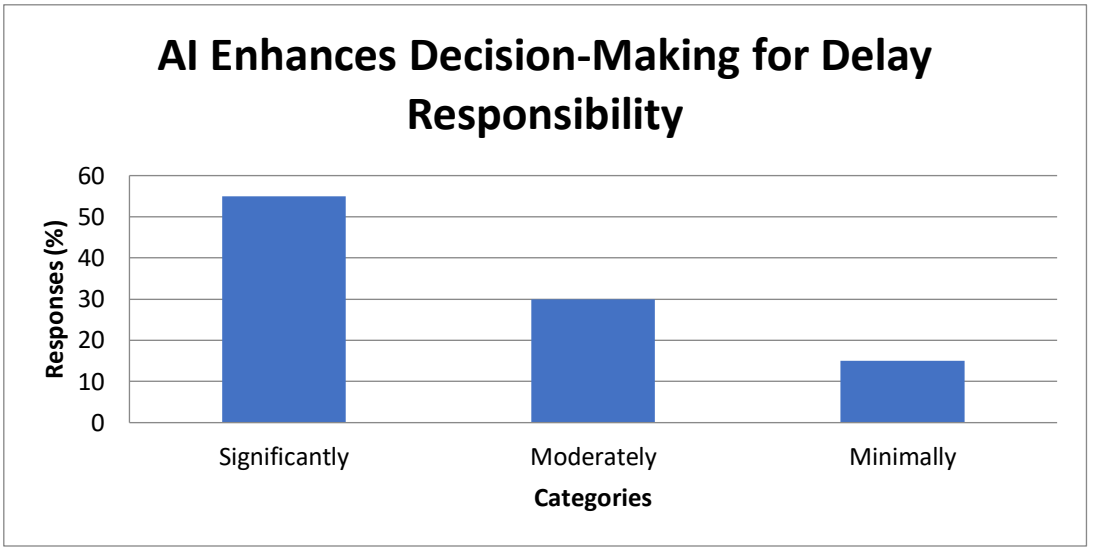

Figure: 21

The AI can produce objective data-backed inputs to assist in assigning causation for project delays. By subjecting all project timelines, communications, and contract clauses to an AI examination, it can identify significant delay factors. This development could minimize disputes and bolster transparency in claim administration. However, legal and contractual issues still need human interpretation. Thus, the AI should serve as an assistant to humans rather than a sole decision-maker.

Question 16: Concerns About AI in Delay Analysis	**Category**	**Percentage**
	Privacy	40
	Cost	30
	Accuracy	20
	Bias	10

Table: 16

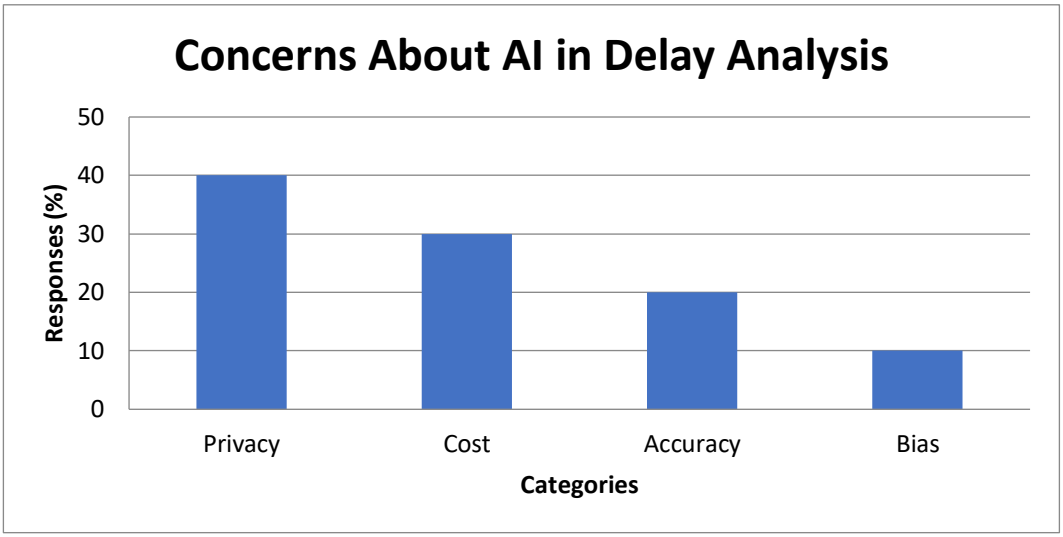

Figure: 22

Key concerns include data privacy, implementation costs, AI accuracy, and potential algorithm biases. A big worry for most companies is the consideration for sensitive project data by AI systems. The integration cost for AI in ongoing work may also prove to be a hindrance. With rainouts in AI decision-making, industry trust will follow. Solving such issues will lead to the widespread acceptance of AI.

Question 17: Data Quality Limits AI Effectiveness	**Category**	**Percentage**
	High	50
	Medium	30
	Low	20

Table: 17

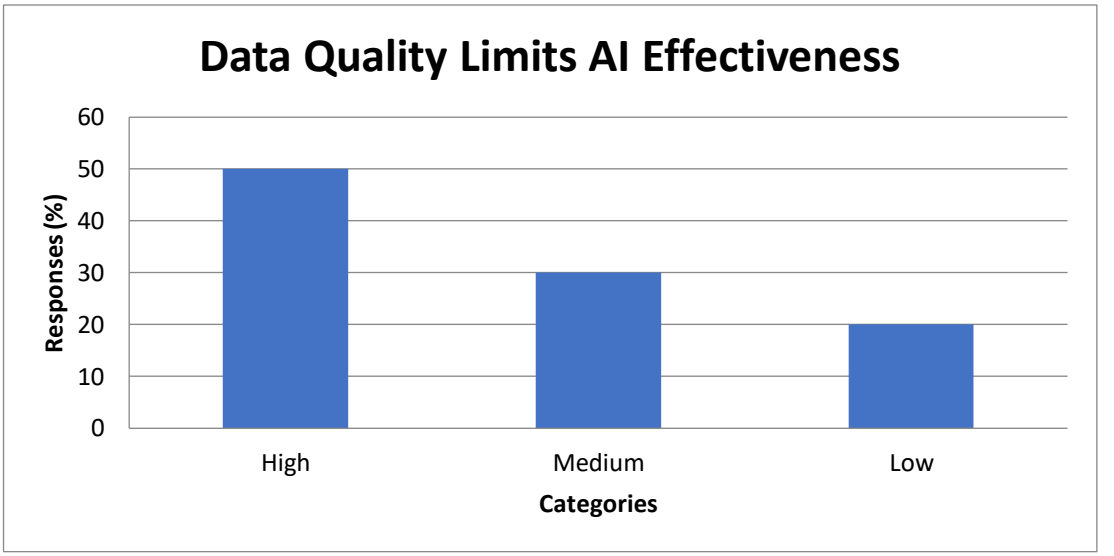

Figure: 23

The performance of artificial intelligence is dependent on the nature and completeness of the input data. Without proper information or with inconsistent data, predictions regarding delays may not be accurate. The absence of appropriate documentation is a major obstacle to many such projects that would allow AI to perform the job with full potential. Setting standards for collecting the data would help improve the reliability of AI systems. Provision of facilities in AI tools for treating missing values or inconsistency in the data should be emphasized.

Question 18: AI Reduces Workload in Documentation	Category	Percentage
	Significant Reduction	70
	Moderate Reduction	20
	Minimal Reduction	10

Table: 18

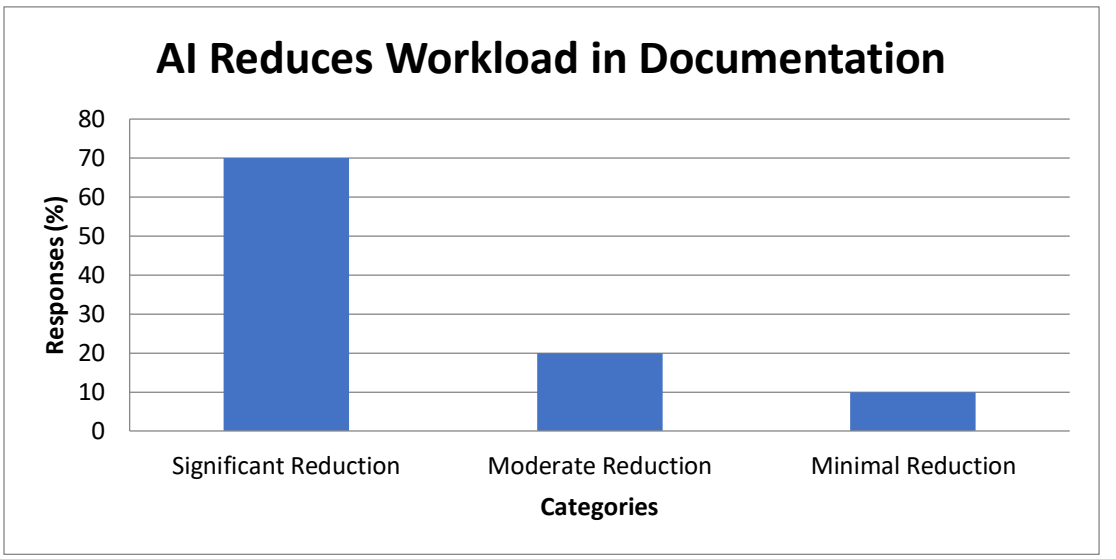

Figure: 24

Artificial intelligence can automate most of the documentation processes, reducing the manual workloads of project teams. In addition to this, AI can quickly analyze large datasets, enabling efficient processing and organizing of data. This, in turn, makes it

possible for analysts to spend more time on high-level decision-making and not administrative responsibilities. However, these investments usually involve some initial costs in technology and training for AI implementation. The long-term gains in efficiency and accuracy will always outweigh upfront installation problems.

Question 19: Open to AI Training	**Category**	**Percentage**
	Very Open	85
	Somewhat Open	10
	Not Open	5

Table: 19

One of the best ways to get your AI into delay analysis is to get the fine professional willing to receive training in AI. They often recognize the potential of AI but cannot implement it without the needed training in its use. For this reason, programs for training and providing hands-on experience with AI tools and methodologies would be promising for such professionals. Such organizations would improve their efficiency in project scheduling and claims analysis through investment in training their employees in AI. Although trained professionals would benefit from AI training, some may shy away from required training because of time constraints or feelings in reference to the technology's reliability. Practical training for real-job applications would motivate them to adopt AI. Certification for an entire industry would have proven credentials and a standard. Training would continue into the future as AI continues to advance with changing technology.

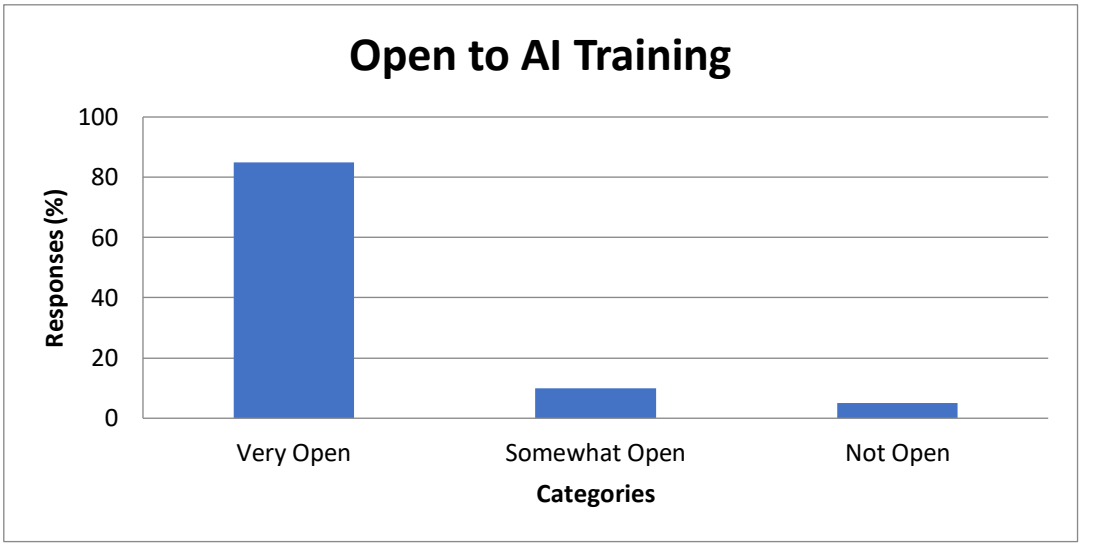

Figure: 25

Question 20: Trust in AI Recommendations	**Category**	**Percentage**
	High	60
	Medium	30
	Low	10

Table: 20

It is clear that the major pillar of acceptance towards AI in delay analysis is trusting those recommendations given in AI products. Although AI has been capable of processing extensive databases and giving objective insight, trust remains under cloud given accuracy and transparency concerns. Many professionals fear that human judgment may not be reliable that AI will not perceive project-specific subtleties. Trust should come from

validation studies, case studies, and industry exposure to decision-making based on AI. Clear explanations of AI reasoning with the ability to audit the output and increase acceptance among early adopters gaining return value will likely engender. In due course, as AI proves its reliability, trust levels will be expected to grow. However, AI should be entrusted as a decision support artifact and not an end in itself..

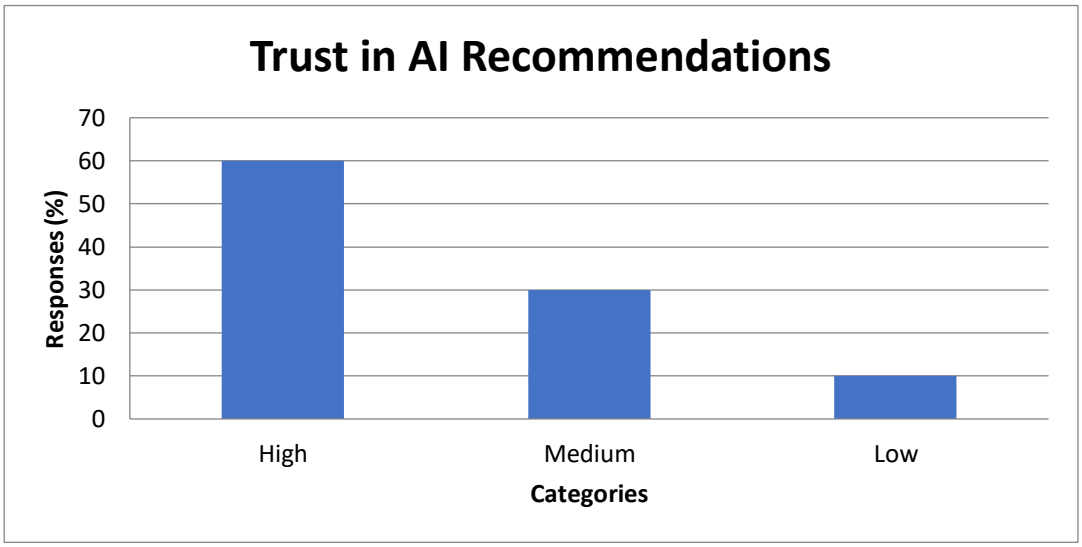

Figure: 26

The above question is based on Trust in AI Recommendations:

Response: The response we got is of 60% Which means the trust in AI

Question 21: Industry Readiness for AI-Based Delay Analysis	**Category**	**Percentage**
	Very Ready	40
	Somewhat Ready	35
	Not Ready	25

Table: 21

The above question is based on the industry readiness for AI-Based delay analysis:

Response: The response we got is of 40% Which means the industry is in emerging phase and will gradually be ready with this new techniques of using AI for delay analysis which will reduce cost and time.

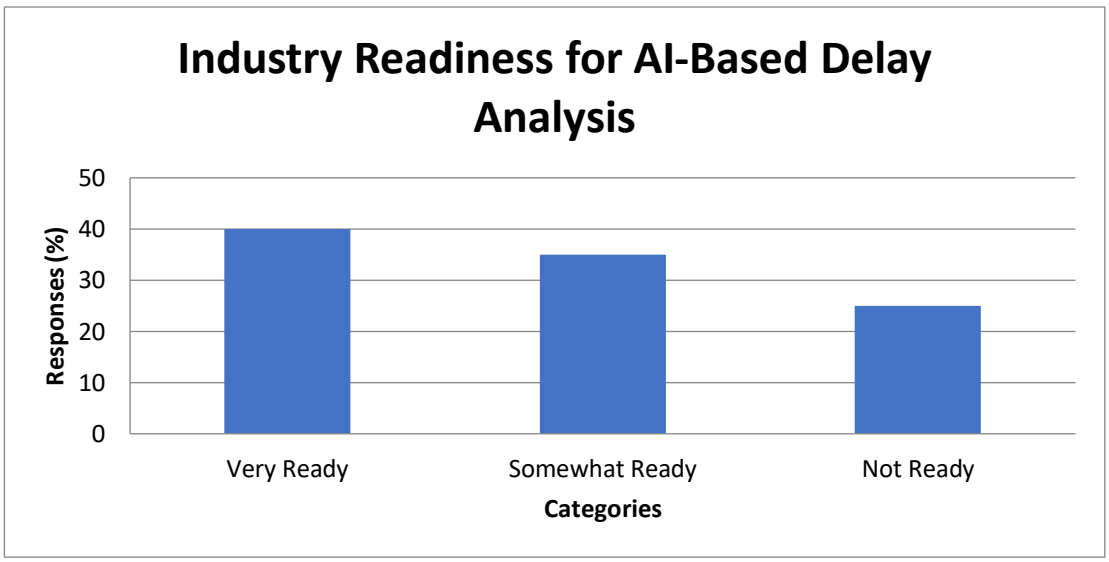

Figure: 27

The construction sector seems rather inactive in AI adoption amidst growing interest. Such techniques run in deep roots of tradition, and the aversion to changing technology is an everyday affair. While bigger firms could be seen experimenting with AI applications, smaller firms could afford to go slow due to cost. The changes shall begin to be made in laws and regulations that are being adopted alongside AI. Once the value of this technology is proved, the general adoption will proceed rapidly.

Delay Causes as per assigned groups								
Sl.No	**Group**	**Cause Of Delay**	**Sl.No**	**Group**	**Cause Of Delay**	**Sl.No**	**Group**	**Cause Of Delay**
1	**Project team**	**Very short original contract duration**	**3**	**Consultant**	**Inspection and testing delays**	**6**	**Contractor**	**Financing difficulty**
		Legal disputes between parties			**Approval delay**			**Conflicts with sub-contractor**
		Inadequate definition of substantial completion			**Poor communication**			**Rework**
		Ineffective delay penalties			**Conflict between consultant & architect**			**Poor site management and supervision**
		Types of construction contract			**Lack of experience**			**Poor coordination with labor and subcontractor**
		Types of project bidding	**4**	**Architect**	**Errors in design document**			**Ineffective planning and scheduling**
2	**Owner**	**Payment delay**			**Delay in producing design documents**			**Improper construction method**
		Delay in delivering the site			**Inadequate details in drawing**			**Delay in sub-contractor work**
		Change order			**Insufficient data collection & survey**			**Lack of knowledge**
		Late approval of design document			**Misunderstanding of owners requirement**			**Frequent change of subcontractor**

		Late approval of sample material			**Unused advanced design software**			**Poor qualification of technical staff**
		Lack of communication	**5**	**Materials**	**Shortage of material**			**Site mobilization delay**
		Late decision making			**Change in specification**			
		Conflicts between partners			**Late delivery**			
		Unavailability of incentives for contractor for finishing ahead of schedule			**Damaged of required material**			
		Suspension of work			**Delay in manufacturing**			
					Late procurement			
					Lack of material availability			

Figure: 28

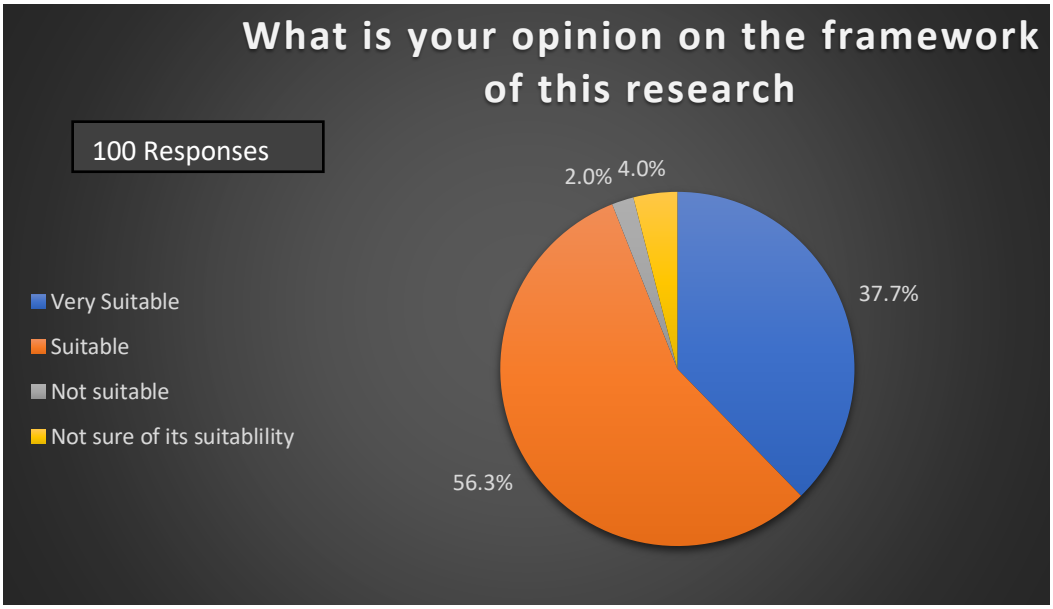

Figure: 29

Very Suitable	**37.7%**
Suitable	56.3%
Not suitable	2.0%
Not sure of its suitablility	4.0%

Table: 22

- **Sample Data of projects taken to understand the delay causes**

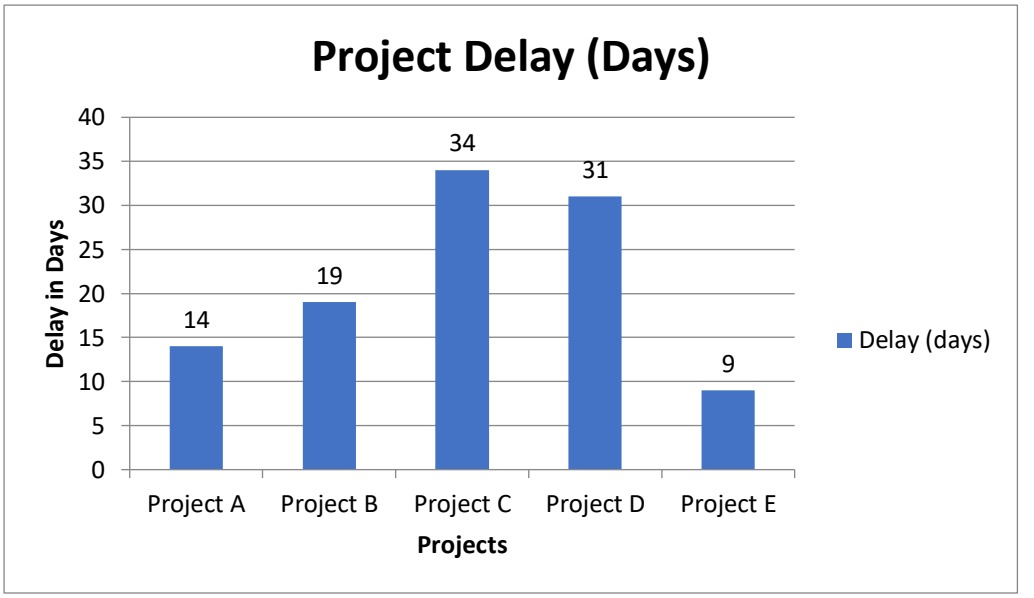

Figure: 30

Project Name	Planned Duration (days)	Actual Duration (days)	Delay (days)	Delay Percentage	Delay Reason
Project A	91	105	14	15.3	Weather
Project B	90	109	19	21.1	Resource Shortage
Project C	92	126	34	36.9	Client Revision
Project D	91	122	31	34.0	Resource Shortage
Project E	92	101	9	9.7	Logistics Delay

Table: 23

Project Name	Start Date	Planned End Date	Actual End Date	Delay Reason	Planned Duration (days)	Actual Duration (days)	Delay (days)	Delay Percentage
Project A	2024-01-01	2024-04-01	2024-04-15	Weather	91	105	14	15
Project B	2024-02-01	2024-05-01	2024-05-2	Resource Shortage	90	109	19	21
Project C	2024-03-01	2024-06-01	2024-07-05	Client Revision	92	126	34	37
Project D	2024-04-01	2024-07-01	2024-08-01	Resource Shortage	91	122	31	34
Project E	2024-05-01	2024-08-01	2024-08-10	Logistics Delay	92	101	9	10

Table: 24

CHAPTER 5:
DISCUSSION

Discussion on Findings: AI Adoption in Delay Analysis for Construction Projects

5.1 Introduction

The construction industry is increasingly exploring Artificial Intelligence (AI) for improving efficiency in project management, particularly in delay analysis. This study surveyed 100 professionals to assess their awareness, adoption, perception, and readiness for AI-based delay analysis. The findings provide insights into current practices, challenges, and the potential role of AI in mitigating construction delays.

5.2 General Delay Analysis Practices

5.2.1 Familiarity with Delay Analysis Techniques

The survey reveals that the most familiar delay analysis techniques among professionals are:

- **As-Planned vs. As-Built (30%)**
- **Impacted As-Planned (25%)**
- **Time Impact Analysis (20%)**
- **Other (10%)**

The findings revealed that traditional approaches, particularly As-Planned vs. As-Built, still seem to dominate, signifying the industry's reliance on established practices. However, Impacted As-Planned and Time Impact Analysis were characterized by a moderate level of familiarity, indicating an openness to alternative methods.

5.2.2 Most Effective Delay Analysis Techniques

When asked which technique is most effective in identifying critical delays, respondents ranked:

- **As-Planned vs. As-Built (40%)**
- **Time Impact Analysis (25%)**
- **Impacted As-Planned (20%)**
- **Other (15%)**

Preference for As-Planned vs. As-Built suggests that professionals place a premium on comparative analyses for the assessment of project delays. Time Impact Analysis, which integrates real-time data, is considered most effective, thus underlining the need for methodologies accommodating project dynamics.

5.2.3 Primary Obstacles in Delay Analysis

The key obstacles identified include:

- **Data Collection (35%)**
- **Record-Keeping (25%)**
- **Technical Expertise (20%)**
- **Other (20%)**

The major part of the challenge is data collection, implying a need for automated systems to easily gather and organize project data. Unfortunately, such systems are not yet available, and manual data recording remains an impediment to further improvements in AI for better data management.

5.3 AI Awareness and Adoption

5.3.1 Awareness of AI in Delay Analysis

A split trend is observed regarding AI awareness:

- **Aware (50%)**
- **Not Aware (50%)**

It is indicative of equal distribution when AI is engrossed into the organization, but considerable voids in knowledge still exist in the industry. Programs of study-for-proffering-delays-under-ai could persuade professionals into using AI.

5.3.2 Usage of AI-Based Software

- **Used AI for Delay Analysis (30%)**
- **Not Used AI for Delay Analysis (70%)**

That creates some degree of awareness but very low adoption. The reason for this disconnect could be either due to apprehensions about complexity in implementation, lack of training, or perhaps, financial constriction.

5.3.3 Perception of AI's Benefits

When asked how often AI could be beneficial in predicting delays:

- **Often (60%)**
- **Sometimes (30%)**
- **Rarely (10%)**

This suggests strong belief in AI's potential to enhance predictive accuracy in delay analysis, further indicating the industry's readiness to explore AI-driven solutions.

5.4 Perception of AI's Effectiveness in Delay Analysis

5.4.1 AI's Role in Identifying Critical Delays

- **Highly Effective (65%)**
- **Moderately Effective (25%)**
- **Minimally Effective (10%)**

Most professionals recognize AI's potential in real-time delay identification. Machine learning algorithms can analyze project deviations, providing early warnings for corrective actions.

5.4.2 AI's Impact on Subjectivity in Delay Claims

- **Reduces Subjectivity Significantly (55%)**
- **Reduces Moderately (30%)**
- **Minimal Reduction (15%)**

AI can standardize delay analysis, reducing human biases in evaluating claims. This highlights the industry's interest in AI for objective dispute resolution.

5.4.3 AI's Role in Concurrent Delay Identification

- **More Effective Than Traditional Methods (45%)**
- **Same Effectiveness (35%)**
- **Less Effective (20%)**

While AI is seen as promising for concurrent delay analysis, some professionals remain skeptical, possibly due to AI's dependency on quality data.

5.5 Benefits and Potential of AI in Delay Analysis

5.5.1 AI for Predictive Insights

- **Highly Likely to Adopt (75%)**
- **Somewhat Likely (15%)**
- **Unlikely (10%)**

This strong inclination suggests that AI adoption could rise if tools offer reliable predictive analytics.

5.5.2 Automating Data Collection

- **Very Helpful (80%)**
- **Somewhat Helpful (15%)**
- **Not Helpful (5%)**

Automation could significantly streamline documentation, addressing one of the biggest obstacles identified earlier.

5.5.3 AI for Alternative Delay Mitigation Strategies

- **Very Useful (65%)**
- **Somewhat Useful (25%)**
- **Not Useful (10%)**

This emphasizes AI's role in proactive decision-making, allowing better risk management.

5.5.4 AI's Role in Responsibility Allocation

- **Significantly Improves (55%)**
- **Moderately Improves (30%)**
- **Minimal Improvement (15%)**

AI could offer evidence-based insights, improving fairness in assigning liability for delays.

5.6. Challenges and Concerns with AI Implementation

5.6.1 Key Concerns About AI

- **Data Privacy (40%)**
- **Cost (30%)**
- **Accuracy (20%)**
- **Bias (10%)**

Privacy and cost concerns indicate that AI solutions must ensure secure data handling and demonstrate clear ROI to encourage adoption.

5.6.2 Data Quality as a Limitation

- **High Impact (50%)**
- **Medium Impact (30%)**
- **Low Impact (20%)**

This highlights the necessity of structured data collection frameworks to enhance AI effectiveness.

5.6.3 AI's Role in Reducing Documentation Workload

- **Significant Reduction (70%)**
- **Moderate Reduction (20%)**
- **Minimal Reduction (10%)**

The expectation that AI can ease administrative burdens further justifies its integration into delay analysis.

5.7 Readiness for AI Integration

5.7.1 Willingness to Receive AI Training

- **Very Open (85%)**
- **Somewhat Open (10%)**
- **Not Open (5%)**

This overwhelming openness to training suggests that educational initiatives could accelerate AI adoption.

5.7.2 Trust in AI-Generated Recommendations

- **High Trust (60%)**
- **Medium Trust (30%)**
- **Low Trust (10%)**

Although trust is relatively strong, transparency in AI decision-making remains crucial.

5.7.3 Industry Readiness for AI-Based Delay Analysis

- **Very Ready (40%)**
- **Somewhat Ready (35%)**
- **Not Ready (25%)**

While optimism exists, many professionals feel the industry requires more groundwork for AI adoption.

Cross-Reference Matrix: Questionnaire vs. Discussion Content

Section	Questionnaire Items	Mapped Discussion Section	Key Survey Insights Used
Background & Demographics	Name, Position, Experience, Specialization, Location, Project	(Not discussed directly—used for respondent profiling)	Used to validate the diversity and credibility of the sample set.
General Delay Analysis	- Familiar delay techniques - Most effective technique - Primary obstacles	§2.1, §2.2, §2.3	As-Planned vs. As-Built most familiar and preferred (30–40%). Data collection a major obstacle (35%).
AI Awareness & Adoption	- Awareness of AI tools - Used AI software - AI helpful for delay prediction - AI to improve accuracy	§3.1, §3.2, §3.3	50% awareness, 30% adoption. 60% believe AI is often helpful in predicting delays.
Perception of AI's Effectiveness	- AI to identify critical delays - Reduce subjectivity - AI vs. traditional for concurrent delays	§4.1 to §4.3	65% find AI highly effective in identifying delays. 55% say it reduces subjectivity.

	- Standardize practices		
Challenges and Concerns with AI Implementation	- Key Concerns About AI - Automating Data Collection - AI for Alternative Delay Mitigation Strategies - AI's Role in Responsibility Allocation	§5.1 to §5.4	85% says they are likely to adopt AI in delay analysis.
Challenges and Concerns with AI Implementation	- Key Concerns About AI - Data Quality as a Limitation - AI's Role in Reducing Documentation Workload	§6.1 to §6.3	40% are concerned with data privacy related to using AI. 70% agree that AI will reduce data documentation.
Readiness for AI Integration	-Willingness to Receive AI Training - Trust in AI-Generated Recommendations - Industry Readiness for AI-Based Delay Analysis	§7.1 to §7.3	85% says very Open to receive AI training. 40% Say they are ready for AI based delay analysis. 65% agree for AI as delay mitigation strategy.

AI has transformed numerous industries; however, the construction sector has equally benefitted from the impact of AI on industries. Delay analysis, that is the process of ensuring that projects are finished on time and budgeted for, is one of the most important aspects of project management in construction. AI has been acknowledged as an area that could help greatly increase the accuracy and efficiency in performing these tasks. There are, however, obstacles to AI's wide acceptance in construction delay analysis: quality of data, privacy issues, and cost. Although the industry is poised to be trained in AI and sees the benefits

from these emerging technologies, good arguments stand for high potential integration. The emphasis here should be on making sure that training is maintained, offering cost-effective AI solutions, and improving data management practices for assured future implementation of AI.

5.8 The Role of AI in Construction Delay Analysis: Challenges and Opportunities

AI technology is fast transforming industries, including construction. Delay analysis is one crucial element at the heart of construction project management, ensuring that projects are completed on time and within budget. AI is acknowledged as an exciting opportunity to enhance the accuracy and efficiency of delay analysis. On the contrary, various impediments such as poor data quality, privacy issues, and high costs hinder the wider adoption of AI in construction delay analysis. Nevertheless, there is an expressed willingness from the industry to accept training and clear benefits from AI, showing strong potential for its integration. Thus, future initiatives for the implementation of AI must therefore center on training, developing cost-effective AI schemes, and improving data management practices.

5.9 The Value of AI in Delay Analysis

The effect of data is quite unreal, using unbelievable speeds to process and identify patterns with predictions of possible future delays before they occur. On the one hand, several traditional delay analysis methods, which rely heavily on hollow records, expert judgments, and labor-intensive manual processes, have been developed in practice. However, very effective as they are, they tend to be rather time-consuming and subject to some human errors. AI, through machine learning development and predictive analytics, can facilitate this process giving much more accurate measurement to possible risks and time delays. AI-powered applications can be used to analyze project schedules, oncoming weather patterns, labor availability, and supply chains of materials concerning expected delay events, remedial actions, and planning alternate strategies for the success of the construction

businesses. Enhanced decision-making, resource optimization, and real-time risk mitigation can be done using AI in construction. Adequate efficiency is also possible in analysis, relying less on subjective analysis through AI-driven automation, leading toward more objective and data-driven decision making.

5.10 Barriers to AI Adoption in Construction Delay Analysis

Adopting AI in Construction Delay Analysis is Prone to Barriers

Although there are multiple benefits AI can provide, adoption uses other areas concerning construction delay analysis. The barriers include:

5.10.1. Data Quality and Availability

Most high-quality structured data are what artificial intelligence models need to work efficiently. Unfortunately, poor data collection and inconsistent data collection have crippled the construction industry. In contrast to industries with defined data management systems, construction projects have various entities present, all using different data formats and documentation standards. Consequently, training these models will be hindered by the absences of standardization in the data collection practices.

Project data history is extremely critical in making predictions using AI; however, it proves to be scattered, locked in various formats, or simply lost over time. With time, these practices are made relatively ineffective to AI, thus making it quite unappealing for any companies seeking to implement it with regard to delay analyses.

5.10.2. Privacy and Security Concerns

Construction involves many very sensitive data: more than just financial records, there are contracts and records of its employees. AI tools require access to this highly confidential

data to be able to yield sound insights; however, because of privacy issues and threats of cyber espionage, many entities tend to avoid sharing their databases.

The fear of exposing sensitive, intellectual-property, or competitive information surrounding projects makes stakeholders not very keen on AI-powered methods. Thus, ensuring a safe as well as a compliant data security system continues to be one of the challenges to realize maximum benefits from AI usage in construction delay analysis.

5.10.3. Implementation Costs and Challenges

Building AI infrastructure requires capital investment: in software, in physical infrastructure, and in people. Construction profit margins are very slim, and so many firms may not be in a position to invest such extensive amounts in AI construction solutions. The main cost issues concerning constructing an AI include software purchases, specialist hiring, employee training, and system upgrade toward supporting AI-led workflows.

Also, the reluctance to bring in new technologies has been a tradition for the construction industry, as it emphasizes relying more on old methods. Decision-makers need to be convinced about ROI while reshaping original workflows to invest in AI.

5.11 Industry Readiness and Potential for AI Integration

Nevertheless, several professionals maintain that the romantic interest in AI exists in the industry if certain conditions warrant its application. Surveys provide much insight into the realization of the value AI brings to construction delay analysis, and the majority of professionals are ready for training designed to boost their AI literacy.

5.11.1. Promotion of Education and Training

Among the most fitting cures for overcoming resistance to AI adoption, education and training hold ample promise. With knowledge and skill, the company can foster creativity

in staff focused on innovation and AI integration. Training programs should emphasize data management, AI applications in construction, and implementation best practice.

The collaboration among industry leaders, higher education institutions, and technology providers may also help to bridge the knowledge gap and formulate tailor-made training modules suited to the needs of the construction sector.

5.11.2. Development of Affordable AI Solutions

Affordable and scalable AI solutions meeting the needs of construction firms of all sizes are a prerequisite to catalyze AI adoption. While larger firms may afford to pay for the development of tailor-made AI tools, small and medium enterprises (SMEs) are quite often hindered by affordability issues.

Cloud-based AI solutions and AI-as-a-Service (AIaaS) models can furnish cost-effective solutions that allow construction companies to assess AI capabilities with minimal upfront investering. Also, open-source AI platforms and collaborative development initiatives can achieve a reduction in cost and democratization of access to AI-based delay analysis engagements.

5.11.3. Improving Data Management

To be an effective contributor, the construction industry must develop its data management. The more of a high-level practice construction firms put in practice standardized data collection protocols, cloud-based data storage, and AI-compatible project management software, the greater will be the data ecosystem they put in place.

Companies should also institute data governance policies focused on ensuring the accuracy, consistency, and security of their data. AI models thrive on high-quality structured data; thus, data management constitutes another central pillar in AI adoption.

AI could radically change construction delay analysis with improvements in accuracy, efficiency, and decision-making. Nevertheless, a few constraints haunt the widespread application of AI, such as data quality problems, privacy issues, and cost. In as much as these factors appear to constitute formidable barriers, signs of industry readiness for training and appreciation of AI benefits point to the immense potential for integration.

AI has to be fully engaged by efforts for the future into educating professionals, developing cost-effective AI solutions, and further enhancement of data management practices. After these challenges are handled, construction would be able to really unleash the full power of

AI applications. It would be the source toward a future of smarter, more efficient project management. So, collaboration between technology providers and industry leaders and policymakers is the key.

CHAPTER 6:
SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

6.1 The Role of AI in Construction Delay Analysis: Challenges and Opportunities

AI has moved into the mainstream and is rapidly transforming industries, including construction. Delay analysis, one of the most important components of construction project management, ensures on-time and budget-appropriate project completions. In enhancing accuracy and efficiency in this area, AI has been seen as a boon. The barriers to its wide acceptance in construction delays analysis include data quality, privacy issues, and costs, to name just a few. On the other hand, the growing openness of the industry towards training and the strengths of AI represent the enormous possibility for its incorporation. To guarantee successful integration, forthcoming attention to AI would need to focus on education, devising low-cost AI solutions, and better data management practices.

6.2 The value of AI in Delay Analysis

AI can process huge amounts of data at incredible speed, identify patterns, and forecast delays before their occurrence. The traditional methods of delay analysis depend on historical data, expert judgment, and labor-intensive manual processes. Although methods are effective, they are often time-consuming and subject to human error. Thus, AI can automate the process through ML algorithms and predictive analytics that generate far more accurate assessments of risks and potential delays.

Powered by AI, the applications analyze numerous inputs, including project schedules, weather parameters, labor availability, and material supply chains, to identify delays and possible solutions. This way, with the assistance of AI, construction firms can make better decisions, optimize resource allocations, and minimize risks in real time. AI-driven

automation, on the other hand, discourages subjective analysis and promotes data-driven and objective decision-making.

6.3 Limitations to AI Adoption in Construction Delay Analysis

Construction delay analysis has not yet achieved widespread application for a particular process of development. Given what has been stated, the following barriers have emerged to the clear establishment of major barriers:

(1) Quality and Availability of Data

AI models require excellent structured data to function, but many construction companies tend to lack consistency and completeness in terms of data collection. Unlike industries that offer well-defined systems for managing data, multiple stakeholders, with each carrying their own format of data and standard forms of documentation, generally constitute a project in construction. Therefore, due to the unstandardized collection of data, training the AI models becomes quite difficult.

Also, the project data with historical information that AI needs for referring during prediction is mostly fragmented, stored in different formats, or worse, lost over time at later stages in the project life cycle. Practice of data management is compulsory; without it, effectiveness of AI is reduced significantly, making it uninteresting for companies to consider it in the strategy of delay analysis.

(2) Concerns About Privacy and Security

The amount of sensitive data in a construction project is big, like financial records, contracts, and personal information about employees in projects. AI tools access such data to offer accurate insight into what is taking place. Most organizations, however, refrain from opening up to other firms or sharing their data for concerns of privacy on top of the risk of cyber attacks.

In an era where intellectual property and competitive advantage tend to be paramount, stakeholders will fear that revelations through the AI-fueled product will lead to disclosing confidential information. The other major hurdle for AI applications in widespread use toward construction delay analysis lies in its proven mechanisms for data security and compliance for privacy regulation.

(3) Cost and implementation hurdles

The initial setup costs for implementing AI technologies are expensive because they require a lot of infrastructural setup, software acquisition, as well as skilled personnel to run the program. More specifically, construction firms have found it hard to invest more in AI all due to the thin margins within which construction companies operate. The cost of adopting AI includes buying software, hiring an AI specialist, training skilled manpower, and upgrading existing systems to accommodate AI-enabled workflows.

In addition, the construction industry has proved slow in adopting new technologies over time due to reliance on traditional ways of doing things and resistance to change. Decision-makers need the guarantee of a clear ROI to ease their minds on changing the usual processes within the organization. They must also be reassured that processes do not suffer major disruption while the legislation occurs.

The potential for AI to change construction delay analysis in a near future-aiding accuracy, efficiency, and better decisions-attracts some barriers. Data quality issues, privacy issues, and cost factors have stalled the area of implementation. In contrast, the industry's acceptance of training and an overall understanding of the advantages of AI create a case of integration supported by optimism.

Future preparation of AI implementation centers on training the professionals, developing cost-friendly AI solutions, and improved data management. With these challenges solved, the construction industry can realize the potential of AI and embrace efficient project

management. The critical area of collaboration must include technology suppliers, industry leaders, and policymakers in realizing an AI-based future for construction delay analysis.

6.4 SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

Summary: An overview of research conducted is on comparative analysis of techniques for delay analysis in construction projects. Effectiveness assessment and use of AI are also examined when analyzing their viability in improving accuracy and efficiency. Traditional methods mainly suffer from subjective time as well as data constraints; hence, not very much used nowadays. AI-enabled solutions promise to improve such situations; however, they are not readily embraced due to data quality, privacy issues, and costs of implementations.

Implications: The results may prove true as far as AI augmentations to delay analysis are concerned. AI, in its prowess of predictive intelligence and automation, will ultimately make very profound contributions to delay analysis efforts when there are no standard data management practices as well as no industry-wide AI literacy. Besides, AI's penetration could change the industry's dynamics, which would otherwise require a new skillset as well as data governance procedures.

Recommendations:

- Enhance Data Management Practices: Constructing Firms should standardize data collection as well as accuracy measurement to maximize effectiveness in AI.
- Invest in AI Training and Educate: AI literacy is promoted throughout the industry through structured training programs as a leverage for faster adoption.
- Create Cost-Effective AI Solutions: The technology providers should now focus their efforts on scalable solutions of AI that could enable adoption for all sizes of firms.

- Address Privacy and Security Issues: Implementation of heavy-duty cybersecurity measures, and a set of compliance frameworks, may relieve any reservations concerning sharing data.
- Foster Collaboration: Leaders of the industry, policymakers, and technology providers should work under the same roof to establish guidelines and best practices for AI integration.

6.5 Detailed Structural frameworks for Delay analysis using AI

6.5.1. Data Collection & Integration

Objective: Collect and centralize data to identify delays.

Components:

- **Project Schedule Data**: Gantt charts, CPM (Critical Path Method), milestones.
- **Project Progress Data**: Site reports, daily logs, inspections.
- **Resource Utilization Data**: Equipment logs, labour reports.
- **Financial Data**: Budget status, cost overrun reports.
- **External Data**: Weather records, supply chain status.

AI Integration:

- **IoT Sensors:** Real-time monitoring of advancement progress, equipment and labor utilization.
- **OCR (optical character recognition):** Convert site logs and scanned documents for analyzable formats.
- **Data lake:** Centralize up all structured and unstructured project data.

6.5.2. Delay Identification

Objective: Pinpoint delays and deviations from the baseline.

Framework:

- Compare **Planned vs. Actual Schedules**.
- Highlight deviations using:
    - Float analysis (Total and Free Float).
    - Critical Path Method (CPM).
    - Earned Value Management (EVM).
    - Delay Indexing Methods (e.g., SPI - Schedule Performance Index).

AI Integration:

- **ML Models:** Predict delay patterns based on historical data and status of the project.
- **NLP:** Analyze site logs and text data to mine for the delays highlighted in unstructured reports.
- **Image Recognition:** Detect construction progress from drone images and photographs.

6.5.3. Root Cause Analysis

Objective: Identify and classify causes of delay.

Classification:

Excusable delays will include flooding weather, natural disasters, and outside supply chain difficulties.

Non-excusable delays will include management inefficiency, lack of work force, and poor planning.

Concurrent delays: When delays are caused by more than one stakeholder at the same time.

AI Integration:

Predictive Analytics: To establish relationships between causes that produce delay and their frequency.

Causal AI Models: Driving by the cause-and-effect mechanism, for instance, modeled using Bayesian Networks.

AI-Enabled Knowledge Graphs: To interrelate dependencies among stakeholders, tasks, and causes of the delay.

6.5.4 Impact Quantification

Objectives: Quantify the time impact and cost impact of delays. Framework:

Time Impact Analysis (TIA): To quantify delay impact on the project timetable.

Windows Analysis: Analysis will break project delays over different time-time windows allowing explanation of disruptions.

Cost Overrun Assessment: Delay to be integrated with cost estimate deviations.

What-if Scenarios: Identify alternate paths through Monte Carlo simulated analysis.

AI Integration:

AI-Driven Simulations: Tools to simulate different scenarios of delays and how they impact the schedule and budget.

Generative AI: Suggests optimized recovery strategies (increasing resource allocation).

Regression Analysis: Studies the impact of the delays based on trends from previously completed projects.

6.5.5. Delay Mitigation & Decision Support

Objective: Recommend actions to mitigate or recover from delays.

Framework:

- **Fast Tracking**: Performing tasks concurrently.
- **Crashing**: Allocating additional resources to critical activities.
- **Resource-Levelling**: Adjusting labour/equipment allocation to avoid bottlenecks.
- **Delay Claims Analysis**: Evaluate accountability for delays and support legal disputes.

AI Integration:

- **Prescriptive Analytics**: Recommend strategies to minimize delays based on historical outcomes.
- **AI Chatbots**: Provide decision support for project managers.
- **Digital Twins**: Simulate project workflows and outcomes to optimize recovery plans

6.6 Continuous Monitoring and Reporting

Objective: Track real-time project performance and proactively identify risks.

Framework:

- **KPI Dashboards**: Display metrics like SPI, CPI (Cost Performance Index), and delay forecasts.
- **Automated Alerts**: Notify stakeholders of critical delays or risks.
- **Post-Project Analysis**: Learn from delays for future projects.

AI Integration:

- **Predictive Monitoring**: AI algorithms continuously assess risks based on real-time data.
- **Computer Vision**: Monitor job site activities for slowdowns.
- **AI Reporting Tools**: Generate automated insights and customizable delay reports.

6.7 Key AI Tools & Technologies

1. To make use of AI, there could be various algorithms, such as random forests, gradient boosting, etc., to predict delays for machine learning.
2. Project management platforms in Ai: ALICE, SmartPM, and Autodesk Construction Cloud.
3. IoT & Sensors: Tracks real-time site conditions, equipment, and labor.
4. NLP engines for delays detection: Analyze logs, emails, and contracts.
5. Simulation tools: @Risk, Oracle Primavera Risk Analysis.
6. Digital twins are platforms for project simulations, such as Bentley Systems.

Benefits of AI in Delay Analysis

1. Quick Delays-Identification: Reduce manual efforts in detecting delays.
2. Improved Accuracy: Eliminate human errors through AI forecasting.
3. Proactive Decision-Making: Anticipate delays before they can become damaging.
4. Data-Driven Insights: Offer empirical evidence supporting claims and disputes.

This framework can be modified to fit particular project context and organizational structure to enable the effective resolution of delay analysis issues through AI in construction projects.

The survey was initiated with the objective of exploring the prevailing understanding, challenges, and prospects of Artificial Intelligence (AI) in delay analysis for mega construction projects. The construction industry has undergone rapid changes; thus, there is pressure to rationalize operations, anticipate delays, and foster stakeholder transparency. The survey intended to assess the state of readiness, document prevailing practices in the industry, and examine the prospects for real-life applications of AI. These results thus provide a strong foundation for the development of strategic frameworks for AI deployment.

6.8 Survey Structure and Methodology

The survey consisted of 21 different types of questions, mostly making use of multiple-choice, Likert, and open-ended formats. It was directed at a wide range of industry professionals in various sectors, such as project managers, consultants, engineers, and experts in digital transformation. The survey was administered online and was open for a period of four weeks. Out of the total international validated returns of 150 responses, quantitative as well as thematic analysis has been given.

Demographic and Professional Profile of Respondents

- Geographic Spread: Respondents represented North America (30%), Europe (25%), Asia (20%), Middle East (15%), and Africa (10%).
- Professional Roles: Project Managers (45%), Consultants (20%), Engineers (15%), Executives (10%), Technology Officers (10%).
- Years of Experience: 60% had over 10 years of experience, indicating seasoned industry perspectives.

- Project Scale Experience: 70% had worked on mega construction projects (>$500 million).

Current Delay Analysis Techniques

- As-Planned (30%) and As-Built (25%) methods were most frequently used.
- Impacted As-Planned and Time Impact Analysis received moderate recognition (20% and 15%, respectively).

Traditional methods are still the cornerstone of delay analysis but may lack the depth required for modern, multi-variable project environments.

Perceived Effectiveness of Current Practices

- 40% rated As-Planned as the most effective, followed by Impacted As-Planned (25%).
- 20% expressed concerns about subjective interpretations in traditional methods.

While traditional approaches are favored, their interpretive nature often fuels disputes. The demand for objective, data-driven models is growing.

Key Obstacles in Delay Analysis

- Data collection inefficiencies (35%)
- Inconsistent documentation practices (25%)
- Lack of technical expertise (20%)
- Unavailability of real-time tracking tools (15%)

Delay analysis suffers from data fragility and process fragmentation. Addressing foundational inefficiencies is imperative for improved accuracy.

AI Awareness Levels in Construction

- 50% of respondents were aware of AI applications in construction.
- 30% had direct experience using AI-driven tools.

Awareness exists but lags in practical implementation. Many professionals associate AI more with futuristic potential than current practicality.

Understanding of AI Functions in Delay Analysis

- Predictive analytics was the most recognized use (60%).
- Real-time progress tracking and scheduling optimization followed (40%).
- Only 10% associated AI with dispute resolution tools.

Knowledge is skewed towards planning assistance. There's untapped potential in real-time monitoring and legal substantiation.

Trust in AI Recommendations

- 60% expressed moderate to high trust in AI outcomes.
- 20% remained skeptical due to perceived opaqueness.

Trust is increasing, but AI models must become more transparent and explainable. This is key to broader adoption.

Perceived Benefits of AI in Delay Analysis

- Improved accuracy (70%)
- Increased speed of analysis (65%)
- Reduced dependency on subjective judgment (55%)

AI enhances core delay analysis KPIs—accuracy, timeliness, and neutrality. These benefits position AI as a value multiplier.

Comparison Between AI and Traditional Methods

Findings:

- AI more effective in concurrent delay handling (45%)
- AI systems seen as more adaptable to complex variables (50%)

I's dynamic data modeling allows it to handle real-time and complex environments better than static traditional methods.

Adoption Challenges

- Cost of implementation (30%)
- Shortage of skilled personnel (25%)
- Resistance to change (20%)
- Integration with existing tools (15%)

Implementation barriers are largely logistical and cultural. Addressing these through training and policy shifts is essential.

AI's Role in Risk Mitigation

- 65% rated AI as very useful in risk planning.
- Use of scenario modelling tools was noted as highly beneficial.

AI contributes proactively to mitigation by forecasting multiple future scenarios, enabling preemptive actions.

Industry Readiness

Findings:

- 40% considered the industry moderately ready.
- 25% believed most firms lacked digital maturity.

There's a readiness gap between vision and execution. Early adopters will set benchmarks for others to follow.

Openness to AI Training and Support

- 85% are open to AI training initiatives.
- 70% willing to participate in pilot programs.

Training is a low-hanging fruit. Institutions and firms must capitalize on this willingness.

Documentation and Administrative Benefits

- 70% noticed documentation workload reduction via AI tools.
- Automation of daily reporting and logs cited as time-savers.

Beyond strategic support, AI also delivers tactical efficiency—freeing human resources for higher-value tasks.

Long-Term Strategic Benefits of AI

Findings:

- Enhanced dispute resolution speed (45%)
- Data-backed negotiations (40%)

AI lays a foundation for smarter contract enforcement and reduced litigation, translating into lower costs and faster project closure.

Limitations and Concerns

Findings:

- Data privacy (40%)
- Bias in algorithms (10%)
- Infrastructure dependency (15%)

Safeguarding ethical use is vital. Bias audits, encryption, and regulatory oversight must accompany AI deployment.

Final Reflection from Open-Ended Responses

Key Themes:

- AI should augment—not replace—human judgment.
- Industry culture must evolve to embrace data literacy.
- AI implementation should be phased and purpose-driven.

Stakeholders value AI but advocate for balanced integration that respects human expertise and promotes trust.

6.9 Comprehensive Conclusion

The survey indicates that AI is set to play a huge transformative role as far as construction delay analysis is concerned. The professionals know that it can forecast, mitigate, and document; however, barriers such as cost, readiness, and transparency need to be addressed strategically. Investments in training, phased implementation, and governance frameworks will be important for AI in delivering on its promise. Properly aligning such things will make AI become a cornerstone of predictive, transparent, and efficient project management under mega construction projects.

6.10 Recommendations for Future Research

The analysis of delays in construction projects that facilitate improvement of project success through the avoidance of disputes and optimization of project delivery is, of course, very important. However, several gaps in this area require investigations into further details. The following are the recommendations for future research to improve upon the comparative study of delay analysis techniques vis-a-vis their actual application on construction projects.

1. Development of a Standardized Framework for Delay Analysis

- Thus, there is no framework for delay analysis applicable uniformly to all regions; it is therefore not implemented consistently among various projects.
- Further research should devise a model that brings in an integration of the best methodologies while attuning them with respect to the global setting of contractual and legal interpretations.
- The framework needs to incorporate types of contract, for example FIDIC, NEC, JCT, project sizes, and different possible types.

2. Integration of Artificial Intelligence and Machine Learning in Delay Analysis

- AI and machine learning have great potential for improving the predictive accuracy and time involved in delay analysis. Future studies should focus on how Analytics empowered by AI will improve conventional techniques for analysis of delays, such as:
- Models based on machine learning techniques for predicting anticipated delays with the historic data base.
- Forensic delay analysis driven by AI: to facilitate quick and more accurate dispute settlements.
- Automated risk assessment by using big data analytics.

3. Real-World Comparative Case Studies Across Multiple Regions

- Many studies focus on **specific regions** or industries, making it difficult to generalize findings globally.
- Future research should conduct **comparative case studies across diverse geographic locations**, considering factors such as:
  - Economic conditions and regulatory environments.
  - Climate-related project delays.
  - Cultural and administrative challenges in different regions.

4. Cost-Benefit Analysis of Delay Analysis Techniques

- While various delay analysis techniques exist, **their cost-effectiveness is rarely evaluated.**
- Future research should assess:

- **The economic impact of delay analysis techniques** on construction projects.
- **The trade-offs between accuracy and cost** of different techniques, helping stakeholders choose the most suitable approach.
- **Cost-benefit analysis** of implementing AI-driven vs. traditional methods.

5. Advancing Delay Analysis in BIM (Building Information Modeling) Environments

- **BIM is increasingly used** for project planning and execution, but its potential in delay analysis remains underexplored.
- Future research should investigate how **BIM-based delay analysis models** can:
  - Improve visualization of delays and their impact.
  - Enhance collaboration between stakeholders.
  - Reduce conflicts in delay claims.

6. Delay Analysis in the Context of Sustainability and Green Construction

- Sustainability-driven projects face **unique delay challenges**, such as:
  - Environmental regulations.
  - Availability of eco-friendly materials.
  - Green technology integration.
- Future studies should explore how **traditional and modern delay analysis techniques apply to sustainable construction projects** and whether new methods need to be developed.

7. Legal and Contractual Considerations in Delay Analysis

- Legal disputes arising from project delays are common, yet **there is no universal agreement on the best legal approach** for delay claims.

- Future research should investigate:
    - The legal implications of different delay analysis techniques under **various contract types (FIDIC, NEC, JCT, etc.)**.
    - The role of **alternative dispute resolution (ADR) methods**, such as arbitration and mediation, in delay analysis.
    - How emerging **digital contracts and blockchain-based project tracking** can improve accountability in delay claims.

8. The Role of Human Factors in Delay Analysis Effectiveness

- Many delay analysis techniques **do not account for human-related delays**, such as:
    - Poor decision-making by project managers.
    - Inefficient communication among stakeholders.
    - Resistance to adopting new delay analysis methods.
- Future research should examine **behavioral factors influencing delay management** and strategies to improve human decision-making in delay resolution.

9. Enhancing the Accuracy and Reliability of Delay Analysis Reports

- Many delay analysis reports are subjective and vary depending on the analyst's expertise.
- Research should focus on:
    - **Reducing subjectivity** in forensic delay analysis.
    - Developing **automated data validation tools** to improve accuracy.

- Using **real-time project monitoring systems** to provide continuous insights into potential delays.

10. Understanding Delay Analysis in the Post-Pandemic Construction Industry

- The COVID-19 pandemic significantly impacted **project schedules, supply chains, and workforce availability.**
- Future research should explore:
  - How **pandemic-related delays** should be analyzed differently from traditional delays.
  - The role of **remote project management tools** in mitigating delays.
  - **Resilience strategies** for minimizing the impact of future global crises on construction projects.

Dear [Participant's Name],

I am conducting a research study as part of my thesis at the Swiss School of Business and Management, examining the role of Artificial Intelligence (AI) in enhancing delay analysis techniques within construction projects. The study aims to understand the current challenges in traditional delay analysis and evaluate how AI can address these limitations to improve project management outcomes.

As an experienced professional in the construction industry, your insights are invaluable to this research. By participating in this survey, you will contribute to a deeper understanding of how delay analysis techniques are currently used, the specific challenges faced, and the potential benefits of AI-driven methods. Your input will help in developing a comprehensive framework to support more effective, data-driven delay management strategies in construction.

This survey will take approximately 10–15 minutes to complete. Please be assured that all responses are confidential, and any data collected will be anonymized and used solely for academic purposes. Participation is voluntary, and you may choose to withdraw at any time.

To begin the survey, please click the following link: [Insert Survey Link]

Thank you for considering this opportunity to contribute your expertise to a study that aims to advance the field of construction project management. Should you have any questions about this survey or the research, please feel free to contact me directly at [Your Email Address].

Warm regards,

[Your Full Name]
[Your Program/Department]

Swiss School of Business and Management
[Your Contact Information]

Background and Demographic Information

Name-

Position: -

Years of Experience

Specialisation: -

Location: -

Project:-

General Delay Analysis Practices

1. Which delay analysis techniques are you most familiar with? (e.g., As-Planned, As-Built, Impacted As-Planned, Time Impact)
2. Which technique do you find most effective in identifying critical delays? (Please specify)
3. What are the primary obstacles you face when conducting delay analysis? (e.g., data collection, record-keeping, technical expertise)

AI Awareness and Adoption

4. Are you aware of any AI or machine learning tools specifically designed for delay analysis in construction?
5. Have you used any AI-based software for delay analysis in your projects? (Yes/No)
6. How often do you think AI could be beneficial for predicting delays in complex projects?
7. Do you believe AI has the potential to improve the accuracy of delay analysis in construction projects?

Perception of AI's Effectiveness in Delay Analysis

8. How effective do you think AI could be in helping identify critical delay factors in real-time?
9. To what extent do you think AI-driven tools could reduce the subjectivity in analyzing delay claims?
10. In your opinion, would AI tools be more effective than traditional delay analysis techniques in identifying concurrent delays?
11. Do you believe AI tools could help standardize delay analysis practices across the industry?

Benefits and Potential of AI in Delay Analysis

9. How likely are you to adopt AI tools if they could offer predictive insights for delay risks?
10. How helpful would it be if AI tools could automate the collection and organization of data (e.g., records of progress, resource allocation, cost)?
11. Do you think AI tools could provide valuable insights on alternative strategies to mitigate delays?
12. To what extent do you believe AI could enhance decision-making in allocating responsibility for delays?

Challenges and Concerns with AI Implementation

13. What concerns, if any, do you have about using AI in delay analysis? (e.g., data privacy, costs, accuracy, bias)

14. How often do you think lack of data quality or completeness might limit AI's effectiveness in delay analysis?
15. To what extent do you think AI tools could reduce the workload in documentation and data processing for delay analysis?

Readiness for AI Integration

16. Would you be open to receiving training to better understand and implement AI tools in delay analysis?
17. How likely would you be to trust AI-generated recommendations for delay-related decisions?
18. To what extent do you believe the construction industry as a whole is ready for a shift towards AI-based delay analysis?

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