Modeling and Optimization of Quantitative Risk in Fast-Track Infrastructure Development Projects

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Abstract :- The construction industry increasingly adopts the fast-tracking approach to meet the growing demand for rapid delivery of infrastructure projects. However, overlapping activities inherent in the fast-track strategy introduce distinctive risks or alter existing risk characteristics, leading to "overlapping risks." This study develops a quantitative risk assessment and simulation model to evaluate the economic impact of overlapping risks in fast-track infrastructure projects. The proposed model integrates Monte Carlo simulation with a proprietary optimization engine to assess the influence of overlapping risks on project duration and cost under three different overlapping degrees. A commercial renovation project serves as the case study for model demonstration. Results indicate that overlapping risks can significantly increase total project costs, despite a high probability of meeting target durations. Eight critical risks were identified as major drivers of project performance, affecting duration, cost, or both. The optimization procedure further reveals that the best mitigation strategy involves a combination of varying overlapping degrees to minimize economic impacts while achieving the target schedule. This research contributes a robust decision-support model for fast-track project planning by explicitly quantifying overlapping risks, capturing their probabilistic impact distributions, and highlighting interdependencies among risks.

Keywords: Construction Safety, Quantitative & Qualitative risk assessment, Simulation, Data Analysis

1. Introduction

Decision-makers in construction projects encounter heightened risks when accelerating schedules to achieve timely and cost-effective delivery. While all construction projects are inherently risky, fast-track projects carry additional risks that can undermine both the acceleration strategy and overall project cost. In particular, overlapping activities introduce risks that vary across different degrees of overlap, yet these risks are often overlooked in conventional schedule models. Previous studies have proposed simulation approaches for fast-track projects, but they typically assume that rework risks are a simple linear function of overlap duration. This assumption neglects the reality that overlapping risks exhibit nonlinear impacts on time and cost, with certain risks allowing recovery of schedule delays but not the associated costs.

Traditional qualitative techniques, such as probability–impact matrices, classify risks into severity categories (high, medium, low), but they do not estimate the magnitude of overlapping risk effects on project performance. Consequently, there is a pressing need for quantitative analysis that explicitly captures the distribution and intensity of overlapping risks. Such analysis would enable project decision-makers to make evidence-based trade-offs, allocate limited resources effectively, and prioritize mitigation strategies for the most impactful risks in fast-track construction projects.

2. Literature Review

The research community has developed various models to study fast-track construction projects and the impact of rework using diverse approaches. Early contributions drew insights from classical studies, some originating in product development, while more recent works (2016–2022) have advanced models for risk assessment and schedule optimization through overlapping or crashing techniques. These studies highlight the relevance of fast-tracking as a strategy to meet the increasing demand for rapid project delivery.

However, fast-track projects are inherently exposed to higher risks, particularly those arising from overlapping activities. Existing studies acknowledge risks associated with acceleration but largely overlook the fact that different degrees of overlap may generate distinct risk profiles. Most models simplify risk by assuming rework increases linearly with overlap duration, an assumption that fails to capture the nonlinear and variable nature of overlapping risks. As a result, decision-makers lack tools that can evaluate how different overlapping strategies influence project outcomes in terms of time and cost.

To address this gap, the following research questions are posed:

1. What is the probability of achieving desired fast-track performance metrics under different overlapping risk scenarios, and what are the project's most probable duration and cost outcomes?
2. Which overlapping risks and activities exert the most significant influence on project performance?
3. What is the optimal degree of overlapping that minimizes total cost while ensuring project duration does not exceed the original baseline?

This study proposes a Monte Carlo simulation-based risk assessment model to answer these questions. Unlike previous approaches, the model accounts for the occurrence of different risks at varying degrees of overlap, quantifies their probabilistic impacts on both time and cost, and explores the trade-offs between acceleration and risk exposure. The model seeks to identify acceleration strategies that minimize economic threats while maintaining the feasibility of the fast-track delivery strategy.

3. Materials and Methods

3.1. Model Outputs and Outcomes

The first step in the research process was to define the desired outputs and outcomes of the proposed model. The model was designed to:

1. Estimate the overall project risk by incorporating different overlapping risk scenarios.
2. Generate probability distributions of project duration and cost under the influence of overlapping risks.
3. Identify the risks with the greatest impact on project performance, thereby supporting decision-makers in prioritizing responses.
4. Determine the optimum combination of overlapping degrees that minimizes the risk impact on cost while satisfying the project duration constraint.

These outputs provide both quantitative insights into risk exposure and practical guidance for selecting effective acceleration strategies in fast-track construction projects.

3.2. Model Development

The proposed simulation model is structured into four main areas:

1. **Schedule logic** – defines activity sequencing and precedence relationships.
2. **Risk parameters** – captures the characteristics and distributions of overlapping risks.
3. **Risk occurrence** – models the likelihood and impact of risks across different overlapping degrees.

4. **Model outputs** – provides project duration, cost, and optimum overlapping strategies.

Figure 2 illustrates the relationships among these four areas. The following subsections describe the variables, equations, and logic applied within each area.

Indexes and Notation:

- i = activity number
- p = predecessor activity
- j = risk
- m = risk for a specific activity and degree of overlapping
- N = total number of activities
- M = number of risks within the same degree of overlap

3.3. Model Verification and Validation

The verification and validation (V&V) of the simulation model followed the recommendations of Sargent to ensure correct implementation and accuracy consistent with the model's intended application. A subjective validation approach was adopted, as the problem was considered a non-observable system.

- **Internal verification** was conducted by testing potential scenarios to inspect formulas and logic. Once correctness was confirmed,
- **Internal validation** was performed by executing the model multiple times to assess its behavior and consistency.
- **External validation** was then carried out using an independent review process . Two construction project managers with over 20 years of experience participated in this step: one drawn from the interview group and another not previously involved. Both agreed that the model adequately addressed the stated research questions.

One reviewer observed that, although the model is valid for academic research, its adoption in practice may be limited since such detailed risk analyses are not typically performed in construction projects. Nevertheless, the results presented below—adapted from —are consistent with the adopted verification and validation procedures, providing confidence in the model's reliability and relevance.

3.4. Demonstration of the Simulation Model

The simulation model was demonstrated using data from a real construction project combined with expert assessments of risks provided by experienced construction professionals. The case study project was the renovation of a four-story, 67,000-square-foot (SF) academic building at a higher education institution in the United States. The total scope comprised 67,319 gross square feet (GSF), plus an additional 9,959 GSF allocated to different departments, including office areas and computational research laboratories.

For the demonstration, the **first-floor buildout** was selected as the focus of analysis. This section of the schedule was characterized by:

- **Total area**: 16,478 SF
- **Baseline duration**: 145 days (without overlapping)
- **Baseline cost**: approximately USD 552,000 (order of magnitude estimate)

The simulation considered the initial ten activities along the critical path schedule. Within this network, nine overlapping activity pairs (labeled P1 to P9) were identified. Each pair was analyzed under three potential overlapping degrees (25%, 50%, and 75%), resulting in **27 overlapping alternatives** for risk evaluation. Risk data for these alternatives were derived from expert input and used as inputs to the simulation model.

5. Results & Discussions

The risk analysis process demonstrated in this study reveals that the impact of overlapping risks on project duration and cost can vary considerably. These differences are evident when examining the overall magnitude of impacts, the likelihood of meeting target goals, and extreme low-probability, high-impact scenarios.

5.1 Impact on Duration and Cost

The total overlapping risk impact proved more significant for **cost** than for **duration**. Most statistical measures—minimum, mean, median, and mode—indicated that project duration was unlikely to exceed the target baseline. By contrast, cost-related measures suggested notable overruns: both the mean and median total costs were 7–10% higher than the target cost.

This indicates an asymmetry: the project has a **greater than 99% probability** of achieving the fast-track target duration, but less than **1% probability** of meeting the target cost. The most probable outcome is completion within the desired timeframe but with cost increases that may reach **27%** above budget.

5.2 Extreme Impact Cases

The analysis also highlighted extreme cases—low-probability but high-consequence outcomes. In such scenarios, project duration could increase by **7–14%**, while costs could escalate by **63–75%**. These represent situations where multiple risks materialize simultaneously with severe consequences. Although such risks are often deprioritized in standard assessments, we align with the view that decision-makers should evaluate them carefully and consider mitigation measures.

5.3 Top Overlapping Risks

The results showed that top overlapping risks influencing project duration and cost vary by:

- **Target performance metrics** (duration vs. cost),
- **Project phase** (early vs. late activity pairs), and
- **Overlapping degree** (25%, 50%, or 75%).

Key findings include:

- All top risks affected **both duration and cost**, though the intensity varied. For example, risk *P8-25-R13 (Work environment)* significantly influenced both metrics, warranting dual mitigation strategies.
- Duration-related risks were concentrated in **later overlapping pairs (P7–P9)**, while cost-related risks appeared mainly in **early pairs (P1–P2)**.
- Duration impacts were most pronounced at **25% and 75% overlap**, while cost impacts were concentrated at **75% overlap**.

5.4 Managerial Implications

The findings underscore the importance of applying the proposed analysis during both **planning** and **execution** phases:

- In the **planning phase**, project managers can evaluate desirable durations, identify specific risks, and design proactive mitigation strategies. They can also analyze optimal overlapping combinations to balance acceleration and risk exposure.
- In the **execution phase**, managers can make informed adjustments rather than reactive or "blind" decisions. For instance, if *crew interference* risk (ranked among the top risks in Table 2) is significant for Pair

8 at even a 25% overlap, the manager may choose to avoid overlapping in that pair altogether. For Pair 7, the adjustment could be to reduce the overlapping degree.

Although proposing detailed mitigation measures was beyond the scope of this study, the results demonstrate that structured risk quantification can guide practical and evidence-based decisions in fast-track construction projects.

Conclusion

This study proposed a risk simulation model for fast-track construction projects, explicitly accounting for the fact that different risks with varying probabilities and impacts may arise at different degrees of overlapping. By integrating Monte Carlo simulation with an optimization procedure, the model quantified how overlapping risks influence project duration and cost.

The findings demonstrate that overlapping risks affect **cost** more significantly than **duration**. While the probability of meeting the fast-track target duration was as high as **99.7%**, the likelihood of achieving the target cost was below **5%**. The most probable project outcome was an expected duration of **114 days** and a total cost of approximately **USD 592,000**, representing cost growth despite time savings.

Importantly, the analysis showed that the **optimal overlapping strategy** is not a uniform degree of overlap but rather a **combination of different overlapping levels** across activities. This approach reduces the overall economic impact while maintaining the acceleration strategy's viability.

The study contributes a structured and quantitative decision-support tool for project managers, enabling them to:

- Evaluate overlapping risk distributions beyond traditional linear rework assumptions,
- Anticipate nonlinear impacts on duration and cost, and
- Select overlapping strategies that balance acceleration benefits with controlled risk exposure.

Future research may extend the model by integrating specific mitigation actions, testing larger project networks, and validating results across diverse construction sectors.

References

1. Blacud, N.A.; Bogus, S.M.; Diekmann, J.E.; Molenaar, K.R. Sensitivity of Construction Activities under Design Uncertainty. J. Constr. Eng. Manag. 2009, 135, 199–206. [CrossRef]

2. Williams, G. Fast Track Pros and Cons: Considerations for Industrial Projects. J. Manag. Eng. 1995, 11, 24–32. [CrossRef]

3. Mulholland, B.; Christian, J. Risk Assessment in Construction Schedules. J. Constr. Eng. Manag. 1999, 125, 8–15. [CrossRef]

4. Krishnan, V.; Eppinger, S.D.; Whitney, D.E. A Model-Based Framework to Overlap Product Development Activities. Manag. Sci. 1997, 43, 437. [CrossRef]

5. Tian, Q.; Zhang, Y.; Liu, Z.; Yan, J.; Zhou, X. Research on DSM-Based Product Development Coupling Activity Overlapped Execution Model. In DEStech Transactions on Computer Science and Engineering, Proceedings of the 4th International Conference on Modelling, Simulation and Applied Mathematics (MSAM 2020), Wuhan, China, 11–13 January 2020; DEStech Publications Inc.: Lancaster, PA, USA, 2020.

6. Oh, G.; Hong, Y.S. Managing Concurrent Execution of Multiple Activities in Product Development Process. Concurr. Eng. 2020, 28, 210–221. [CrossRef]

7. Rasul, N.; Malik, M.S.A.; Bakhtawar, B.; Thaheem, M.J. Risk Assessment of Fast-Track Projects: A Systems-Based Approach. Int. J. Constr. Manag. 2021, 21, 1099–1114. [CrossRef]

8. Ma, G.; Liu, X. Model and Algorithm for Dependent Activity Schedule Optimization Combining with BIM. Adv. Civ. Eng. 2020, 2020, e9727256. [CrossRef]

9. Laryea, S.; Watermeyer, R. Managing Uncertainty in Fast-Track Construction Projects: Case Study from South Africa. Proc. Inst. Civ. Eng. Manag. Procure. Law 2020, 173, 49–63. [CrossRef]

10. Abuwarda,Z.;Hegazy,T.Multi-DimensionalOptimizationModelforScheduleFast-Trackingwithoutover-Stressing Construction Workers. Can. J. Civ. Eng. 2019, 46, 1160–1173. [CrossRef]