Beyond Guesswork: Predicting Project Delays and Timelines with a Forward-Looking Risk-Adjusted Approach

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Abstract

This article presents an alternative approach to calculating extensions of time (EOTs) and delay-related claims in the project environment through the use of Time Impact Analysis (TIA) in combination with Quantitative Schedule Risk Analysis (QSRA). The authors present theoretical and pragmatic arguments in favor of adopting a probabilistic approach to the calculation of time overruns and their cost while identifying areas for further research. The research offers original contribution by way of integrating two established methodologies into a novel framework that addresses the inherent limitations of conventional delay analysis approaches in environments where uncertainty and interdependencies are prevalent but rarely quantified. The rationale for this research originates from the progressing industry recognition that deterministic delay analysis approaches fail to account for complex relationships and uncertainties inherent in project schedules. To add credibility, the proposal is evaluated by a focus group - consisting of practitioners specialized in EOT implementation and delay analysis. The study aims to present conceptually the effectiveness of combining TIA and QSRA within a project environment. It also seeks to explore the practical implications and benefits of adopting a probabilistic approach compared to existing techniques. The core contribution of this study sits in the

advancement of methodology that provides more systematic and robust basis for delay quantification and EOT negotiations, leading to the reduction in disputes and suboptimal settlement outcomes.

Keywords: scheduling, delay analysis, extension of time, risk management, construction management

Introduction

Change management and delay analysis constitute an essential and frequent part of project management (Voropajev, 1998; Ndekugri et al., 2008; Zhao et al., 2010). While most prevalent and complex within major programmes, the intricacies connected with an accurate estimation of impacts rendered by change or delay events cause significant theoretical and pragmatic dilemmas on projects of any size and genre (Braimah, 2013). Despite problems associated with the process – such as poor standardization, limited understanding, and procedural perplexity – the accuracy of the impact estimate remains the fundamental issue (Yang and Kao, 2009; Braimah, 2013). Noting that the implementation of change and prospective delay analysis is a forecast, the precision of these predictive evaluations remains restricted. The literature demonstrates a clear link between immature forecasting and project failure, with significant consequences for both budgets and schedules (Ekanayake and Perera, 2016; Perera et al., 2016). In response to these issues, this research study aims to address the following research question: How do probabilistic scheduling methods improve delay analysis in projects?

Traditional predictive schedule analytics are treated have always been treated with caution or ambivalence. On one hand, they are considered indispensable for planning, resource allocation, and establishing a baseline for project control. On the other hand, any project, regardless of its scale, is not only a unique prototype but is also subject to broad assumptions, uncertainty, and multi-dimensional interdependencies (Hancock et al., 2020). The available literature shows that views on this matter are equally polarized. Some authors indicate that, based on efficiency trends and general project type, projects are similar (Locatelli et al., 2014; Flyvbjerg, 2021). Conversely, others indicate that each project is distinct, notwithstanding certain similarities (Pitsis et al., 2018). This is due to the ever-changing environment, effects of randomness, and intentional and non-intentional variability of external and internal factors. It is challenging to claim that that the results and outcomes of a project carried out in two significantly different environments would be uniform (van Marrewijk et al., 2008; Ezzat Othman, 2013). One cannot also disagree with a view that the timing of project delivery may cause performance fluctuations – a project in a period of stability is likely to perform steadily, while the same project delivered in turbulent times will be prone to performance fluctuations (Kakar et al., 2022). In any case, however, change management and prospective delay analysis (in fact, any type of delay analysis) are still likely to be present in these environments (Apurva et al., 2020).

A critically overlooked factor contributing to the ambiguity and inaccuracy in change management and delay analysis is the presence of inherent shortcomings within the techniques employed to assess the impact of change or delays. This includes the predominantly deterministic and static nature of typical project schedules, which hinder adaptability and risk evaluation (Kirchsteiger, 1999; Khamooshi and Cioffi, 2013; Abdel Azeem et al., 2014; Ballesteros-Pérez et al., 2018). Scheduling determinism manifests on several levels. Predominantly, it is reflected in activity durations that are denominated as single point estimates – thus are presented as certain and accurate estimates – and are not acknowledging the impact of uncertainties and risk events associated with those very activities (Zarghami, 2022). This creates a fallacy that project schedules are resistant to the influences originating from risks and unavoidable randomness affecting the previously drafted critical path. In other words, treating a forecast as a certainty is a broad assumption that has been widely discussed in the literature. (Dodin and Elmaghraby, 1985; Cho and Yum, 1997; Nassar and Hegab, 2006; Creemers et al., 2014). Schedule sequencing and logic abide to the same principle. When time forecasts are created, the resultant critical path is a product that is 'temporarily correct' and highly likely to be invalidated by shifts in the project reality. Nevertheless, the predicted sequence is perceived as an indisputable reality. For example, if inclement weather does not allow delivery to continue, unavoidably schedule sequence will alter. Lastly on determinism, project schedules do not resemble the true extent of interdependencies within the project (Nightingale and Brady, 2011).

Despite extensive computational efforts and intricate design in creating a comprehensive schedule, its accuracy remains limited if it fails to account for all potential variations arising from inherent randomness (Konior, 2019). While schedule determinism may cause sufficient concerns, further deficiencies are introduced to the conventional Critical Path Method (CPM) schedule through its staticism (Alzraiee et al., 2015). In other words, once the timeline is agreed and maintained, the logic and location of most activities on the Critical Path does not shift drastically (Street, 2000). While some alterations may occur in line with maturing project scope, the initial number of activities and their logic will be perceived in terms of surety rather than probability – specifically where CPM schedules are contractually essential (Arantes and Ferreira, 2021). Accordingly, any time calculations contained within do not include analytical views on aspects such as the likelihood of task existence – noting that far-distanced tasks may cease to exist by virtue of changes to the progressing schedule or management actions – or conditional branching, signifying a modification in the project timeline and interdependencies due to either purposeful adjustments or unexpected alterations (Lee et al., 2006). For instance, project leadership may react to time slippages by altering the critical path via re-sequencing or assumption-based planning, which in consequence may eliminate some previously scheduled activities (Muriana and Vizzini, 2017).

An attempt to address such deficiencies – noting early lack of computational power – was the Program Evaluation and Review Technique (PERT) (Van Slyke, 1963), which, while a pioneering effort to introduce probabilistic estimates, was compromised by merge bias and unrealistic assumptions (Wyrozębski and Wyrozębska, 2013) and the difficulty in generating three-point estimates for long schedules (Ragel and Al, 2021). Although its foundational concepts inspired further academic inquiry – recently leading to analytical tools like Path Variance- and Activity-Variance Criticality Indices and checks of path dominance (Hasan and Lu, 2024) – PERT itself is still under investigation. The contemporary academic discourse, including research from Salhab et al. (2022) and Zarghami (2022), continues on refining PERT metrics, advocating for prioritising variability over deterministic float to better identify sources of schedule risk. Consequently, Monte Carlo simulation may be preferred, approach for quantitative schedule risk analysis (Mongalo and Lee, 1990; Deshmukh and Rajhans, 2018).

When being cognizant of these flaws and realities and framing them within change management and prospective delay analysis realities, one can acknowledge that accurate assessment of any prospective time impacts cannot be achieved within the confines of a strictly deterministic schedule. Firstly, the addition of fragnets and recalculation of activity or milestone dates based on deterministic calculation will not reflect the reality and dynamism of the project – the chance that the sequencing and logic of the CPM schedule will remain unchanged is marginal (Ballesteros-Pérez et al., 2020). Secondly, any introduction of scope alters the complexity, density and interdependency within the activity network. Failing to account for such implications may give rise to a misconception that change, or prospective delay analysis is exhaustive and entirely accurate. In other words, it accounts for all known probable prospective impacts and exposures associated with the alteration – whether delay- or change-related. Lastly, CPM schedule determinism and staticism may lead to a scenario where satisfaction of due entitlements is diluted, as only one possible scenario is being analyzed and accepted as certainty, disregarding a number of other likely outcomes.

Nonetheless conducting change and prospective delay analysis of CPM schedules comes with challenges. Incorporating change or delay scenarios within the project timeline can introduce further risks and uncertainties. These predominantly refer to events that arise directly from new activities related to changes, delays, or mitigation efforts. (Zuo and Zhang, 2018). For example, if a set of change-related activities is inserted into the CPM schedule's logic and sequencing, the insertion creates further risks within activity network. The initial risks associated with the change itself (the new scope in isolation) may be proximate and easily acknowledgeable; they can be quantified and included in the analysis of change- or delay-related impacts and factored in as foreseeable consequences. However, in a broader context, the ripple created by the added fragnet is not only less predictable, but also less detectable; its apprehension may require a deeper pragmatic understanding of the intricacies of the project and the interdependencies between tasks. And even with these abilities and collaboration with project stakeholders, probabilistic delay analysis may not be feasible as these events may be either far distanced or unfamiliar at the time of conducting the analysis.

The conventional approach

Whilst TIA serves as the technical foundation for EOT claim, its usage is governed by the formal contractual process. TIA is an impartial forensic tool for both parties: a contractor applies it to derive evidence-based proof for a time extension, while an employer uses it to validate the claim. But before any technical analysis can be initiated, the contractual basis for the claim must first be established. The conventional process of implementing EOT, a contractual adjustment to the project completion date granted due to qualifying delays not caused by the contractor, or conducting prospective delay analysis, here exemplified via the application of TIA, is in principle uncomplicated and can be confined to five steps as shown in Figure 1. (Arditi and Pattanakitchamroon, 2006; Wasfy and Nassar, 2022). Firstly, there must be a confirmed existence of a 'true' delay and/or a valid EOT claim. 'True' in this context denotes real, tangible delay that conforms to the contractual definition of a delay. In other words, the delay in this study encompasses critical delays that impact project completion dates or critical milestones, rather than non-critical delays that can be absorbed by float. Conversely, a valid EOT claim, within most Standard Forms of Contract, arises when the contractor expects to be or is delayed by specifically enumerated reasons. Typically, these are conditions explicitly listed in the contract. For example, in The International Federation of Consulting Engineers (FIDIC) Red Book suite of contracts, EOT conditions are listed in Sub-clause 8.4 (1999 Red Book) or Sub-clause 8.5 (2017 Red Book) and include events such as variations or substantial changes to the works. Both types of eventualities may be subject to specific contractual processes. For instance, in the ECC New Engineering Contract (NEC), the grounds for EOT (referred to as Compensation Events) are listed in Clause 60.1 and are subject to a contractual notification process (Clauses 61.1 and 61.3) and assessment rules. Similar mechanisms function in other Standard Forms of Contract - the JCT contract (SBS 2016) provides a good example, where Relevant Events are defined within Clause 2.29 and the notification process is described within Clause 2.27.1 - and in bespoke project contracts.

Secondly, once a condition giving rise to an EOT or delay event is identified, accepted, and detailed, a scheduling professional or a delay analyst should obtain a baseline schedule and amend it to reflect the progress made between the date of schedule origination or acceptance and the date of the analysis to ensure completeness and accuracy. Thirdly, a change or delay event gets framed into a delay fragnet (typically via the creation of a new network of activities, adjustments made to the existing activity durations or delays added to successor activities), which is a projected summary of missed or additional scope of work with its own logic. Fourthly, the addition of the fragnet is evaluated in terms of its impact on the existing CPM activity network and completion dates of interest. The evaluation associated with this step may be a straightforward process but equally may constitute a prolonged effort involving various experts and stakeholders. The impact assessment normally is focused on the identification of scope adjustments, modification of activities and the necessary shifts in CPM sequencing and logic, including any mitigatory measures (noting the duty to mitigate) (Said, 2009). At this point, significant effort must be dedicated to determining the precise placement of the fragnet within the overall CPM activity network to accurately represent assumed project progression. This process involves a thorough analysis and understanding of optimal positioning in relation to other activities and the overall schedule, as well as any necessary adjustments or modifications to maintain the integrity and effectiveness of the timeline. Lastly, the schedule is recalculated to ascertain new activity, milestones and completion dates.

Figure 1. Conventional Time Impact Analysis

There are several benefits of this methodology, with its relative conceptual straightforwardness and a manageable level of effort in implementation and execution (Ghimire and Mishra, 2019). These advantages are particularly prominent so long as TIA is not conducted on relatively complex and interdependent schedules, and where the added scope (fragnet or fragnets) is small to moderately extensive. Other include familiarity and pragmatism, which in project environment are important factors noting the pace of the environment and varied skillsets within project teams. Nevertheless, these benefits come with a trade-off; while the methodology maintains practicality, the outcomes generated through this process may be less accurate and potentially magnify the existing shortcomings of traditional CPM (Critical Path Method) scheduling (Braimah, 2013). The analysis itself may also require a substantial amount of effort in cases where project schedules represent complex projects. Lastly, significant time may be required to effect TIA and still result in challenges in assigning liability for delays and their causes, additional concurrency questions and problems with identifying and understanding delay-drivers if contemporaneous records are limited (Fan, 2012).

The proposed approach (Integration of TIA and QSRA)

In the view of the authors TIA can be further advanced in terms of its accuracy and process. This paradigm shift can be made with the assistance of Quantitative Schedule Risk Analysis (QSRA) (Koulinas et al., 2020). QSRA is a systematic approach used to assess and embed into CPM schedules various uncertainties. The method involves the use of Monte Carlo methods to evaluate the impact of various probable events on CPM schedules and can be deployed at any stage of the project. By considering factors like task duration estimates, resource availability, assumptions, randomized paths and potential risk events, QSRA can generate a series of probabilistic forecasts of project completion timelines (Moses and Hooker, 2005; Keizur et al., 2020).

Conceptual rationale

TIA is a ‘forward-looking’, prospective method; as per AACE RP 52R-06 (AACEI, 2006) it aims to establish the possible impact of delay to the schedule. Based on this characteristic one can agree that central to its possible enhancement is the utilization of Monte Carlo methods and other probabilistic techniques (Nabawy and Khodeir, 2020). This is substantiated by the principle that any analytical approach designed to approximate uncertain phenomena should account for the impact of risk and uncertainty. Ignoring these factors can lead to flawed predictions and inadequate cognizance of potential future outcomes. Ordinary TIA often fails to adequately account for these factors (Keane and Caletka, 2015). Additionally, the fragnets intended to represent upcoming events lack any probabilistic assumptions (Khamooshi and Cioffi, 2013). Events are depicted deterministically, assuming static durations for newly added scope and a rigid sequence in the updated CPM schedule. However, it is theoretically impossible to predict these aspects, thereby neglecting all aspects of uncertainty and risk. In other words, the assumption that a purely theoretical forecast will have an exact empirical representation in future is misguided and an abuse of the concept. It also overlooks the evidence of numerous delayed projects and fails to account for the inevitable presence of risk and uncertainty.

Furthermore, integrating Quantitative Schedule Risk Analysis (QSRA) into a Time Impact Analysis (TIA) offers the key advantage of flagging critical areas for mitigation (‘mitigation’ here is used as a coherent umbrella term for any risk response with the acknowledgment that formal standards – such as those from International Organization for Standardization (ISO) and the Committee of Sponsoring Organizations of the Treadway Commission (COSO) – define a much broader spectrum of actions), thereby specifying risk prioritization based on a probabilistic schedule. As a result, the delay approximation becomes not only more precise but also more actionable, significantly enhancing the likelihood of successfully mitigating delays and improving project outcomes. Within conventional TIA these factors face two challenges. Firstly, the mitigation measures included only consider a known status quo at the time of analysis and assume their complete success in a deterministic manner. In essence, the assertion that the proposed mitigations will be effective and have a measurable positive impact on the project schedule may not hold true in reality. TIA on its own also does not account for the possibility of implementing mitigations in response to emerging issues as developments unfold. In other words, it mistakenly assumes that project participants will be passive in addressing such problems. Lastly, TIA lacks sufficient analytical capabilities to consider changes in the CPM path when planned mitigations are only partially implemented or only partially successful. Despite this, these mitigations can still have a significant impact on the schedule, highlighting the need for more robust analysis tools. In practice, mitigation efforts might reduce delays in one activity but could also necessitate a restructuring of subsequent tasks, ultimately impacting the overall project schedule.

A final conceptual argument is that TIA assumes deterministic stability of project schedules (which follows indirectly from the arguments above) and is poorly sensitive to any interactions that may occur before and after the addition of fragnet, which is itself subjective (Alkass et al., 1996; Fan, 2012). The consequence of this situation is an analysis that fails to uncover the causation and critical interdependencies within the project schedule, which are essential for understanding and apportioning delay liabilities. Many of these interdependencies manifest not as direct links, but as correlations that arise from underlying drivers. For example, project-wide resource scarcity may act as a common driver that can simultaneously delay multiple, logically independent workstreams. Modelling these elements in isolation ignores their correlated behavior, leading to a flawed assessment. This inadequacy not only complicates the assignment of responsibility for delays but also renders effective mitigation impossible.

Pragmatic rationale

The integration of TIA with QSRA offers a multifaceted approach to improve accuracy in prospective delay calculations. Most of all QSRA with relative ease permits for detailed tracking of key schedule sensitivities and drivers (Hulett, 2016). Through random iteration of variables such as activity durations, resource allocations and risk inputs, one can identify schedule factors which are sensitive to shifts. From the perspective of TIA this information is useful as it uncovers the activities and dependencies which are instable, and which have significant contribution to the overall delay (Zhao, 2023). With this data in hand, the parties obtain further detail about delay drivers and more nuanced perspective on the possibility of mitigation or schedule optimization (Williams, 2003; Carnell, 2008). Application of TIA might pinpoint delays but simply speaking TIA on its own will not determine the underlying causes and the activities that are most susceptible to overrun (Zhao, 2023).

A further benefit introduced by QSRA is the analysis and visibility of probabilistic schedule paths (Abdel Azeem et al., 2014). Instead of analyzing a single deterministic critical path as in an ordinary TIA, QSRA considers in detail multiple paths that can influence project outcomes (Khamooshi and Cioffi, 2013; Abdel Azeem et al., 2014; Zhang and Wang, 2021). These insights provide a number of benefits. Firstly, project actors can better understand the interconnectedness of activities and how delays in non-critical paths can affect activities on the critical path through shared resources or dependencies. Secondly, they can inspect the correctness of the deterministic critical path and ascertain whether the adopted sequencing can withstand the effects of uncertainty – in short whether the schedule is realistic (Alexander et al., 1994). A methodical inspection of the probabilistic outputs from a QSRA at a specific confidence percentile not only fortifies the resilience and integrity of the project schedule but also provides an empirical basis for establishing suitable time buffers and the overall contingency. This in turn enables targeted modifications to durations and logical dependencies increasing achievability of the schedule (including allocation of time risk allowances). Thirdly, additional insights allow for the determination of schedule bottlenecks if several activities are shared across (being non-exclusive to a single probabilistic path) a multitude of probabilistic paths (Lee et al., 2013). There is also a myriad of softer benefits such as the ability to visually highlight areas vulnerable to delays, enhanced understanding of the overall schedule risk profile, flexibility in choosing a less risky path to project completion, potential prioritizations of scope and improved performance monitoring of key milestones as an equivalent to a delay early warning system (Hulett, 2016).

Monte Carlo Methods, which are an integral part of QSRA, also allow for systematic and statistically-informed analysis of multiple delay scenarios, which is not possible with deterministic TIA (Hendradewa, 2019; Keizur et al., 2020). By randomly (re)adjusting input variables, project stakeholders can explore the outcomes of various what-if scenarios, each accounting for different input combinations and permitting project actors to see the likely futures and compare their implications (Takakura et al., 2019). In turn, this supports the identification of the optimal content, structure and location of the fragnet, minimizing delays in line with the duty to mitigate through optimization and understanding of the presumable critical path movements – similarly to schedule buffer refinement (Burdett and Kozan, 2015). Schedule buffers in this context represent additional time added to individual activities or schedule to account for or act as a cushion to absorb unforeseen events and to maintain flexibility of the schedule (Kuchta, 2014). Furthermore, QSRA can incorporate conditional branching, enabling the testing of various conditional eventualities where specific activities may or may not take place depending on certain conditions (Verschoor, 2005; Hu et al., 2022). This permits for a more comprehensive and flexible analysis, accommodating the dynamic nature of 'the real-world'. As a result, project teams can better anticipate schedule fluctuations and critical path disruptions, leading to more resilient and adaptable project schedules. It can be used, for example, to explore the impact of weather conditions on the availability of specific resources and their effect on the project schedule or, by assigning probabilities to the occurrence of specific activities, help to assess the influence of external factors on activities that may or may not necessitate additional effort (such as prolonged permit approvals, inspections, repeated tests). In essence, one can generate a more comprehensive understanding of possible delay detail and improve decision-making (Khodabakhshian et al., 2023).

Figure 2. Proposed approach - Probabilistic Time Impact Analysis

In summary, the synergy between TIA and QSRA represents a paradigm shift in delay analysis. By integrating probabilistic elements of project reality into the conventional CPM schedule through Monte Carlo simulation, this approach comprehensively addresses uncertainties and constraints. It paves the way for proactive risk mitigation, detailed resource management, and an in-depth analysis of potential project outcomes. Lastly, the method significantly enhances the robustness of project planning by incorporating realism and offering a deep, nuanced understanding of the schedule. In the context of Forensic Delay Analysis (FDA), it allows for a thorough examination of all schedule intricacies and interdependencies, thereby increasing the credibility and accuracy of delay measurements.

Validation

Data collection

In order to ascertain the benefits and potential shortcomings of the presented method, the new approach was subjected to a focus group evaluation. The focus group was attended by 10 project controls and project delivery practitioners who are routinely involved in change management (EOT implementation), delay analysis and risk analysis. The focus group was conducted both in person and via a live online conference utilising MS Teams application. The participants were selected through non-random purposive sampling. The authors elected to use purposive sampling (specifically, expert sampling) noting that a deliberate choice of the participants will ensure correct identification and selection of individuals that are able to materially contribute to the topic. Potential participants were identified through professional networks and selection criteria focused on a deep, practical understanding of these methodologies, moving beyond just theoretical knowledge. Essentially, the authors sought experts with an exhaustive knowledge of TIA and QSRA, requiring the hands-on technical acumen to manage the entire quantitative modelling process – from initial data gathering to final results interpretation. This sampling was particularly appropriate for this study as it allowed the researchers to work with professionals with highly specialized know-howe in EOT implementation and delay analysis, which required very nuanced and niche experience. Given the complex nature of TIA and QSRA methodologies, random sampling would have been inefficient and potentially counterproductive, as it could have included participants without the requisite domain knowledge to provide comprehensive and meaningful evaluation of the proposed framework. Furthermore, purposive sampling enabled the researchers to achieve theoretical saturation with a smaller, more focused sample size, which is methodologically consistent with the qualitative, exploratory nature of this investigation. The deliberate selection of experts with diverse industry backgrounds also enhanced the credibility and transferability of the findings by incorporating multiple professional perspectives on the practical applications of the integrated approach.

Another deciding factor was the availability of experts to participate in the study, noting the niche character of the subject matter. To eliminate bias and ensure the widest possible representativeness of the focus group the participants were chosen from a broad array of functional roles engaged in FDA and EOT implementation, considering functional seniority and pragmatic exposure to the investigated matter. The focus group was also conducted in a neutral environment – not specific to any company affiliation of the participants – to ensure there were no external factors that could influence the opinions expressed by the participants. In the group of experts, there was also one observer. The functional demographics of the focus group were as follows:

Table 1. Focus group demographics

The focus group was presented with a simulated project schedule for a nuclear submarine project, which served as the basis for testing the new approach of delay analysis. The schedule was a standard cost- and resource-loaded Primavera P6 project schedule, containing all necessary data to determine the delay and its likely cost. The schedule imitated a real major project and was prepared with technical integrity for modelling purposes by Oracle (thus it was objectivized). Prior to any discussions, the focus group received a neutral step-by-step presentation of two methods for calculating project delay. The initial approach presented involved TIA and delay calculation by way comparing a deterministic schedule completion date to the new completion date. This new date was determined after inserting additional fragnets to represent a change event and recalculating the schedule. The difference between the two dates, as well as the resulting cost and resource variations, were used to determine the delay and its cost.

The second approach presented to the focus group was the newly proposed method, which combined both TIA and QSRA. The schedule was subjected to QSRA, which involved: a) adding uncertainty ranges to activity durations, project duration and cost risks, b) a fragnet to represent a change event along with additional risks related to the new scope, and c) running a Monte Carlo simulation in Primavera Risk Analysis software. The probabilistic (risk-adjusted) completion date was determined by taking a P50 value (which represents the median and is perceived as the most probable outcome due to central tendency) from the Monte Carlo simulation (Holt and Scariano, 2009; Prasad, 2022). This date was then compared with the completion date generated by the deterministic delay measurement using a conventional TIA. The focus group was presented with comparative results and the following eight questions aimed at comprehensively capturing their sentiment regarding the novel method, its technical and pragmatic utility within the project environment, and the identifiable advantages and disadvantages of the approach.

1. What are the potential benefits of incorporating risk quantification into forensic delay analysis (particularly prospective) and/or change management?
2. What are the potential disadvantages of incorporating risk quantification into forensic delay analysis?
3. In which forensic delay analysis is the risk quantification more beneficial: prospective or retrospective?
4. What would be the impact on project disputes and change management of using Forensic Delay Analysis in conjunction with Quantitative Schedule Risk Analysis?
5. What prevents project professionals in implementing risk quantification into forensic delay analysis?
6. What factors (e.g. complexity/size) of a project affect the application of Forensic Delay Analysis and Quantitative Schedule Risk Analysis?
7. How would the integration of Forensic Delay Analysis and Quantitative Schedule Risk Analysis impact the construction project budget?

8. In your opinion, are either of these methods being applied in a standardized and consistent manner on the projects you have worked on to date, and what could further assist in their standardization and consistent application?

Each question was addressed in sequence, with broad group consensus reached before proceeding to the next one. All dissenting views were documented too.

Data Analysis

To identify and analyze the responses gathered via the focus group, thematic analysis was employed noting that it offers flexible approach to qualitative enquiry and allows for the synthesis and evaluation of key feedback points provided (Castleberry and Nolen, 2018). Thematic analysis further allows for identification of ‘the underlying ideas, assumptions, and conceptualizations […] that are theorized as shaping or informing the semantic content of the data’ (Braun and Clarke, 2006, p. 84) . This characteristic was specifically material to our study as the objective of the research was to determine the conceptual and pragmatic benefits of the new approach to calculation of change- and delay-related entitlements. The study employed QualCoder software to analyze the focus group discussion qualitative transcript. Additional support was obtained from the observers notes on non-verbal communication and sentiment within the group. Initial codes were derived from a line-by-line analysis of the transcript, supplemented by the observer's notes. The process was iterative until all core observations were encapsulated within a relevant primary code. The main codes were organized into categories representing the emerging themes as per the figure below.

Figure 3. Codes and themes

Findings

The qualitative analysis revealed valuable insights and implications regarding the novel approach of integrating TIA (as an example of the FDA technique) and QSRA within a project environment. These findings are detailed below.

The arguments for combining TIA and QSRA

Participants noted that the combined use of QSRA to support TIA to risk-adjust project schedule can refine claims, making entitlement calculations more precise, but also support the implementation of change (EOT) by refining their basis. It was suggested that, beyond the benefits of evidentiary nature, the persuasiveness of a claim demonstrably increases with the quality of its rationale and justification. In the words of one of the focus group experts, the rigor of the novel approach ‘gives a bit more stronger ground for application’ whilst preserving transparency of the approach and results.

The group pointed out that the process outcome, in line with a clear audit trail of the steps taken, can be used to demonstrate to internal and external auditors that the calculation of the entitlement has been done with due care. This enhances credibility by effectively countering the tactical arguments often employed in commercial negotiations surrounding a dispute or change event. The focus group emphasized that the mere ability to present a supported position may make the difference between its acceptance or rejection, or further escalation of the dispute. Having 'more realistic' calculations that methodically predict a given effect in a prospective analysis can be a convincing approach compared to estimates that are not supported by any methodology.

Participants also identified a number of positive features. Central to this was the predictive value and detailed insights provided by probabilistic analysis in combination with quantitative evaluation of the project schedule. The ability to perform scenario analyses, verify schedule sensitivity to specific variables, and accurately allocate project resources based on risk drivers and schedule criticalities were also cited as key benefits. Participants also articulated that the hybrid approach, if used carefully and in the right environment, can currently be a reliable tool for developing deeper business intelligence. When used retrospectively, the combination of Time Impact Analysis and QSRA could be used to conduct careful project post-mortems. For prospective use, the probabilistic view of the future and its likely scenarios were valued.

Understanding the drawbacks of TIA and QSRA integration

The group raised some concerns regarding the new approach. Firstly, they underscored the inherent subjectivity in estimating risk likelihood and impact. This could prolong commercial negotiations and, more critically, make the overall model more vulnerable to manipulation to support a predetermined output – something that is undesirable in a contentious environment where evidence is essential to resolving a commercial impasse. Secondly, the participants underscored the potential inconvenience associated with the process and model itself, which to put in the words of one of them may be simply 'difficult for people to understand'. Given the intricacy of modern CPM schedules and the questionable clarity of Gantt charts, they felt that adding another analytical layer would compound the intricacy of the process. Finally, this complexity raised issues of practicality and accessibility. The combination of advanced techniques was perceived as perhaps too demanding for experts accustomed to conventional methods, and could 'add an inordinate amount of time into procedures'. The general view was that while the demand for smarter analytics is present, new methodologies should remain pragmatic and be free from know-how constraints.

Several observations were made about the contractual complications that 'could muddy the waters somewhat'. For some, the potential unacceptability of such an approach was its vagueness in terms of both, contractual compliance and commercial practice. For others, the probabilistic approach appeared to be incompatible with established legal doctrine vis-à-vis FDA, which predominantly insists on a retrospective assessment. In such cases, the usefulness of forward-looking analysis may be confined to strictly internal applications rather than contributing to dispute avoidance via strengthening the validity and quantifiability of claims. Some respondents also argued that probabilistic analysis may be excluded from contractual provisions or simply become inapplicable (or even redundant) within certain contractual scenarios. For instance, a change that alters the scope but pragmatically does not increase the risk profile of the works would fall in this category. Lastly, as a consequence of the preceding arguments, contract managers and project lawyers might blindly resist the new approach in the context of EOT or delay management due to their unfamiliarity with the underlying methods.

Resource and pragmatic hurdles in TIA-QSRA integration

Participants highlighted that the risk adjustment process and the execution of combined QSRA and FDA model adds value 'if the project has the resources and capacity dedicated for something like that'. The group emphasized that the success of such an analysis relies on the maturity of the schedule and risk data (specifically the risk register), what can pose challenges in projects that are either time-constrained or immature. Project data is notoriously contentious, fragmented and incomplete. Simply agreeing on input values and their acceptable quality characteristics can take more time than a simpler assessment. And when combined with limited resources and weaker implementation capacity, it may end up being unpragmatic. Therefore, a deeper cost-benefit rationalization should precede the application of the new approach. At the same time, a combination of TIA and QSRA was considered particularly feasible for major projects - noting their appetite for analytical detail, extended delivery cycle and cumulative value of potential benefits.

Another important limitation was the subjectivity of the approach and its output. The focus group noted the potential issues arising from this subjectivity. Parties contesting the results of FDA commonly raise objections to undermine the evidential weight of the opposing party's material and to set the scene for rebutting their arguments. A popular strategy is to simply allege subjectivity, aiming to weaken the entitlement calculations by underscoring their self-serving exaggeration. Considering this regularity, the group further stressed that the usefulness of the proposed approach hinges on its meticulous execution and analytical impartiality, although all participants accepted that complete impartiality can never be attained. Thus, objections to the value of the analysis can be minimized but not eliminated. The group further emphasized that introducing additional variables and outputs could complicate otherwise straightforward negotiations, potentially diverting attention away from the core issue (such as extent of EOT or delay) to mere technicalities.

A unified approach to prospective probabilistic delay analysis

The group recognized that standardization of the proposed approach may be desirable, particularly in relation to the QSRA component. A few participants expressed dissenting views, referencing existing recommended practices developed by various governmental or professional bodies.

Nevertheless, a majority consensus emerged within the group, whereby it was acknowledged that there appeared to be not widely recognized, or universally accepted standards specifically tailored for this unique methodology. The group acknowledged that in the case of the FDA there exists some degree of standardization through the delay analysis protocols. However, they also confirmed that the existing guidelines only serve as a basis for conducting QSRA and contain broad principles with limited technical specificity required to create robust and repeatable models. The absence of standardized technical guidance means that practitioners are forced to navigate the modelling landscape without detailed directives on reliability and reproducibility. This gap, in turn, can undermine the credibility and comparability of analytical outcomes across projects. Several participants proposed employing benchmarking to evaluate the adequacy and quality of developed models.

Additional frontiers of using TIA and QSRA

In the view of the focus group, the proposed approach holds particular merit within large and continuous projects due to several inherent characteristics. Large projects typically have at their disposal substantial resource allocations, which in turn secure the necessary infrastructure, technological capabilities and maturity for effective deployment of advanced approaches. Participants signaled that such projects are managed and delivered by highly competent and experienced teams, who not only possess the necessary know-how but also adaptability to accommodate the complexities associated with new methodologies. The same does not hold true within less mature environments, which are typically associated with smaller-scale undertakings. Finally, large projects benefit from an extended time frame, which allows for training, iterative refinement and integration of the new methodologies into conventional workflows, thereby maximizing their benefits. Consequently, in the group's view, the suitability of the new method is grounded within environments characterized by ample resources, expert teams and adequate time investment for successful execution and achievement of desired results.

Discussion

The reception of progress within project management often evokes caution, presenting a paradox that underlines the expectative for innovation while at the same time inhibiting the adoption of the new (Davies et al., 2019). In parallel, some experts pose that, among the broad array of project failure drivers, inadequate innovation is particularly prominent. (Boateng et al., 2015). The method outlined in this paper offers a preliminary framework for forecasting project delays and outcomes, as well as for optimizing schedules. The study also acts as a foundational step toward theorizing the aforementioned approach.

Operational constraints are indeed impacting not only the project environment but also private and public sectors (Leybourne, 2006). Furthermore, any advanced analytics may pose challenges for projects with limited teams and resources (Bilal et al., 2019). However, these challenges should not be seen as impediments to progress but rather serve as catalysts for innovation. The authors believe that adoption of any technical advancements is contingent on the operator's willingness to innovate (Ozorhon and Oral, 2017). The new approach does not require the use of non-existent or unfamiliar processes; TIA is commonly used for delay calculation, while QSRA is routinely applied in any project environment (Hulett, 2016; Keizur et al., 2020). This paper proposes integrating the two methodologies into a synergistic approach to maximize the collective value added by both techniques. Despite the additional resources and effort required, the insights generated by the proposed approach offer a compelling benefit. It may be also convincing from the pragmatic perspective. For projects, the cost-benefit ratio remains favorable, even allowing for the complexity and timescale of large, long-term assessments. Even for smaller projects and thus smaller-scale analyses, the effort is worthwhile if the costs associated with the analysis are outbalanced by the potential savings or profit gains. Beyond financial returns, it also provides insights to improve future decisions.

While data scarcity can be a common challenge for analytical models like TIA or QSRA (Oh and Choi, 2020), the proposed methodology has a distinct advantage. Its reliance on data already available in most project environments makes it significantly more accessible than other techniques (Koulinas et al., 2020). The authors agree that the wealth of delay measurement enhancement sits within the currently available academic literature (Braimah, 2013). However, many of these proposals are impractical either due to their incongruity with current processes or restrained applicability. The proposed approach, in contrast, can be supported by processes typical of any project. Regarding contractual conditions and dependencies, the focus group's perspective is that particular methodologies possess contractual attributes and are subject to the technical or legal frameworks of the project. Although most standard contract forms overlook FDA and QSRA (Keane and Caletka, 2015), the proposed methodology remains suitable for contracts that mandate prospective analysis, such as the NEC (New Engineering Contract).

The focus group noted that while the FDA has developed numerous standards and guidelines over time, QSRA remains unregulated (Shahsavand et al., 2018). This situation complicates the definition of steps to establish a risk-adjusted schedule and the integration of FDA and QSRA. While acknowledging some dissent, the authors contend that a defined process offers benefits. Establishing uniform guidelines reduces variability, which in turn enhances the credibility, quality, and reliability of risk-adjusted Time Impact Analysis (TIA). This addresses a significant challenge, well-documented in the literature, where the lack of standardized Delay Analysis Techniques (DATs) often undermines the integrity and repeatability of the results. Furthermore, this uniformity enables integration of inputs and outputs across teams and stakeholders, what not only improves coordination but also ensures that the enhanced analytical rigour is maintained within the entire project lifecycle. Nevertheless, the authors do not endorse the implementation of firm frameworks. Instead, they emphasize the importance of distinguishing between the creation of comprehensive risk modelling practices and the establishment of general guidelines for risk and schedule management. Some members of the focus group expressed support for the former approach; however, at present, there is a paucity of technical guidance in the available literature.

Beyond its primary function, focus group participants praised the methodology's considerable value for project learning. Prospectively, combining Forensic Delay Analysis (FDA) with QSRA not only enriches forecasts by integrating probabilistic data and schedule integrity checks, but also helps to identify the most critical drivers of project outcomes. Retrospectively, the proposed methodology can exploit as-built data to forensically uncover the root causes of delays. In short, the analytical process itself delivers inherent value regardless of the perspective. The rigorous process of collecting data also fosters greater project controls awareness during delivery, whilst also documenting lessons learned that might otherwise be undetected.

Conclusions and limitations

This article posits that combining prospective FDA methods and QSRA can improve delay analysis in both change management and delay claim scenarios. The primary academic contribution sits in this novel integration of these methodologies, which addresses a critical gap in current delay analysis approaches by incorporating probabilistic element into what has been conventionally a deterministic domain. Such a study has been lacking in the academic literature despite lack of effective prospective DATs and the demand for well-founded forecasts (Grzeszczyk et al., 2024). The findings suggest that the proposed method may offer several benefits, including increased accuracy in entitlement calculations and a more in-depth prospective delay analysis process. It could also contribute to dispute avoidance by providing project stakeholders with additional insights permitting proactive delay mitigation. The authors believe that this study will stimulate further research into similar hybrid methodologies.

The authors validated the combination of FDA and QSRA by conducting a focus group. This methodology served a dual purpose: it systematically evaluated the theoretical underpinnings of the approach and confirmed its practicality. Unlike other studies that have examined these approaches in isolation, this investigation develops a hybridized framework that integrates probabilistic analysis into delay assessments, a problem previously unaddressed. This in turn means a more comprehensive understanding of project schedules and their drivers, increased knowledge of probable outcomes, and more accurate entitlement calculations. While the approach may be resource-intensive these drawbacks can be mitigated through robust data management, appropriate data architecture, and adequate resourcing. The authors are of the view that these issues will diminish in parallel to the adoption of the approach and increase in organizational maturity.

It is important to acknowledge the limitations inherent in this study. The methodology was demonstrated in simulated project scenario thus further research is required to validate its applicability across diverse, real-world projects, each with own contractual and operational nuances. Furthermore, although the method shows promise in the study, it may face adoption challenges due to its unfamiliarity in commercial, project and legal frameworks. Also, the depth and breadth of discussion during the focus group may have been influenced by the varying levels of technical knowledge of the participants. This could potentially have skewed the dynamics of the group discourse and the feedback provided. Lastly, the conclusions of this research must be interpreted with due caution, acknowledging theoretical and practical constraints, and the potential for subjectivity in the analytical method. While these factors define the boundaries of this investigation, they also illuminate promising avenues for future academic inquiry that can build upon the foundations established above.

Disclosure of interest

The authors report there are no competing interests to declare.

Availability of data

The data that support the findings of this study are available from the corresponding author, GG, upon reasonable request.

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Tables

Table 1. Focus group demographics

Role	Experience (years)	Count	Industry Experience
Risk Manager	10+	1	Nuclear, Transport, Rail
Risk Manager	5+	1	Nuclear, General Engineering
Risk Manager (observer)	5+	1	Nuclear, Transport, Rail, Utilities
Program Manager	20+	2	Nuclear, Energy, Water, Mining, Defense, Oil & Gas
Head of Performance	20+	1	Nuclear and Energy
Head of PMO and Digital	20+	1	Nuclear, Transport, Rail, Utilities, Aviation
Head of Risk	20+	1	Nuclear, Rail, General Engineering
Head of Schedule	20+	1	Nuclear, Transport, Rail, Utilities, Aviation, Energy, Defense
Senior Planner	15+	2	Nuclear, Transport, Rail, Utilities, Aviation

Figures

Figure 1. Conventional Time Impact Analysis

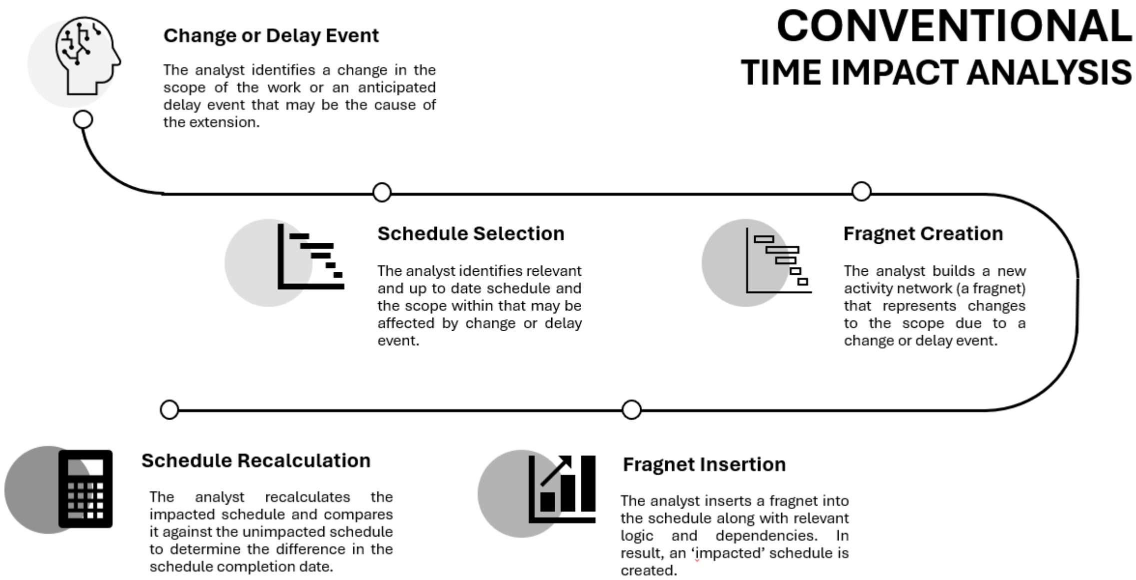

Figure 2. Proposed approach - Probabilistic Time Impact Analysis

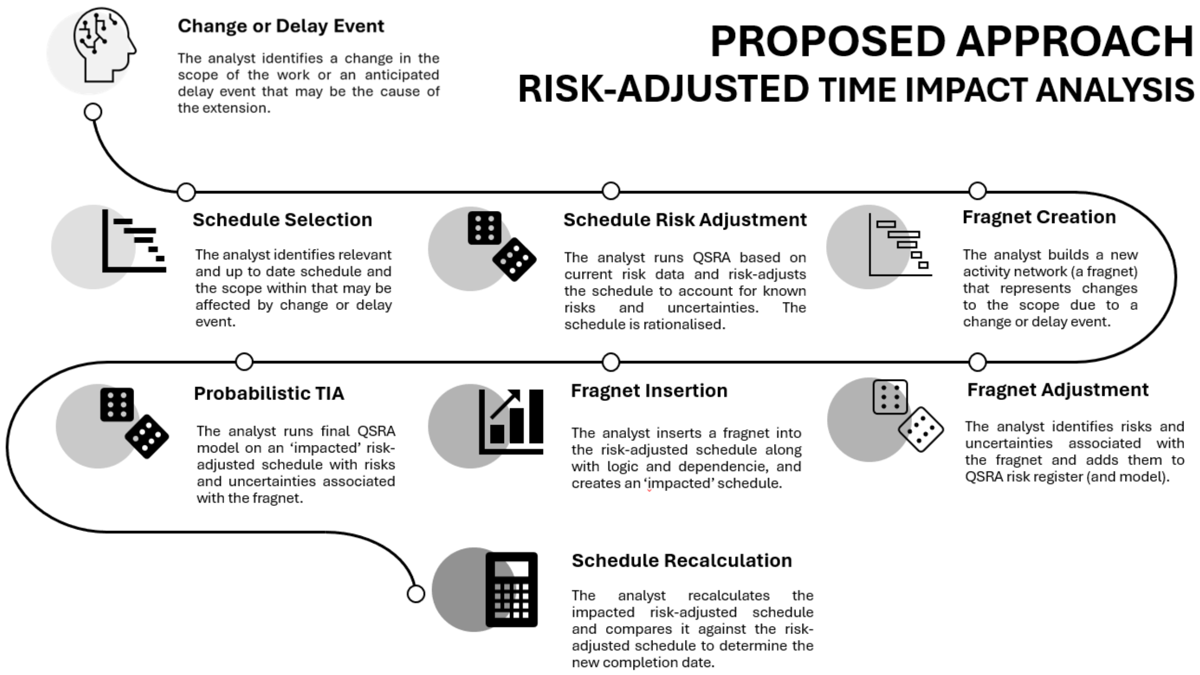

Figure 3. Codes and themes