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SCHEDULE DELAY IN CONSTRUCTION DELIVERY METHODS UNDER EXTREME UNCERTAINTY

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ABSTRACT

Increasing global disruptions, such as pandemics, trade policy shifts, and supply chain shocks, have intensified uncertainty in construction project delivery. Yet much prior research has examined how project delivery method selection influences project outcomes under conventional conditions, with limited attention to performance under extreme uncertainty. This exploratory comparative study examines schedule delay performance across four delivery methods, Design–Bid–Build (DBB), Design–Build (DB), Construction Manager-at-Risk (CMAR), and Integrated Project Delivery (IPD), with the COVID-19 period (2020–2022) serving as an empirical case of extreme uncertainty. Using publicly verifiable multi-source project documentation, including Federal Emergency Management Agency (FEMA) disruption records, Engineering News-Record (ENR) reports, and project documentation, this study compiled a dataset of 17 non-residential construction projects using a self-defined, normalized Uncertainty Schedule Delay Index (USDI). Descriptively, within this dataset, more collaborative delivery methods, such as IPD and CMAR, tended to show lower schedule delays than DBB and DB. To contextualize these findings, practitioner insights were collected through interviews highlighting early engagement, proactive procurement, and effective team communication. Together, these findings contribute exploratory comparative evidence on delivery method performance and offer practical insights for schedule risk management under extreme uncertainty.

KEYWORDS

Collaboration, integration, schedule delay, uncertainty, Integrated Project Delivery (IPD).

INTRODUCTION

RISK AND SCHEDULE DELAYS IN THE CONSTRUCTION INDUSTRY

The construction industry is widely recognized as a complex and high-risk sector characterized by multiple stakeholders, long decision cycles, and strong dependence on external conditions.

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Construction projects therefore face multiple interacting risks, including labour, managerial, technical, financial, and environmental risks, which can jointly affect project performance (Ghamarimajd et al., 2024).

Among the various risk types, schedule delays are widely recognized as one of the most severe issues affecting construction projects. Existing research indicates that schedule delays are not only a common manifestation of project failure but also a key trigger for cascading project problems (Park, 2021). Evidence from 113 large public projects in the U.S. and the U.K. shows that delayed projects experienced an average schedule overrun of about 23% (nearly 10 months), with significantly greater delays observed in projects that also incurred cost overruns (Park, 2021).

EXTREME UNCERTAINTY AND PROJECT DELIVERY METHODS

Given the severe consequences of schedule delays for construction projects, the industry has long been committed to reducing the risk of such delays by improving project management approaches. Among these approaches, project delivery methods are widely considered one of the key managerial decisions influencing project success, as they determine the allocation of responsibilities, risks, and decision rights among project participants (Ahmed & El-Sayegh, 2020).

In this study, project delivery method refers to the contractual governance structure that defines relationships among owners, designers, and constructors. These governance arrangements shape collaboration mechanisms, decision-making processes, and risk allocation throughout project execution.

However, the COVID-19 pandemic delivered an unprecedented external shock to the construction industry. Unlike conventional project risks, the pandemic constituted a highly uncertain event whose impacts were characterized by suddenness, systemic nature, and long-term consequences. Lockdown measures, labour mobility restrictions, and global supply chain disruptions significantly affected project execution and schedule performance (Gamil & Alhagar, 2020). Under such conditions of extreme uncertainty, project delivery systems that function well under normal circumstances faced an unprecedented stress test (Perminova et al., 2008).

RESEARCH GAP AND STUDY SCOPE

While schedule delays have been widely studied, much of the comparative evidence regarding delivery methods is derived from relatively stable project environments. Systematic comparative datasets capturing systemic shock periods, such as the COVID-19 pandemic, appear to remain limited (Zhong et al., 2022). In addition, the mechanisms through which delivery governance structures may influence schedule performance under extreme uncertainty remain insufficiently understood.

To explore this issue, this study constructs a multi-source comparative dataset of seventeen non-residential U.S. construction projects implemented during the COVID-19 period (2020–2022). Using publicly traceable documentation, the study compares schedule delay performance across multiple project delivery methods using both raw delay months and a normalized Uncertainty Schedule Delay Index (USDI).

RESEARCH QUESTIONS

To address the identified gaps in understanding schedule delay behaviour under conditions of extreme uncertainty, this study is guided by the following research questions:

- RQ1: How do different project delivery methods perform in terms of schedule delay under extreme uncertainty, such as the COVID-19 pandemic?

- RQ2: Do more collaborative delivery methods, such as CMAR and IPD, tend to show lower schedule delay than DBB and DB under extreme uncertainty?
- RQ3: How can normalized schedule delay measures help compare project delay across projects with different scales and conditions?

LITERATURE REVIEW

PROJECT DELIVERY METHODS AND PROJECT PERFORMANCE

Project delivery methods define the contractual and governance structure through which responsibilities, risks, and decision rights are allocated among project participants. Traditional models such as DBB typically involve sequential phases and limited early collaboration, whereas DB, CMAR, and IPD introduce greater integration and joint decision-making (Ibrahim & Hanna, 2019). Prior studies suggest that more integrated delivery approaches can reduce coordination problems and improve cost and schedule outcomes, particularly in complex projects (Ashcraft, 2022). Empirical evidence also indicates that collaborative delivery models such as IPD may improve schedule reliability and reduce cost growth in some settings, especially healthcare construction (Hanna et al., 2023). However, most of this literature is based on relatively stable project environments, and systematic comparisons under extreme uncertainty remain limited.

LEAN CONSTRUCTION AND COLLABORATIVE PRODUCTION SYSTEMS

Lean Construction is a production-oriented management philosophy that seeks to improve workflow reliability, reduce waste, and enhance collaboration across project participants (Garcés et al., 2025). Common Lean practices such as the Last Planner System and pull planning aim to stabilize workflow through collaborative planning, constraint removal, and more reliable commitments (Agrawal et al., 2024).

DELIVERY METHODS VS. LEAN PRODUCTION SYSTEM

Although Lean practices are often associated with collaborative delivery environments, project delivery methods and Lean production systems are conceptually distinct. Delivery methods define the contractual and governance relationships among project participants, whereas Lean Construction focuses on production management, value generation, and workflow control (Garcés & Peña, 2023). Collaborative agreements such as IPD often include early stakeholder involvement, shared risk-reward mechanisms, and joint decision-making processes (El-adaway et al., 2017), which may create conditions that support collaborative planning and adaptive project management.

Building on this distinction, this study adopts a conceptual enabling pathway: governance features such as early involvement, aligned incentives, and shared decision-making may foster greater collaboration and, in turn, increase the likelihood of adaptive behaviours consistent with Lean principles. However, because internal Lean practices cannot be directly verified in the dataset, this pathway is treated as a conceptual explanation.

RESEARCH GAPS

Despite growing interest in collaborative delivery methods and Lean Construction, three gaps remain. First, few studies compare delivery methods under extreme disruptions such as the COVID-19 pandemic. Second, existing research often focuses on delivery labels without examining internal production practices, making it difficult to distinguish contractual effects from Lean-related effects. Third, comparative studies using normalized delay measures across heterogeneous projects remain limited. As an initial step to address these gaps, this study

compares schedule delay outcomes across delivery methods using USDI and publicly documented project data from projects executed during the COVID-19 period.

METHODOLOGY

RESEARCH DESIGN

This study employs an exploratory comparative design to examine schedule delays across project delivery methods under extreme uncertainty (2020–2022). The design combines descriptive quantitative comparison of traceable project records with qualitative contextual interpretation of project narratives and one practitioner interview.

POPULATION AND SAMPLE LIMITATION

The target population includes non-residential U.S. building projects (2020–2022) documenting: (a) a baseline schedule or planned completion timeline and (b) a clear project delivery method. Projects were eligible if delivery methods and schedule outcomes were traceable through public documentation. Since no comprehensive registry exists for this subset, the population size is unknown; thus, the dataset is an available, traceable sample constructed for exploration rather than representative.

DATA SOURCE AND CASE SELECTION

Cases were identified from multi-source public records, including FEMA documentation, ENR reporting, and owner or project documentation. To enhance traceability, each record includes source types and cross-source corroboration where feasible. Data reliability was evaluated using a structured classification framework (Table 1).

Public reporting may involve selective disclosure and publication bias. This is particularly likely when project teams curate narratives of success. Therefore, this study treats public sources as traceable but potentially biased. When multiple sources existed for a given data point, owner- or official-released information and neutral third-party reporting were prioritized over promotional materials to improve reliability.

Table 1: Public source reliability classification framework

Source Tier	Source Type	Examples	Reliability	Use in this study
Tier 1	Official institutional records	Government reports, regulatory filings, owner official report	High	Used as primary evidence when available
Tier 2	Independent professional reporting	ENR, major newspapers, construction drive	Moderate to High	Used as independent corroboration
Tier 3	Owner or institutional communication	University announcements, Contractors' post	Moderate	Used when supported by other sources

DATA PROCESSING

Key project attributes (e.g., project name, delivery method, building type, and planned vs. actual completion dates) were consolidated into a structured analysis table. Delay information was extracted using standardized rules: explicit statements such as "delayed by X months" were recorded as X; statements indicating "on schedule" were coded as 0 months. Projects lacking

sufficient schedule outcome information were coded as "Not Available (N/A)" and excluded from delay-based calculations requiring numeric values. For phased projects, the completion time of the core unit or the first operational phase was adopted as the representative milestone to improve comparability, consistent with how schedule impacts were publicly reported.

VARIABLES

- Delay duration: Raw delay was measured in months relative to the publicly documented baseline. Delay = 0 indicates reported on-schedule completion; N/A indicates insufficient public schedule outcome information for extraction.
- Project complexity grouping: To reduce confounding by heterogeneity, projects were grouped into two complexity categories. This grouping draws on the view that project complexity is shaped by project size, variety, interdependence, and context (Vidal & Marle, 2008). Group 1 (High Complexity) includes large healthcare and major non-residential building projects with extensive building systems, regulatory constraints, and multi-phase construction. Group 2 (Medium Complexity) includes smaller non-residential projects such as renovations or limited-scope upgrades with fewer system interfaces and lower coordination intensity.

USDI CALCULATION METHOD

To construct a comparable measure of schedule delay, this study computes the Uncertainty Schedule Delay Index (USDI) for each project as follows:

$$USDIi = 1 - \frac{Di - Dmin}{Dmax - Dmin}$$

Where:

- USDIi: Uncertainty Schedule Delay Index for project i, ranging from 0 to 1, with higher values indicating better relative schedule delay performance (i.e., lower delay).
- Di: Actual delay months for project i
- Dmin: Shortest delay value within the complexity group (i.e., the project with the least delay)
- Dmax: Longest delay value within the complexity group

When Di = Dmin, USDIi = 1, indicating the best schedule delay performance within the group;

When Di = Dmax, USDIi = 0, indicating the worst schedule delay performance within the group.

The USDI standardizes schedule delay outcomes to reduce the influence of absolute delay differences across projects within the same complexity level. This normalization enables a comparative assessment of schedule delay performance across different project delivery methods under comparable conditions. Subsequently, the average USDI score for each delivery method was calculated across all groups, allowing for a relative comparison of schedule delay outcomes among the various delivery approaches. Qualitative insights were used to contextualize the quantitative findings.

COMPARATIVE ANALYSIS STRATEGY

The analysis focuses on descriptive comparisons of raw delay distributions and USDI patterns across delivery methods (DBB, DB, CMAR, IPD), stratified by complexity groups. Because of small sample size and available sampling, inferential statistics are not used for causal claims. Reporting both raw delay and USDI is intended to improve transparency and reduce over-interpretation of normalization.

QUALITATIVE INTERVIEW

To contextualize the quantitative patterns, we conducted an approximately one-hour open-ended interview with an anonymized senior project manager (pseudonym: "Interviewee A") from a large U.S. general contractor. The interview was audio-recorded with the interviewee's consent and transcribed to capture practitioner reflections on schedule disruptions during the pandemic. Identifying details (employer name, project names, locations, client names) were removed during anonymization. The anonymized transcript is archived and can be provided upon request subject to conference/journal policies and confidentiality requirements. The interview is used as interpretive evidence.

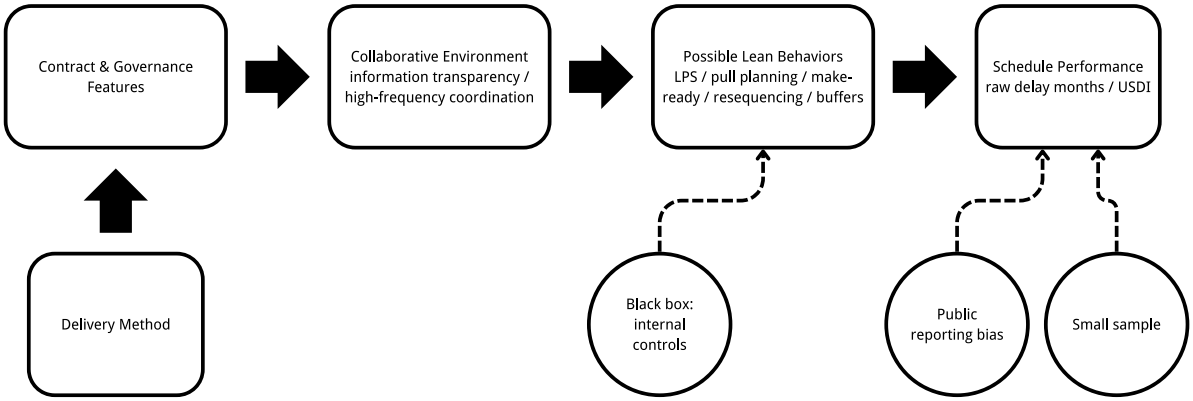

Figure 1: Analytical framework for examining delivery methods and schedule delay performance

METHODOLOGICAL LIMITATION

This study classifies projects by reported delivery method as a commercial/legal governance structure. It does not directly verify internal production planning and control practices (e.g., Last Planner System, pull planning, takt planning). Therefore, the internal production system is treated as a methodological "black box," and the study cannot isolate whether observed performance differences are driven by contractual governance, associated Lean practices, or other unobserved project factors.

RESULT

SAMPLE OVERVIEW AND DELAY DISTRIBUTION

The dataset includes 17 construction projects across four primary delivery methods: IPD, DB, CMAR, and DBB. The projects were grouped into two complexity categories: high-complexity Group 1 (N = 9) and medium-complexity Group 2 (N = 8). Sample characteristics, reliability tiers, and the distribution of recorded schedule delays and USDI values are presented in Tables 2 and 3.

Among Group 1 projects, recorded delays ranged from 0 to 9 months, with a median delay of 3 months. In Group 2, delays ranged from 0 to 12 months, with a median of 5.5 months. Descriptively, projects delivered through DBB and DB tended to exhibit longer delays, whereas IPD and CMAR projects generally showed shorter delays within this dataset.

Descriptively, the observed delay patterns suggest variation across delivery methods. Within Group 2, DBB and DB projects tended to show longer delays than IPD and CMAR projects. Conversely, IPD and CMAR projects generally showed lower delays in this dataset, although the study does not establish whether this pattern is attributable to delivery structure, collaborative practices, or other project-specific factors.

The observed delay patterns suggest that schedule performance may vary by delivery method, particularly in the medium-complexity group. However, given the small sample size and the descriptive nature of the analysis, these findings should be interpreted cautiously.

Table 2: Summary of group 1 project delay and USDI values

Project name	Delivery method	Delay month	Reliability Tier	USDI
Penn Medicine-HUP Pavilion	IPD	0	1	1
UC San Diego-Hillcrest Phase 1	IPD	0	2,3	1
SCAD 44/45 Phase 1	DB	0	2,3	1
Georgia Washington University Renovation	IPD	N/A	3	N/A
Piedmont Medical Centre-Fort Mill	DB	N/A	1	N/A
Samaritan Healthcare Expansion	DB	7	2	0.23
Confidential Medical Research Facility	CMAR	3	2,3	0.67
Three Cross Regional Hospital	CMAR	3	2,3	0.67
Elmhurst Hospital Expansion	DBB	9	2	0

Table 3: Summary of group 2 project delay and USDI values

Project name	Delivery method	Delay month	Reliability Tier	USDI
Medical Office Building (MOB)	IPD	0	2	1
Elliot Hospital	DB	10	2	0.17
University of Arizona-Student Success District	CMAR	N/A	1	N/A
University of Delaware-Worrilow Hall Renovation	CMAR	N/A	2	N/A

Table 3: Summary of group 2 project delay and USDI values (continued)

Project name	Delivery method	Delay month	Reliability Tier	USDI
Joyce Cummings Centre-Tufts University	CMAR	3.5	2	0.71
NYC P.S. 360	DBB	12	1,2	0
Philadelphia Police Public Service Building	DBB	6	2,3	0.5
Stephen F. Austin High School Rebuild	DBB	5	1	0.58

COMPARATIVE DELAY OUTCOMES ACROSS DELIVERY METHODS

Normalized delay outcomes were compared across delivery methods using the USDI metric. Across the observed cases, IPD projects consistently reported high USDI values, including several projects with no recorded schedule delay. CMAR projects generally showed relatively favourable delay outcomes, with several projects demonstrating moderate delay durations compared to other delivery methods. DB projects displayed the greatest within-method variation, with USDI values ranging from 0.17 to 1.0, including both projects with no delay and projects experiencing longer schedule extensions. DBB projects exhibited the lowest overall USDI values in the dataset, including several projects with the longest observed delays. These patterns indicate that schedule delay outcomes varied across delivery methods within the dataset.

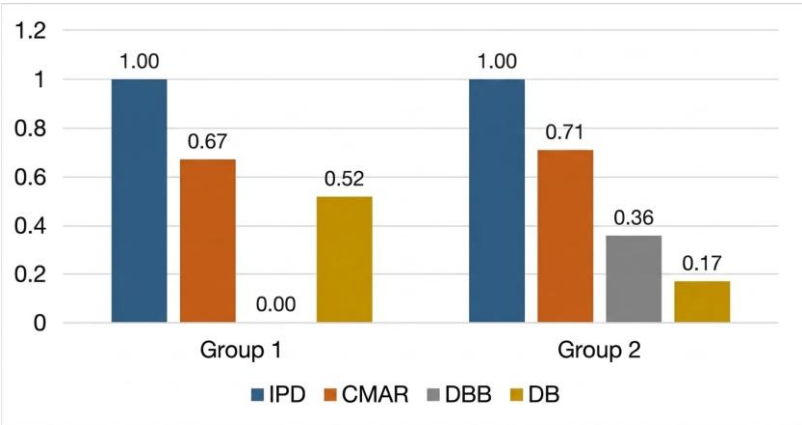

Figure 2: Comparative analysis of USDI

DISCUSSION

INTERPRETATION OF DELAY PERFORMANCE PATTERNS

Within this dataset, the descriptive results show lower delay outcomes in IPD and CMAR projects than in DBB and some DB projects. At the same time, the results also show that the formal delivery label alone does not fully explain performance differences. This is most visible within the DB category, where USDI values ranged from 0.17 to 1.0, indicating substantial variation among projects delivered under the same contractual structure.

This within-method variation is analytically important. If a single delivery method category can include both very strong and relatively weak schedule outcomes, then the delivery label itself is unlikely to be a sufficient explanation of project resilience under extreme uncertainty. Instead, the results suggest that attention should also be directed toward the governance and coordination conditions enacted within projects.

GOVERNANCE FEATURES AS POSSIBLE ENABLING CONDITIONS

One way to interpret the observed pattern is that delivery methods matter not only as contractual forms, but also as governance environments that may enable early coordination, shared decision-making, and adaptive collaboration. Prior research has suggested that collaborative delivery arrangements are often associated with earlier involvement of key participants, more integrated decision-making, and stronger alignment of project incentives (Ahmed & El-Sayegh, 2021). Under conditions of systemic disruption, such features may be particularly important because they can reduce response time, improve information sharing, and support faster adjustment to changing constraints.

This interpretation is also relevant to the contrast between DBB and the more collaborative delivery environments observed in this study. In more sequential structures, decision-making and coordination may remain fragmented across organizational boundaries, making rapid adaptation more difficult when procurement conditions, labour availability, or site restrictions change unexpectedly. By contrast, arrangements that support earlier coordination and more frequent communication may be better positioned to respond to disruption in real time.

THE DB OUTLIER AND THE ROLE OF COLLABORATION MECHANISMS

The large variation among the DB cases led to a closer qualitative review. The DB project with the lowest observed delay (USDI = 1.0) was selected for an in-depth interview with a senior project manager who was directly involved in the project. The goal of the interview was to better understand what project practices may have contributed to this result.

The interview indicated that the project team responded to the pandemic through early procurement adjustments, close coordination, and fast communication among key participants. These observations help explain why projects under the same delivery method can still have very different delay outcomes. They also suggest that performance under extreme uncertainty may depend both on the formal delivery method and how effectively collaborative coordination is carried out within the project team.

POSSIBLE LINKS TO LEAN CONSTRUCTION PRINCIPLES

This question is especially important in the context of Lean Construction. Lean research has long argued that project performance depends heavily on the quality of production planning, coordination, and workflow management (McHugh et al., 2021). From that perspective, collaborative governance structures may matter because they create more favourable conditions for adaptive behaviours such as earlier constraint identification, faster resequencing, more reliable commitments, and tighter coordination across participants.

At the same time, the present study does not directly verify the use of specific Lean tools such as the Last Planner System, pull planning, or takt planning in the analysed projects. The findings therefore should not be interpreted as evidence that Lean implementation explains the observed outcomes. Rather, the results suggest a more limited and more defensible interpretation: collaborative contractual and governance conditions may increase the likelihood of adaptive coordination under disruption, and such coordination is broadly consistent with Lean Construction principles, although Lean implementation itself was not verified in this study. Related theoretical arguments have been advanced in prior research, including work on digital Last Planner applications and resilient workflow coordination during disruption (McHugh et

al., 2021), but those mechanisms were not directly examined in the present study and therefore are not discussed here in detail.

CONTRIBUTION OF THE STUDY

Taken together, this study makes two main contributions. First, it examines project delivery methods under conditions of extreme uncertainty by looking at project performance during the COVID-19 period. Second, the findings show that schedule resilience should not be explained by contract type alone. It should also be understood in relation to project governance and how collaboration actually worked in practice.

The main contribution of this study is not to argue that one delivery method is always better. Instead, it shows that under extreme uncertainty, differences in delay outcomes are only meaningful when they are interpreted together with the project's governance and collaborative conditions.

CONCLUSION

This exploratory study compared schedule delays in DBB, DB, CMAR, and IPD projects during the COVID-19 disruption period using raw delay months and the normalized USDI indicator. In this dataset, IPD and CMAR projects generally showed lower delay outcomes, while DB projects showed greater variation. These findings suggest that under extreme uncertainty, schedule performance may be related both on delivery method and the actual level of collaboration.

A possible explanation is that more collaborative delivery methods may support faster response when projects face disruption and may therefore help reduce delay. However, delivery method only provides a framework for collaboration. Project outcomes still depend on how participants coordinate, communicate, and make decisions in practice. This may also help explain the greater variation observed among DB projects

LIMITATIONS

This study is exploratory and not intended to support statistical generalization. The sample is small (N = 17), and all cases were drawn from publicly traceable projects. As a result, the full population is unknown, and the sample cannot be assumed to represent the broader distribution of project types or delivery methods.

The data source also introduces reporting limitations. Publicly available project information is traceable, but it may be incomplete, selectively disclosed, or uneven in reliability. Cross-source checks were used when possible, but publication bias and reporting inconsistency cannot be fully ruled out.

In addition, delay was measured using raw delay months and USDI to improve comparability across cases. However, publicly reported delay data were not always complete, and USDI should be understood as a relative normalization measure rather than a precise benchmark.

Finally, the study does not directly verify internal project operations. It cannot determine whether the observed delay outcomes are primarily related to delivery method, collaborative governance, Lean practices, or other project-specific conditions.

FUTURE RESEARCH

Future research should strengthen external validity through larger datasets, clearer population frames, and more systematic source-reliability assessment. More importantly, it should open the black box between delivery structure and performance by directly observing governance and production practices. Comparative designs such as DBB-with-Lean versus DBB-without-

Lean, or DB projects with stronger versus weaker collaboration mechanisms, could help distinguish the effects of contractual form from enacted coordination practices. In addition, analysis by disruption phase may help identify which governance arrangements are most effective at different stages.

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