

# COMPARATIVE EVALUATION OF FORENSIC DELAY ANALYSIS METHODS IN MEGAPROJECT DISPUTE RESOLUTION

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## Abstract:

Disputes regarding delays are common and complex in the management of construction megaprojects, and may also lead to significant legal and financial consequences. Forensic Delay Analysis (FDA) techniques are vital to the analysis of causes and liabilities of such delays. In this paper, an evaluation of many FDA methods, specifically As-Planned vs. As-Built, Impacted As-Planned, Time Impact Analysis, and Collapsed As-Built, is compared, particularly concerning applicability, advantages, and disadvantages in large infrastructure projects. Using case study analysis and interviews with experts, the study examines how a number of parameters, including data availability, complexity of project design, and stakeholder expectations, affect the selection and effectiveness of these methods in various dispute resolution cases. The importance of ensuring that the method chosen for FDA corresponds with the specifics of the project and the dispute context is further emphasized to enhance the credibility and accuracy of its findings and take it toward acceptance in legal and arbitration settings.

**Keywords:** *Forensic Delay Analysis (FDA), Megaprojects, Dispute Resolution, Construction Delays, As-Planned vs. As-Built, Impacted As-Planned, Time Impact Analysis, Collapsed As-Built, Delay Analysis Methods, Case Study, Expert Interviews, Project Complexity, Data Availability, Stakeholder Expectations, Legal and Arbitration Settings.*

## 1. Introduction

### 1.1 Background

Megaprojects are some of the largest and perhaps most audacious in their ambitions and transformations of society today. They include large-scale infrastructure development programs such as airports, dams, mass transit systems, and urban redevelopment programs. They are characterized by being very costly, long-duration, multi-organizational collaborative endeavors that are highly vulnerable to public and political scrutiny. Because of their complex and dynamic environment, delays occur very frequently if not inevitably during megaproject executions. Delays are commonly caused by unforeseen conditions at the project site, changes in scope, bad weather, delays in procurement, lack of workforce, and misalignment among stakeholders (Boateng et al., 2012). The repercussions of such delays can be economic and far-reaching, often causing legal disputes and reputational damage to the parties involved. In high-risk projects, even minor disturbances to the schedule can result in a contractually bound penalty, cash flow problems, or failure to deliver an operational project. As megaprojects are ever-increasingly becoming larger and more complex, traditional project control measures are either not possible to apply or not efficient at resolving time-related disputes. Therefore, there is a need for a more structured and evidentiary methodology to determine the causation and liability for delays, which brings forward the very critical aspect of Forensic Delay Analysis (FDA) in current project management and dispute resolution practices.

### 1.2 Importance of Forensic Delay Analysis in Megaprojects

The forensic delay analysis has become one of the major instruments to resolve construction disputes, especially where claims of delay bear on completion and obligations of stakeholders. The FDA includes a backward look at the project schedules in order to investigate the causes of the delays, the extent of the delays, and the parties responsible for the time overrun. The purpose of the FDA is to assist both parties, the contractor and the client, in justifying or disproving claims that are based on a well-considered methodology founded on scheduling data, project records, and contractual clauses (Ackermann, Eden, & Williams, 1997). In dispute resolution—whether by litigation, arbitration, or adjudication—

FDAs are often considered the rock of evidence. Choice of the right FDA will be critical in determining the legal standing of a claim, and its credibility. Methods such as Time Impact Analysis (TIA), Collapsed As-Built (CAB), and Window Analysis are well known with an assorted methodological framework specific to differing data environments and dispute contexts (Gibbs, Lord, Emmitt, & Ruikar, 2017). Furthermore, with the advancement of technology and digital project management tools, the modern FDA approaches enhance objectivity and limit the degree of subjectivity present in analyses using data analytics, artificial intelligence, and decision support systems (Hammam, El-Anwar, & El-Said, 2018). The spirit of FDA is not only for resolving disputes but also for empowering project delivery performance by identifying systemic schedule risks and encouraging proactive delay mitigation strategies.

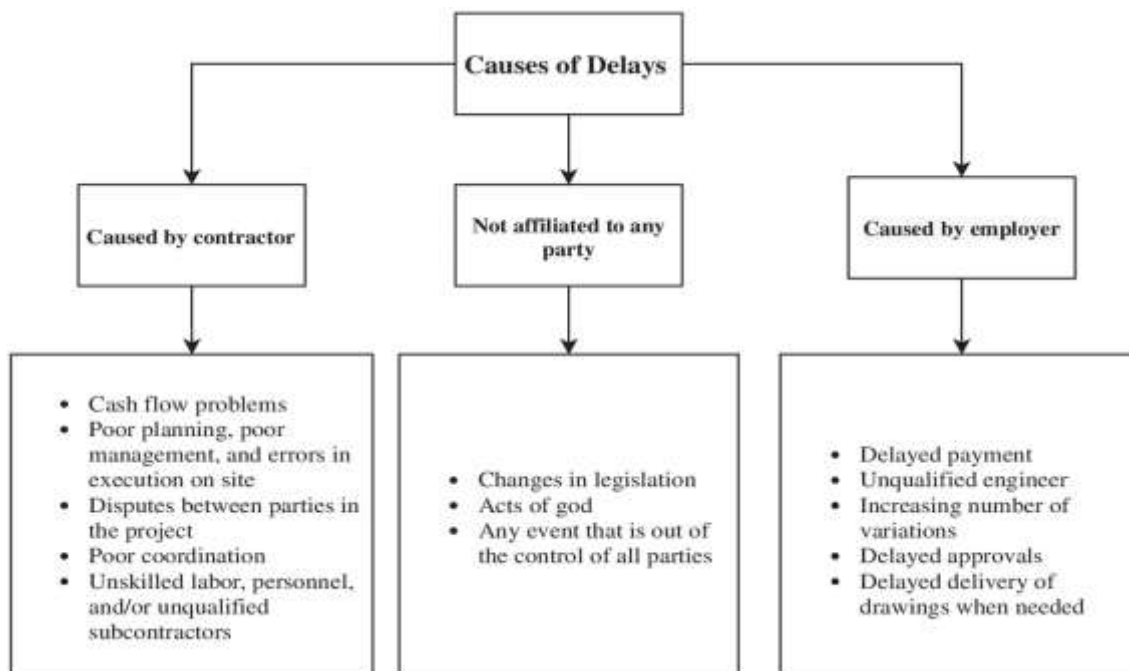
### 1.3 Purpose of the Study

The primary goal of this research study is to perform a detailed comparative assessment of the major forensic delay analysis (FDA) techniques in application in contexts of megaprojects. This aims to address the theoretical bases, procedural methodologies, and situational relevancy of different FDA techniques, with specific consideration to strengths and weaknesses as well as evidentiary merits for use in dispute resolution. It would also seek to measure the applicability of such techniques in relation to practical requirements of complex activities involving infrastructure projects while being tested for their adequacy and credibility in attributing project delays. Plus, it could hint the practical application to judge the reality while being tested for adequacy and credibility in attributing project delays considering the practical contest of complex infrastructure projects with respect to these methods. A further appraisal of integrated decision-making frameworks such as Analytic Hierarchy Process-Relative Importance Index (AHP-RII) for selection of the most appropriate FDA method under specified project conditions has also been undertaken. The final aim of this study is to streamline delay analysis practices and create an informed, fair, and efficient settlement pathway for schedule-related disputes in megaprojects.

### 1.4 Scope and Limitations

This research is strictly interested in the application of FDA methods to construction megaprojects, particularly in the civil and infrastructure development area. The focus includes projects that are typically defined in terms of budgets above several hundreds of millions of dollars over long timeframes involving various stakeholders. The analysis is limited to delay-related issues and does not extend to cost disputes, quality claims, or other project risk types. In addition, the study restricts itself to methods that are widely acknowledged in both academic literature and industry practice. The evaluation is theoretical and comparative based on synthesis of previously completed research, case studies, and published frameworks. Although some practical insights were drawn from empirical studies and doctoral research (e.g., Yerramreddy, 2014), the study is not based on direct field investigations or legal assessments. Moreover, jurisdiction-specific legal implications of FDA are not explored in depth, in consideration of the variability of laws across different countries and contractual regimes. Through this demarcation of the scope, this research endeavors to critically examine the FDA methodologies with respect to delay-related claims in megaproject contexts: thereby contributing to academic scholarship and practice in dispute resolution.





**Figure 2:** Schedule delay analysis methodology

## 2. Overview of Forensic Delay Analysis (FDA)

### 2.1 Definition and Purpose

The FDA is a specialized technique in project management, construction engineering, and construction law that is used to investigate and evaluate project delay events. This analytical procedure is carried out retrospectively to determine causes, magnitude, and consequences of delays in construction projects, especially those that lead to disputes between contractual parties. The force behind any FDA is to see whether a delay is excusable in terms of a contract and whether a party has a right to either compensation or an extension of time. Regarding megaprojects, the application of FDA becomes crucial for sharing out responsibility fairly while securing project continuation from delays due to environmental, political, and contractual complexities, like in the case of Bakun hydroelectric dam in Borneo (Sovacool & Bulan, 2011). FDA helps in conflict resolution; however, it is also used as a decision-support tool by all stakeholders involved in a project. A contract administrator, project manager, and attorneys think of it as being used for delay claims-as to their validity and quantification-as direct support for the more objective and substitutivity defensible outcomes. Most of this analytical process needs both qualitative insights and quantitative modeling approaches to yield a true assessment of multifaceted failure in a project (Ackermann & Eden, 2005). In megaprojects, where there are numerous interdependencies and where the stakes are high, FDA not only addresses resolutions but also creates an institutional learning environment for planning and executing future projects (Abotaleb & El-adaway, 2018).

### 2.2 Evolution and Present Developments

Given the disruption caused by the delays in its projects, the forensic delay analysis has attained maturity almost over the last few decades. Further, from the initial days of forensic delay analysis, where simple claims for delays were dealt with, such methods have gone through considerable metamorphosis to attain sophistication and have developed to tackle wholly different forms of disputes concerned with mega projects. The motivation for this evolution stems from factors such as advances in technology, the increasing complexity of mega projects, and the increasing demand for accurate, reliable, and fair methods of delay analysis. As time has progressed, the project lives have become complicated, clearly showing the limitations of the old methods. The researches and applications thereafter had to tour more flexible and dynamic frameworks. Focal point-based system dynamics, as introduced by Boateng, Chen, and Ogunlana (2012), was one major advancement in developing delay analysis into a more flexible framework. With a view of the interdependencies among a variety of different project variables, system dynamics allowed for more realistic simulations of one area's delays being felt across a project. This was particularly useful for weather-related delays and other unpredictable external factors, where previous techniques failed to account for cascading effects. Much effort is going to make FDA methods accessible and easier to work with for a much broader audience of

stakeholders not really technical in nature—for example, project owners and lawyers. Gibbs, Lord, Emmitt, and Ruikar (2017), in this regard, created an interactive exhibit to help stakeholders appreciate the problems of project delay. This exhibit provides a colorful interface to show how delays evolve over time, thereby allowing nontechnical users to engage with delay analysis models much more readily. The effects of various delay events can be visualized, which assists the stakeholders in the decision-making process during the dispute resolution proceedings. Today, the field of FDA keeps on expanding with a strong emphasis on new technological developments in this field. Big Data analytics, artificial intelligence (AI), and machine learning (ML) are gradually being brought into delay analysis. With these technologies comes the possibility to process lots of project data to identify patterns and predict future delays. AI models for predictive purposes, for example, would use historical project data to provide further insight into the possible delays and their causative factors.

### 2.3 Types of Delays in Construction Projects

Generally, delays in the construction phase are classified into three principal categories: *excusable versus non-excusable*, *compensable versus non-compensable*, and *critical versus non-critical*. Each category relates significantly to entitlement and liability under contract law. An **excusable delay** happens to a contractor when evidence is brought forward to show that the conditions are beyond the contractor's control and falling within the contract's provision for extension of time. Examples of such causes include force majeure events, government acts, and severe weather. **Non-excusable delays**, on the other hand, are caused entirely within the contractor's environment, like poor site management, improper planning of resources, and inefficient subcontractor work. Here the contractor usually isn't entitled to an extension of time and could incur liquidated damages. When we talk about delays that might be excusable, there is still a finer distinction to be made between the compensable types of excusable delays and those that are non-compensable. A **compensable delay** is one where the contractor is entitled to both an extension of the time for accomplishing the works and to an additional recovery of costs incurred as a result of the delay. Here, the delay amounting to compensable delay is usually attributable to the client or its agents, for instance, delays in drawing issuance, obtaining approvals, or changing the scope of work. **Non-compensable** delays are those delays that may yet entitle the contractor to a time extension but do not provide for financial recovery since they are usually caused by neutral events, for example, a natural disaster. An equally important dimension is the critical and non-critical delay classification. **Critical delays** affect the critical path of the project and if unmitigated, will lead to a direct day-for-day extension of the project completion date. In a megaproject, delays of critical activities, such as foundation works, structural erection or commissioning, really kill the project delivery. **Non-critical delays** should, even though they happen to raise the project schedule disruption, remain harmless to the overall completion schedule where float exists within the project schedule. These distinctions are not just theories but do carry practical and legal implications with regard to delay analysis. If actual delays are misclassified or if the delay type is clearly not linked to contractual entitlements, this could do a lot to undermine the credibility of the claim, according to Lew, Tan, and Wong (2013). Besides, in situations where several concurrent delays occur—simultaneously coexisting delay events—the method of attributing liability can become even more challenging and may call for refined FDA methods and a lot of care with contractual definition. As such, knowledge of the nature and classification of delays may be a prerequisite for the proper use of the FDA in megaproject dispute resolution. It serves as the analytical underpinning for causation, entitlement, and quantum evaluations, shaping not only the outcome of specific claims but also the wider project delivery mechanisms.

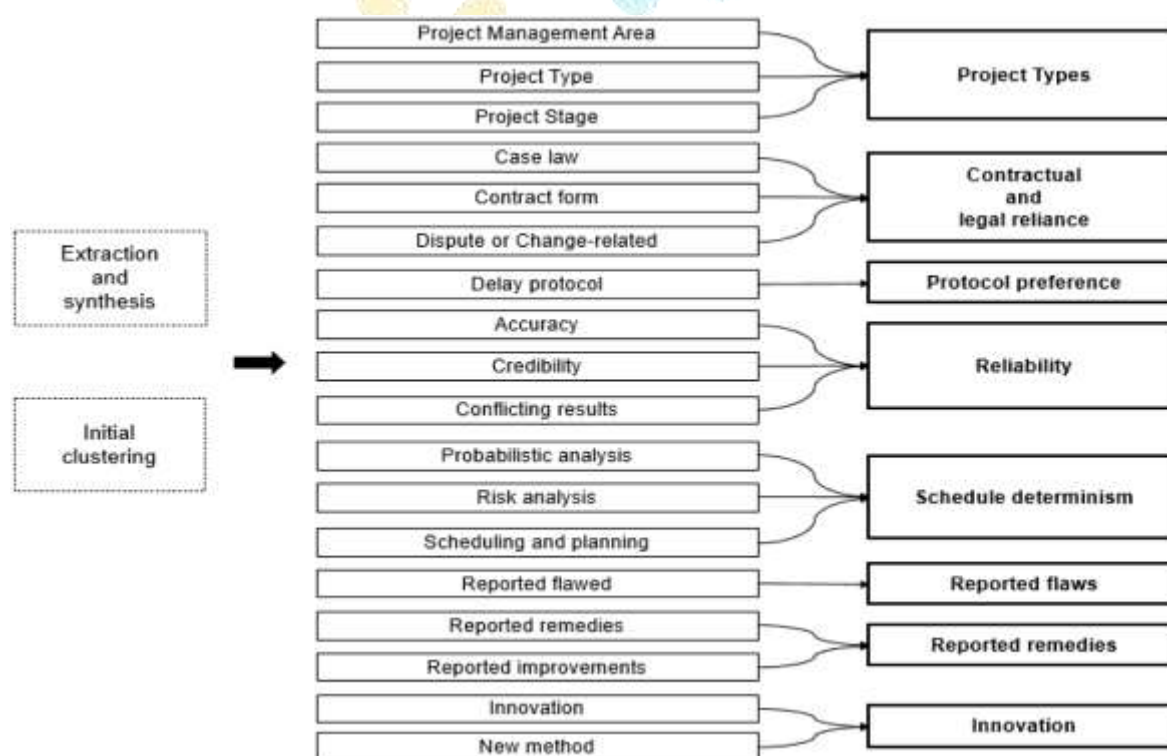
### 2.4 Legal and Contractual Context

FDA's application and assessment resonate profoundly within the legal and contractual enclave of construction contracts. The various normative forms of contract, including those of the International Federation of Consulting Engineers (FIDIC), the New Engineering Contract (NEC), and other national standards, enumerate the rules and responsibilities guiding prudent project scheduling, delay allocation, and dispute resolution. Such contracts would normally contain explicit clauses regarding the extension of time (EOT), delay damages, and the procedures for claim submission and evaluation. For example, FIDIC 1999 Clause 20 places a requirement on the contractor to notify the engineer of any delay event within the prescribed period if he wishes to preserve the right to an extension or compensation. In a similar vein, NEC contracts put emphasis on preventing delay in a more cooperative and proactive style. This is to be exercised through early warning systems and compensation event provisions. It is often unavoidable as to which delay claims would be validly legally enforceable as determined by the accuracy and appropriateness of the method used in the allegation of delay. Delay claims have required clear, methodical, and substantive evidence-based presentations of delay causation, entitlement, and impact, as Gayle did here: "Unfortunately for the claimant, such claims had to have, inter alia, a clear, methodical, and evidence-supported presentation of the causation of delay" (Charrett, 2018; Loots & Charrett, 2019). Under these conditions, the legal scrutiny of the implemented process tends

to focus on compliance with contract terms and contemporaneousness of project records, evaluation reliability of the applied analysis method. Another reason is that the more increasingly complicated the infrastructure projects are in difficult geotechnical environments, particularly soft soil regions, the more substantial contracts have to be in order to allocate and manage time-delay risks (Low, Wong, & Lee, 2018). The growing reliance on formal dispute resolution mechanisms, including arbitration and adjudication, has reinforced the importance of using standardized FDA techniques that align with legal expectations and contractual protocols. This legal rigor is particularly vital in megaprojects where the scale of delay-related claims can span millions of dollars and prolonged legal battles can undermine stakeholder relationships and project feasibility.

### 3. Common Forensic Delay Analysis Methods

The term forensic delay analysis, often abbreviated as FDA, refers to a range of methodologies for evaluating and quantifying project delays. It is, more specifically, important in legal or contractual disputes arising from megaprojects in construction. Delay in megaprojects can incur heavy cost overruns, public outcry, and complicated multi-party claims (Frick, 2005, Puro, Desouza, & Becker, 2012). Each such FDA method has different theoretical underpinning, strengths and weaknesses. The method best suited to a specific situation would therefore differ by project-specific documentation and quality of scheduling data as well as contractual conditions.



**Figure 3:** The Revolution of Forensic Analysis

#### 3.1 As-Planned vs. As-Built Analysis

The technique analyzes the original baseline schedule against the as-built schedule to discern differences and ascertain causation and timing of delays. This method is among the simpler approaches, often acting as a preliminary investigation into delay assessments. Yet, its simplicity can be dangerous in the initial stages of resolving disputes; critics argue that it glosses over complex schedule interdependencies and failingly accounts for concurrency and alterations with execution (Srivastava, 2016; Mehany, 2014). Such static comparisons failed to take into account the dynamic nature of delays in megaprojects such as Boston's Central Artery/Tunnel Project due to political and regulatory interventions (Haynes, 2002).

#### 3.2 Impacted As-Planned Method

The Impacted-As-Planned technique, commonly known for inserting delay-causing event scenarios into the baseline schedule, seeks to analyze the theoretical effect of these delays on the project timeline. The theory behind it is that the original schedule is feasible, is devoid of actual project performance, and is therefore found wanting in complex megaprojects environment settings where initial conditions and scopes often diverge on real execution due to evolution

and rework of the design (Al-Kofahi, 2016; Mehany, 2014). In public sector megaprojects where change orders are mostly stakeholder driven, the approach is highly susceptible to inaccuracy (Purao et al., 2012).

### 3.3 Collapsed As-Built (But-For) Analysis

Using the Collapsed As-Built or "But-For" methodology, analysts would review the as-built schedule reversing this process to get an estimate of what the project completion date "would have been" for each named delay. The reason for the fame of this method inside the courtroom pertains to its direct investigation of causality, as well as its ability to forecast project performance on a hypothetical basis. However, its legitimacy is dependent on the accuracy and completeness of as-built data, which is often not the case with megaprojects, characterized by complex logistics and fragmented documentation (Frick, 2005; Srivastava, 2016). In addition, subjectivity in the reconstruction process can be introduced by the assumptions made during reconstruction; thus, this method is susceptible to quarrels during cross-examinations.

### 3.4 Time Impact Analysis (TIA)

TIA is definitely considered top-shelf methodologies within the FDA milieu as it literally incorporates the delay events right into the latest schedule updates possible while executing the project. Therefore, it assesses the ripple effects which delays achieve in the ongoing status and is widely recognized in all contractually driven projects including ones running under FIDIC and AIA standards. Its strengths lie in constant adaptability while also assessed according to ever-changing project contexts and resource sequencing. For example, Abotaleb and El-adaway (2018) defined TIA as being able to assess the impacts of out-of-sequence work and interdependent delays that are common in infrastructure megaprojects. Despite this advantage, TIA could be time-consuming, demanding huge volumes of data and thus not an appropriate approach in poorly documented projects or very fast track construction environments.

### 3.5 Window Analysis

Windowing analysis represents a hybrid method dividing the project timeline into specific "windows" or periods for analysis of delays and accomplishments within each segment. Hence, the method is somewhere between static and dynamic, fitting long-lasting megaprojects facing various critical paths and frequent updates to the schedule (Haynes, 2002; Prendes-Gero et al., 2019). Sectioning helps show delay patterns and the impacts of repetitively encountered risk factors, such as geotechnical conditions or inefficiencies of contractors. In order to avoid mischaracterizations of causations of delays, analysts must pay special attention while establishing the windows.

### 3.6 Other Emerging or Hybrid Techniques

Recent trends in project control technologies and data analytics have seen the birth of hybrid FDAs from traditional techniques coupled with digital tools. The Earned Schedule Method is one such example, which supplemented the notion of earned value management (EVM) to include schedule performance, and thus, was an enabling factor for earlier delay identification in real time (Srivastava, 2016). Another advanced example of this integration is the 4D BIM-integrated delay analysis which merges the schedule data with 3D models to show the effect and timing of delays visually. These techniques have been good for megaprojects where higher transparency and visualization are demanded from the stakeholders (Prendes-Gero et al., 2019). But there is yet a limited application of the aforementioned techniques as there are technological constraints in many parts of the world. Other factors include training demands and contractual compatibility.

## 4. Evaluation Criteria for Forensic Delay Analysis (FDA) Methods

Several critical criteria determine the suitability and effectiveness of the selection and application of forensic delay analysis (FDA) methods for megaproject dispute resolution. Due to a high-stakes environment, contractual complexities, and social and political implications, FDA methods ought to be assessed using a multidimensional approach encompassing technical, legal, and practical factors. This section will provide an in-depth examination of the main criteria used to evaluate FDA methods in large infrastructure projects.



Prendes-Gero et al. (2019) advocate for the cost-benefit analysis of choosing the adequate FDA method, especially when many actors are involved in resource allocation contestation. Puroo et al. (2012), further assert that complexity should not cloud accountability, especially when FDA findings justify claims in highly publicized public infrastructure projects.

#### 4.5 Transparency and Reproducibility

Transparency and reproducibility are particularly important in building confidence in all stakeholders and in promoting a fair mechanism for dispute resolution. An FDA method must generate results that are logically organized, easy to interpret, and able to be replicated by independent parties. Transparency of the methods supports stakeholder buy-in, thus reducing the risk of lengthy disputes. In contrast, a method with black-box assumptions is likely to invite skepticism and potential legal challenges. Srivastava (2016) felt that administrative clarity in contract management is an absolute must in the prevention of disputes. Transparency mechanisms, such as Window Analysis and TIA, allow documentation in real-time with clear cause-effect relationships. These very characteristics become extremely important in politically sensitive megaprojects, as analyzed by Haynes (2002), where perceptions of the public and media scrutiny sway the outcomes of the projects.

#### 4.6 Applicability in Megaprojects

This flexible and adaptable context-sensitive FDA methodologies megaproject is scale, complexity, and multiple stakeholder diversity. Many megaprojects have specific unique risks such as regulatory delays, social opposition, and supply chain disruptions; these unique risks result from multinational funding or politically entangled execution environments (Sovacool & Bulan, 2011). Thus, the FDA methods must be conscious of nonlinear progress, parallel work streams, and evolving baselines. In such cases, Window Analysis and hybrid models combining system dynamics modeling are also particularly promising since they lend themselves naturally to iterative and modular analysis (Haynes, 2002; Al-Kofahi, 2016). On the contrary, methods that have static modeling frameworks or legitimize rigid assumptions would hardly meet the needs of megaproject fluidity. Applicability also extends to contractual structures; hence, methods need to be aligned with design-bid-build (DBB) or design-build-operate (DBO) models as these impact delay responsibility attribution (Mehany, 2014).

### 5. Comparative Analysis of Forensic Delay Analysis (FDA) Methods

Forensic delay analysis is much more than just words; it comprises different kinds of techniques specific to forensic delay as well as application in many specific cases. As the analysis develops through time and locality, it can become less generalizable. Therefore, in many instances, one will have to rely on other evidence or anecdotal information when having to prove the validity of specific forensic applications. This section elaborates into a fully comprehensive comparative evaluation on defined criteria from practical experiences in megaprojects by numerous stakeholders. The objective is an illustration of the relevant merits and demerits for various commonly used FDA techniques and their match with reality megaproject requirements.



## 5.1 Tabular Comparison Based on Evaluation Criteria

**Table 1** summarizes six common FDA methods defined as key evaluation criteria of accuracy, legality, data needs, complexity, transparency, and adaptation to megaprojects themselves.

FDA Method	Transparency	Legal Acceptability	Data Requirement	Ease of Implementation	Suitability for Megaprojects
Impacted As-Planned	Low	Moderate	Low	High	Low
As-Planned vs. As-Built	Moderate	High	Moderate	Moderate	High
Time Impact Analysis (TIA)	High	High	High	Moderate	High
Collapsed As-Built	High	Moderate	High	Low	Moderate
Window Analysis	High	High	High	Moderate	High
But-For Analysis	Moderate	High	Moderate	Low	Moderate

The description here compares a series of studies, with Yerramreddy (2014) and Huy & Dung (n.d.) emphasizing that TIA and Window Analysis provide a fair amount of analytical rigor and legal defensibility—a very important thing in megaproject claims. On the contrary, easier methods, such as As-Planned versus As-Built, despite being easy to perform, are generally regarded as insufficient for giving evidence regarding really big cases.

## 5.2 Case Studies from Megaprojects

For contextualizing the comparative evaluation, the applicability of FDA methods in some megaprojects and their outcomes is examined.

### Case 1: Bakun Hydroelectric Dam (Malaysia)

Sovacool and Bulan (2011) write that the Bakun Dam was suffering from significant delays and cost overruns, where the absence of reasonable delay analysis mechanisms constituted a field for enormous stakeholder contention. The tremendously vexed and complicated political environment surely put monumental pressure upon the traditional approach. An adaptive method, such as Window Analysis, for example, could afford dynamic insights into the delay events as they changed through project evolution.

### In Case 2, Weather Impacts of a Critical Nature on Large Infrastructure Projects

Boateng et al. (2012) attempted developing a typical system dynamics model in simulations of the functioning of weather on the construction schedule of megaprojects. Hence, this case puts the show towards using delay analysis methods, such as TIA, that could take into account exogenous factors such as environmental disruptions, which are frequent on long-duration projects that spread over great distances.

### In Case 3, Dispute Scenarios Modeled for Legal Preparation

Ackermann, Eden, and Williams (1997) modeled disputes using qualitative and quantitative approaches, demonstrating how hybrid methods add value to litigation preparedness. This approach may be so applied to FDA in combination with other traditional scheduling techniques with causal mapping and sentiment analytics (Hammam et al., 2018), thus becoming very important for complex delay claims related to megaprojects.

### Case 4: Evaluation Through AHP-RII Approach

Huy and Dung proposed a quantitative decision model using the Analytical Hierarchy Process (AHP) and Relative Importance Index (RII) to select suitable FDA methods. Their findings show that Window Analysis and TIA are the best, taking top rankings across multiple evaluative dimensions, thereby supporting their robustness in dealing with megaproject complexities.

### 5.3 Stakeholder Perspectives

The effectiveness of FDA methods can also depend on the perceptions and needs of many stakeholders, all of whom have their own interests and priorities. Contractors seem to prefer methods that will enable them to show causation of delays and justify EOT claims. TIA is preferred when highly dynamic, as it links the live project schedule with cause-and-effect reasoning (Lew, Tan, & Wong 2013). Consultants and Schedulers highlight the need for reproducibility and logical consistency. Techniques like Window Analysis and 4D BIM-integrated techniques are preferred for their analytical rigor and visual clarity, especially when it comes to communicating results to a variety of stakeholders (Yerramreddy 2014). The project owners and their clients look for transparent methods that are relatively abuse-proof and provide defensible justification in case of arbitration and litigation. They may give precedence to legal tempering and cost viability, and thereby are more inclined toward the TIA or Impacted As-Planned approaches. Legal practitioners and arbiters evaluate the admissibility of the FDA method and the clarity of the evidence regarding its application. The Window Analysis technique has gained more popularity due to its segmental and traceable methodology and is thus considered as a reliable ground by many professionals; the Collapsed As-Built faces more questioning due to its nature of modeling, which is mostly based on hypothesis and assumption (Bierling, 2019; Hammam et al., 2018). In the end, Abotaleb and El-adaway (2018) stress that FDA selection should be seen as an integral part of any dispute resolution strategy. This means working with an integrated or hybrid approach that combines the strengths of multiple methods to produce the most balanced and defensible result possible.

## 6. Challenges in Applying FDA in Megaprojects

The techniques of forensic delay analysis (FDA) are essential in establishing the realities in disputes in large-scale construction projects; however, the application of FDA techniques to megaprojects offers unique and serious challenges. These challenges are presented simply by the scale and complexities associated with such projects, media inadequacies, overlapping delay events, and the paradigm changes brought about by digital and AI technologies. To effectively apply forensic delay analysis in the realm of megaprojects, an understanding of these limitations is key toward enhancing the effectiveness and definability of such outcomes.

### 6.1 Scale and Complexity

It has been stated that megaprojects are characterized by their multi-billion-dollar budgets, elongated timelines, high interdependencies between tasks and stakeholders, and much more. The bigger the project is, the more complicated would be its delay analysis. Haynes (2002) highlighted that Central Artery/Tunnel Project and the Boston Harbor Cleanup have been emphasis in coordination problems on the part of multiple contractors, regulatory bodies, and funding sources—a contribution to scheduling complexity. Charrett (2018) further states that the megaproject frameworks in contracts usually consist of layered responsibilities which further complicate the process of attribution of delays to the parties performing the work considered part of the entire odd chain. This situation and other interdependency of work packages, change in project scope, and dynamic objectives from stakeholders would render a typical linear cause, effect analysis—the bases of a traditional FDA—as inapplicable. In addition, Frick (2005) examines how political- and managerial-level discontinuities on the San Francisco-Oakland Bay Bridge project added unanticipated disruptions to the project, thereby inducing cascading delay effects difficult to isolate and analyze under conventional delay-attribution methods.

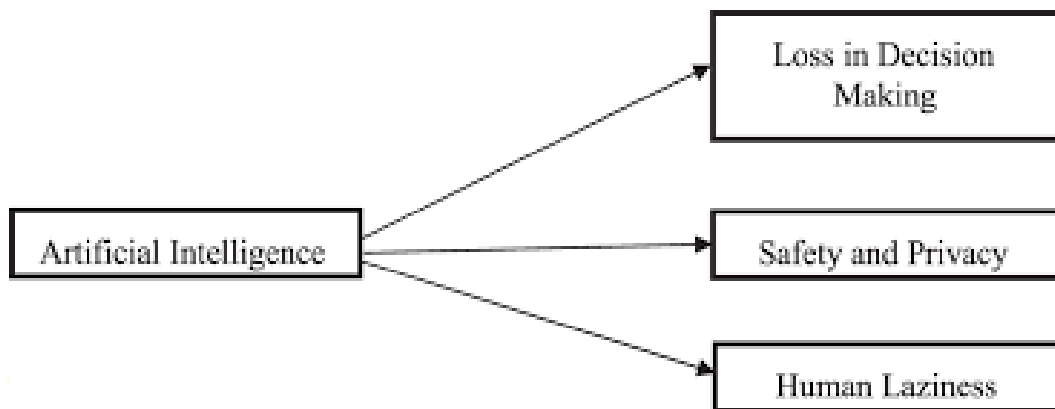
### 6.2 Incomplete or Unreliable Project Records

Effective FDA is based on the documents which one have reliable development. However, one observes that in case of megaproject this record entirely varies like inconsistent, incomplete or even contradictory, according to Srivastava (2016), while project data recording practices have reduced significantly across subcontractors and project segments on many scales making individual and fragmented schedule baselines and event logs. This problem has been reemphasized by Prendes-Gero et al. (2019), which indicate the complications that geotechnical uncertainties and the variability in documentation of such phenomena cause in infrastructure projects. Forensic analysts will have to infer from very scant evidence when critical delay events, such as soil settlement or unforeseen ground conditions, are poorly recorded. This essentially weakens the robustness of their findings. The delay in documentation can also be exacerbated in politically sensitive or publicly funded projects with inefficiencies or intentional lack of transparency in the bureaucracy. Batz (2017) demonstrated that for infrastructure megaprojects in Guatemala, relevant documentation was either withheld or otherwise manipulated to obscure the decision-making process, even further complicating retrospective delay analysis.

### 6.3 Multiple Concurrent Delays

The concurrent delay situation occurs when multiple independent delays hit the critical path simultaneously, which creates a very complicated scenario in megaprojects. As per Mehany (2014), without a detailed record of events that is kept contemporaneously, it becomes extremely difficult to differentiate between concurrent delays being contractor-induced, client-driven, or weather-related. A system dynamics model was introduced by Abotaleb and El-adaway (2018) to simulate ripple effects of out-of-sequence work and overlapping delays. The results indicated that the delay of one section of the megaproject could indirectly impact unrelated components of the project, thereby making it almost impossible to evaluate the time impacts through traditional As-Planned versus As-Built methods. Moreover, Al-Kofahi (2016) explained that change orders, being a common cause of disruptions on large projects, usually produce overlapping impacts on labor productivity and task sequencing. Unless such overlapping concurrent delays are understood in the context of their interaction, forensic delay analysis methods can wrongly identify causation, resulting in unjust results in claims and disputes.

### 6.4 Influence of Technology and AI Tools



**Figure 5:** Integrating Generative AI into Education

In recent years, there have been developed the digital tools and AI aiding the FDA in schedule visualization platforms, sentiment analysis, and machine-learning-based claim classification. While these tools promise greater accuracy and efficiency, challenges remain in their deployment in megaprojects. Puroo, Desouza, and Becker (2012) examined how sentiment analysis tools identify patterns of stakeholder dissatisfaction in public sector projects, which can act as early indicators of risks coming into existence. However, such tools rely on textual data, such as emails and reports, thus running the risk of contextual misinterpretation, especially in a multilingual or culturally diverse environment, usually the case for international megaprojects. These new analytical capacities, Charrett (2018) cautions, might baffle by the extent to which they have separated "transparent" decision-making logic from the use of digital tools. For example, a prediction of delay causation built upon an AI algorithm may not be interpretable to courts or arbitrators, losing its legitimacy despite being very advanced from a technical standpoint. Further, the use of Modeling Information Building (BIM) and 4D scheduling requires advanced digital literacy among the project staff. Many construction teams have learned to live with these systems without being able to adopt their full potential, resulting in digital records underused or misused and therefore not sufficiently able to satisfy forensic requirements to support investigations on delay time.

## 7. Recommendations

### 7.1 Best Practices for Selection of FDA Method

It works as a guiding process to take or arrive at outcomes within the framework of delays. A seasoned method or guideline that needs to be followed is to adopt a contextualized selection framework, with consideration given to such factors as the scale of the project, available data, cost implications from contracts, nature of the delays, etc. Charrett (2018) emphasizes that all FDA techniques must comply with contractual provision and the provisions by which disputes under engineering and construction contracts are settled. Furthermore, the method should be a reflection of the phase of the project under consideration and should also be determined by the nature of events relating to delay. For instance, Al-Kofahi (2016) emphasizes that dynamic models that consider labor productivity effects add more in analyzing delay because there are constant change orders in projects, as opposed to static methods such as Time Impact Analysis (TIA). Likewise, these authors, Prendes-Gero et al. If accurate baseline and progress data are available, they

recommend quantitative delay approaches and highlight the benefits of integrating geology data into projects exposed to subsurface risk. A decision-support framework would include improvements and maturity assessments of schedules with risk profiles, taking pre-implementation checks for forensic analysts and assuring methodological fit-for-purpose for complex megaprojects.

## 7.2 Use of Integrated Project Delivery and Technology

Both technological adoption and collaboration-focused models of delivery, such as the Integrated Project Delivery (IPD), can minimize the causes of delay disputes in their entirety. Further, by engaging early stakeholders, establishing transparent communication paths for information flow, and troubleshooting real-time problems, IPD eliminates the requirement for forensic investigations after the events. As demonstrated by Low et al. (2018), risk frameworks embedded in early-stage planning that utilize a common platform can flag time-related risks proactively and reduce dispute escalation. Among the digital tools that have enhanced visibility into project performance, interdependencies, and change propagation are Building Information Modeling (BIM), 4D scheduling, and system dynamics modeling (Abotaleb & El-adaway, 2018). Such technologies improve the reliability of delay records and support visual simulations, which are especially useful in a complex case involving many concurrent delays. However, as concluded by Sovacool and Bulan (2011), megaprojects like the Bakun Dam continue to languish in stagnation, not because of technology deployment but because of failure to correlate governance processes with the technical tools set-up. Thus, the introduction of governance framework should accompany the technology.

## 7.3 Training and Awareness for Stakeholders

The success of the FDA implementations relies less on the technical factors surrounding the implementations and more on the influences of knowledge. The absence of awareness on the part of the interested parties regarding the causes of delay, entitlement under the contract, and the procedures under the FDA would make room for escalation into conflict. Srivastava (2016) proposed focused training programs in contract administration, claim substantiation, and delay analysis for participants and legal representatives on the project. Moreover, according to Haynes (2002), programs of this nature would be relevant because megaprojects with a public-private partnership component, such as the Central Artery/Tunnel Project, usually operate with conflicting stakeholder assumptions and agendas deserving of resolution. Training will aid in expectation alignment and general collaborative problem resolution. Training should also encompass the utilization of various digital tools and forensic software to boost effective data usage. On the other hand, Puro et al. (2012) indicate that communication training is necessary since early failures in affecting sentiment recognition and engaging stakeholders have been cited as failure indicators in large public sector initiatives. In that respect, training that focuses on soft skills complemented with a good technical background is pertinent.

## 7.4 Recommendations for Contractual Clarity

Ambiguity in contracts indeed contributes enormously to delay-connected disputes. Delay definitions, risk-sharing, claim procedures, and FDA methods must be spelled out from the very beginning of the project. Loots and Charrett (2019) have stressed extension-of-time clauses and delay-attribution protocols, whereby their precise drafting will greatly help reduce subjectivity in FDA in projects related to offshore oil and gas. The argument made by Lew, Tan, and Wong (2013) illustrates how many claims in construction-related projects in Malaysia have been exacerbated by poorly defined contractual delay terms and the different claim management procedures being adopted. Their findings point to standardizing FDA protocols under contracts by possibly referencing a recognized standard, such as the SCL Protocol or ACE guidelines, to facilitate an expedited resolution of disputes. Contractual clarity must also involve some clear articulation regarding data obligations—all concerning what records are required, in what format and frequency, and who will be in charge of such records—so that forensic investigations will not be impeded by scarcity of data or even manipulation. According to Batz (2017), in analyzing the resistance to infrastructure in Guatemala, contentious contractual obligations about transparency and social impact assessments contributed to delays in legal and community response that could have been avoided had the terms been more clearly defined.

## 8. Conclusion

The present study demonstrated that the gap between methodologies for forensic delay analysis and their application to the resolution of disputes over megaprojects is very subtle. While each method carries its own merits, some are better suited to particular conflict alternatives than are others. It was generally found that Time Impact Analysis offered better accuracy in live projects with supportive scheduling data, whereas As-Planned versus As-Built and Collapsed As-Built worked better for retrospective impact analysis with limited evidence. The efficacy of any FDA method in

being technically correct with respect to forensic timing studies for megaprojects is critically contingent upon the method's acceptance within the court of law, which is of utmost importance for the parties involved in the project. Thus, project participants need to take a contextual approach with respect to the parameters governing selected options and criteria of evidence. Ultimately, a balanced and informed selection of forensic delay analysis techniques can contribute significantly to fair and efficient dispute resolution processes in megaprojects, thereby promoting good outcomes and good working relationships among stakeholders.

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