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# Financial Risk Cascades in Mega-Projects with Structural Equation Modeling: Payment Delays, Insolvency, and Project Failure in Saudi Hotel Construction

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## Abstract

Financial risk cascades represent a critical yet understudied phenomenon in mega-project management, wherein primary financial disruptions (payment delays, cost mismanagement) trigger secondary cascades (subcontractor defaults, resource constraints), ultimately culminating in project failure. This study employs Structural Equation Modeling (SEM) to investigate the financial risk cascade mechanism in Saudi hotel construction mega-projects, specifically examining the mediation pathways through which inadequate cost management and payment delays precipitate project failure. Data from 60 construction professionals (M age = 48.2 years, M experience = 18.7 years) working on Al-Madinah Central Area hotel construction projects were analyzed using confirmatory factor analysis and path analysis within a latent growth curve framework. Results revealed that inadequate cost management ($\beta = 0.687$, $p < 0.001$) and payment delays ($\beta = 0.712$, $p < 0.001$) jointly explain 68.4% of variance in project failure risk ($R^2 = 0.684$). Critically, subcontractor performance deterioration and resource unavailability mediate 54.2% of the payment delay → project failure pathway (indirect effect = 0.386, 95% CI [0.301, 0.471]), suggesting that payment cascades operate through supply chain vulnerability channels rather than direct financial stress alone. Moderation analysis revealed that stakeholder coordination quality significantly attenuates the payment delay effect ($\beta = -0.431$, $p < 0.001$), with well-coordinated projects experiencing a 62.3% reduction in risk compared to poorly coordinated projects. Model fit indices demonstrated adequate structural validity (CFI = 0.891, RMSEA = 0.068, SRMR = 0.042). These findings elucidate the mechanisms by which financial risks propagate across project ecosystems and demonstrate that interventions targeting supply chain resilience and stakeholder coordination yield disproportionate benefits in mitigating risk. Implications for mega-project governance in Vision 2030 initiatives are discussed.

## Keywords
Financial risk cascades, Project failure mechanisms, Structural equation modeling, Mega-project governance, Supply chain resilience, Stakeholder coordination, Saudi construction

## 1. Introduction
Mega-projects—construction initiatives exceeding $1 billion with extended timelines, complex stakeholder networks, and strategic importance—represent both engines of economic development and repositories of catastrophic risk. Flyvbjerg et al. (2003) documented that 90% of significant infrastructure projects experience cost overruns averaging 45%, while 50% experience schedule delays exceeding 12 months. Despite decades of project management standardization, financial risk remains the primary driver of mega-project failure (Alshihri et al., 2022; Sanni-Anibire et al., 2022). The paradox is profound: while individual financial risk factors (payment delays, cost misestimation) are well-documented, their mechanisms of action—how primary financial disruptions cascade through project systems to precipitate systemic failure—remain poorly understood. Extant research treats financial risks as isolated threats rather than network phenomena. Payment delay is modeled as a direct cost-schedule stressor, cost mismanagement as a budgetary constraint, and contractor insolvency as a binary trigger for project termination. Nevertheless, field evidence

from mega-projects reveals far more complex dynamics: payment delays trigger subcontractor defaults, which fracture supply chains, create labor shortages, degrade construction quality, necessitate expensive rework, and further strain finances, potentially catalyzing insolvency cascades.This study argues that the financial risk associated with mega-projects should be reconceptualized as a cascade phenomenon—an interconnected chain of secondary consequences that amplifies initial disruptions. Understanding these cascades is crucial because interventions targeting cascade pathways (e.g., supply chain resilience, stakeholder coordination) may prove more cost-effective than directly addressing primary risk factors.

Context: Saudi Vision 2030 and MCA Mega-Projects
Saudi Arabia's Vision 2030 initiative targets transformative infrastructure investment, with construction sector projects valued at 1 trillion Saudi Riyals over the decade. The Pilgrim Experience Program (PEP), a cornerstone of Vision 2030, aims to accommodate 30 million annual pilgrims by 2030, necessitating an expansion of accommodation capacity in Makkah and Al-Madinah. This ambitious mandate has precipitated a wave of mega-projects in the Al-Madinah Central Area (MCA)—a 1.7 million-square-meter region of profound religious, cultural, and economic significance. MCA hotel construction projects represent a unique organizational context combining: (1) financial scale (projects valued 50-500 million SAR, requiring extended financing and multi-year execution), (2) geographic constraints (limited space, high visitor density, restricted work hours), (3) stakeholder complexity (owners, contractors, subcontractors, consultants, government agencies, religious authorities), and (4) regulatory intensity (heightened government oversight, strict safety mandates, heritage protection requirements).

Previous research on MCA construction (Yousef et al., 2024) identified payment delays as the top-ranked risk factor by composite score (12.25/25.0), yet the mechanisms by which payment delays systematically damage projects remain poorly understood. This study pursues that clarification.

Research Objectives
This investigation pursues three primary objectives:
Objective 1: Identify and empirically validate the structural pathways through which financial risk factors (inadequate cost management, payment delays, contractor insolvency) precipitate project failure in mega-projects.
Objective 2: Determine whether supply chain vulnerabilities (subcontractor performance and resource availability) and stakeholder relationship quality mediate and moderate the relationship between financial risk and project failure.
Objective 3: Quantify the relative contributions of direct financial effects and cascade pathways to explaining overall project failure risk, enabling differential resource allocation in risk response strategies.

Research Hypotheses
Grounded in system dynamics theory, organizational interdependence theory, and construction management literature, five primary hypotheses are advanced:
H1 (Direct Financial Effects): Inadequate cost management and payment delays independently predict project failure severity, with standardized path coefficients ($\beta$) $> 0.50$ and $p < 0.01$, controlling for project scale and stakeholder complexity.
H2 (Cascade Mediation via Supply Chain): The relationship between payment delays and project failure is partially mediated through subcontractor performance deterioration and resource unavailability, with the indirect effect accounting for more than 40% of the total effect.
H3 (Coordination Moderation): The quality of stakeholder coordination significantly moderates the relationship between payment delay and project failure ($\Delta R^2 > 0.08$), with effective coordination reducing the impact of payment delay by 50% or more.
H4 (Insolvency Amplification): Contractor financial insolvency moderates the cost mismanagement → project failure relationship, such that the effect of cost mismanagement on failure is amplified by a factor of $\geq 2.5$ under conditions of financial distress.
H5 (Cascade Dominance): Indirect pathway effects (cascade mechanisms) explain a larger proportion of the payment delay → project failure relationship ($\geq$54%) than direct effects, indicating that supply chain and relational pathways represent primary failure mechanisms rather than secondary consequences.

Theoretical Framework and Literature Integration
System dynamics theory (Sterman, 2000) posits that complex systems exhibit counterintuitive behavior arising from feedback loops, time delays, and nonlinear relationships. In project contexts, financial disruptions (payment delays, cost overruns) constitute perturbations generating reinforcing feedback loops: delayed payments → contractor cash

flow stress → inability to pay subcontractors → subcontractor defaults → supply chain disruptions → schedule delays → cost escalation → further financial pressure → intensified crisis. These reinforcing loops amplify initial disruptions within the system's structure.

Significantly, system dynamics theory predicts that interventions at cascade leverage points (e.g., stabilizing cash flow through payment guarantee mechanisms) may produce disproportionate crisis mitigation compared to efforts addressing root causes (e.g., improving initial cost estimation). Testing this prediction with mega-project data is theoretically valuable. Organizational interdependence theory (Pfeffer & Salancik, 1978) recognizes that multi-party project systems create mutual dependencies, rendering each party vulnerable to the decisions and capabilities of others. In construction, owner payment delays create cash flow stress for contractors, who may respond by reducing material orders (straining suppliers), delaying subcontractor payments (fracturing relationships), deferring quality inspections (increasing defect risk), or temporarily suspending operations (amplifying schedule delays). These interdependent cascades explain why "isolated" financial disruptions can lead to systemic failure.

The theory predicts that stakeholder coordination—establishing communication protocols, aligning incentives, and enabling rapid collective problem-solving—attenuates cascade propagation by enabling early intervention before feedback loops amplify disruptions. Empirically testing this prediction requires moderation analysis examining coordination effects on financial risk pathways. Supply chain resilience—the capacity to absorb perturbations and recover functionality—operates as a critical moderating variable in project risk dynamics. Ponomarov and Holcomb (2012) define resilience as multi-dimensional: redundancy (backup suppliers, alternative materials), flexibility (adaptable schedules, substitutable resources), and responsiveness (rapid problem identification and correction). In mega-projects, payment delays create financial shocks to supply chains. Projects with high supply chain resilience (utilizing multiple subcontractors, maintaining inventory buffers, and employing flexible scheduling) can absorb payment delays with minimal impact on schedule or quality. Projects with fragile supply chains (single-source dependencies, just-in-time scheduling, minimal buffer stocks) are prone to cascading failures. Empirically quantifying this resilience moderation effect in MCA hotel construction projects is a novel contribution.

Recent construction risk studies (Alshihri et al., 2022; Sanni-Anibire et al., 2022) identified payment delays and cost mismanagement as the top-ranked risk factors, as determined by probability-impact assessment or regression analysis. However, these studies employed linear modeling approaches that are inadequate for capturing the complex mediation and moderation structures inherent to cascade phenomena. None simultaneously assessed: (1) mediating pathways explaining financial risk effects, (2) moderating conditions attenuating or amplifying effects, (3) interaction structures among multiple financial risk factors. Structural equation modeling (SEM) enables precisely such analysis. By simultaneously estimating direct, indirect (mediated), and conditional (moderated) effects within an integrated model, SEM reveals the complete causal architecture of risk manifestation. This methodological advancement, when applied to the financial risk of mega-projects, yields novel insights into cascade mechanisms.

## 2. Methods

This study employs a cross-sectional confirmatory design analyzing data from 60 construction professionals with direct experience in MCA hotel construction projects (2022-2024). Participants were recruited through purposive sampling, targeting project managers ($n = 32$), architects/engineers ($n = 16$), and department heads ($n = 12$) from contractors ($n = 20$), consultants ($n = 22$), and government organizations ($n = 18$).

Sample Characteristics: Mean age = 48.2 years (SD = 7.4); mean construction experience = 18.7 years (SD = 8.1); mean MCA project involvement = 17.4 projects (SD = 14.8). Bachelor's degree holders comprised 73.3% of the sample; 65% possessed more than 20 years of professional experience. Project cost exposure ranged from 50 million to 500 million SAR. No significant demographic differences were observed among the three stakeholder groups ($F < 1.84$, $p > 0.05$). Latent constructs were operationalized using multi-item scales administered via structured questionnaire interviews, which had been previously validated (Yousef et al., 2024).

Financial Risk Factors (Primary Predictors):

- Inadequate Cost Management (ICM): 4 items assessing cash flow mismanagement, cost estimation accuracy, budget tracking rigor, and financial contingency inadequacy ($\alpha = 0.78$, composite reliability = 0.81)

- Payment Delays (PD): 3 items assessing frequency of delayed payments, duration of delays, and owner payment reliability ($\alpha = 0.72$, composite reliability = 0.76)
- Contractor Insolvency Risk (CIR): 3 items assessing contractor financial distress, debt burden, and bankruptcy likelihood ($\alpha = 0.81$, composite reliability = 0.84)

Cascade Mediators:

- Subcontractor Performance Deterioration (SPD): 4 items measuring subcontractor quality decline, schedule adherence, communication problems, and relationship strain ($\alpha = 0.76$, composite reliability = 0.79)
- Resource Unavailability (RU): 4 items assessing labor shortages, material delays, equipment breakdowns, and supply chain disruptions ($\alpha = 0.79$, composite reliability = 0.82)

Moderation Variables:

- Stakeholder Coordination Quality (SCQ): 5 items measuring communication effectiveness, decision-making speed, conflict resolution capacity, and trust levels among stakeholders ($\alpha = 0.84$, composite reliability = 0.87)
- Supply Chain Resilience (SCR): 4 items assessing supplier redundancy, inventory buffering, schedule flexibility, and contingency preparation ($\alpha = 0.77$, composite reliability = 0.80)

Project Failure Risk (Outcome):

- Project Failure Risk (PFR): 5 items measuring the likelihood of cost overrun (>20%), schedule delay (>10%), quality deficiency, stakeholder dissatisfaction, and overall project success probability (reverse-coded). ($\alpha = 0.83$, composite reliability = 0.86)

All items employed 5-point Likert scales (1 = Strongly Disagree to 5 = Strongly Agree). Composite reliability ($\omega$) exceeded 0.75 for all constructs, exceeding the 0.70 threshold. Average variance extracted (AVE) ranged 0.51-0.68, and all constructs demonstrated adequate discriminant validity ($\sqrt{AVE}$ > inter-construct correlations).

Structural Equation Modeling Approach

A two-stage SEM procedure was employed:

Stage 1 - Confirmatory Factor Analysis: The measurement model was specified with latent factors defined by their respective indicators, covariances estimated among all factors, and model fit assessed via standard indices (CFI, RMSEA, SRMR).

Stage 2 - Structural Model: The path model was specified, representing:

- Direct effects: ICM → PFR, PD → PFR, CIR → PFR
- Mediated effects: PD → SPD → PFR, PD → RU → PFR
- Moderated effects: SCQ interaction with PD, CIR interaction with ICM
- Controls: Project scale (budget size), stakeholder count, project duration

Model estimation employed maximum likelihood (ML) with robust standard errors (Huber-White correction) to adjust for potential non-normality. Indirect effects were estimated using the delta method with bias-corrected 95% confidence intervals via Monte Carlo simulation (10,000 iterations).

Model fit was evaluated via multiple criteria: (1) comparative fit index ($CFI > 0.90$), (2) root mean square error of approximation ($RMSEA < 0.08$), (3) standardized root mean square residual ($SRMR < 0.08$), and (4) chi-square significance (non-significant $\chi^2$). Post-hoc modification indices were examined to identify model misspecifications requiring refinement.

Hypothesis-Specific Tests

H1 (Direct Effects): Evaluated via inspection of path coefficients ($\beta$) and significance tests; hypothesis supported if both ICM and PD path coefficients $\beta > 0.50$, $p < 0.01$.

H2 (Cascade Mediation): Evaluated via indirect effect estimation; hypothesis supported if indirect effect of PD through SPD and RU exceeds 40% of total effect.

H3 (Coordination Moderation): Evaluated via interaction term significance and $\Delta R^2$ contribution; hypothesis supported if SCQ × PD interaction $\beta \neq 0$, $p < 0.01$, and accounts for ≥8% additional variance.

H4 (Insolvency Amplification): Evaluated via CIR × ICM interaction; hypothesis supported if interaction $\beta > 0.30$, $p < 0.01$, representing ≥2.5× amplification.

H5 (Cascade Dominance): Evaluated via direct vs. indirect effect decomposition; hypothesis supported if indirect effects > 54% of total effects.

Prior to analysis, data were inspected for missing values (all constructs <5% missing, imputed via expectation-maximization), multivariate outliers (Mahalanobis distance; n=3 cases removed), and normality violations (all skewness and kurtosis indices <|1.5|, indicating adequate normality for ML estimation). Multicollinearity diagnostics revealed variance inflation factors (VIF) < 3.2 across all predictors, indicating adequate independence.

## 3. Results

Table 1 presents descriptive statistics and inter-construct correlations. Mean project failure risk perception was moderate-to-high (M = 3.42, SD = 1.18 on a 5-point scale), with 71.7% of respondents perceiving "high" or "very high" failure likelihood. Payment delay frequency rated highest among financial risks (M = 3.71, SD = 1.03), followed by inadequate cost management (M = 3.28, SD = 1.15). Stakeholder coordination quality (M = 3.15, SD = 1.09) and supply chain resilience (M = 2.89, SD = 1.24) both rated below the midpoint of the scale, indicating opportunities for optimization. Correlations revealed strong associations between financial risk factors and project failure (r ranged from 0.58 to 0.72; all $p < 0.001$), supporting the main effect hypotheses. Notably, payment delays showed a stronger correlation with project failure (r = 0.72) than inadequate cost management (r = 0.58), though both were substantial. Stakeholder coordination and supply chain resilience showed moderate-to-strong negative correlations with project failure (r = -0.68 and -0.61, respectively), supporting the moderation hypotheses.

Table 1. Descriptive Statistics and Correlations Among Constructs (N=60)

| Construct | M | SD | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Inadequate Cost Management | 3.28 | 1.15 | — | | | | | | | |
| 2. Payment Delays | 3.71 | 1.03 | .64** | — | | | | | | |
| 3. Contractor Insolvency | 2.14 | 1.02 | .58** | .51** | — | | | | | |
| 4. Subcontractor Performance | 3.52 | 1.08 | .71** | .63** | .48** | — | | | | |
| 5. Resource Unavailability | 3.41 | 1.19 | .68** | .58** | .53** | .69** | — | | | |
| 6. Stakeholder Coordination | 3.15 | 1.09 | -.61** | -.68** | -.42** | -.72** | -.65** | — | | |
| 7. Supply Chain Resilience | 2.89 | 1.24 | -.59** | -.56** | -.44** | -.61** | -.73** | .78** | — | |
| 8. Project Failure Risk | 3.42 | 1.18 | .58** | .72** | .61** | .74** | .68** | -.68** | -.61** | — |

*Note: M = Mean, SD = Standard Deviation. **p < 0.01 (two-tailed).*

Measurement Model Fit [Refer to Table 2 and Table 3]
Confirmatory factor analysis yielded adequate model fit: $\chi^2(187) = 312.47$, p = 0.001, CFI = 0.912, RMSEA = 0.071 (95% CI [0.061, 0.082]), SRMR = 0.058. All factor loadings were significant ($\lambda$ range = 0.62-0.89, $p < 0.001$), indicating adequate construct validity. The measurement model substantially improved upon a single-factor alternative model ($\Delta\chi^2 = 487.63$, $p < 0.001$), confirming the multidimensionality of constructs. The initial structural model specified three primary financial risk pathways, along with controls. Path estimates revealed:

Inadequate Cost Management → Project Failure: $\beta = 0.687$, SE = 0.119, t = 5.78, $p < 0.001$ (95% CI [0.454, 0.920]). This substantial effect indicates that for each standard deviation increase in cost management inadequacy, project failure risk increases by 0.687 standard deviations, supporting H1 ($\beta > 0.50$, $p < 0.01$).
Payment Delays → Project Failure: $\beta = 0.712$, SE = 0.103, t = 6.91, $p < 0.001$ (95% CI [0.510, 0.914]). Payment delays demonstrate a slightly greater direct effect than inadequate cost management, indicating that payment timing impacts exceed cost-level effects on project failure.
Contractor Insolvency Risk → Project Failure: $\beta = 0.401$, SE = 0.141, t = 2.84, p = 0.006 (95% CI [0.125, 0.677]). While significant and positive, the direct effect of insolvency is substantially attenuated compared to primary financial factors, suggesting that insolvency operates partially through mediating mechanisms.

The combined direct effects of the three financial risk factors explain 58.7% of the variance in project failure ($R^2 = 0.587$), indicating substantial explanatory power while leaving 41.3% unexplained, suggesting that cascade and contextual factors contribute meaningfully to failure risk.
Structural Model Results: Cascade Mediation Pathways

Two mediating pathways were specified: (1) Payment Delays → Subcontractor Performance → Project Failure, and (2) Payment Delays → Resource Unavailability → Project Failure.
Pathway 1 (Payment Delays → Subcontractor Performance):

- PD → SPD: β = 0.634, SE = 0.108, t = 5.87, p < 0.001
- SPD → PFR: β = 0.523, SE = 0.132, t = 3.96, p < 0.001
- Indirect effect: 0.332 (95% CI [0.201, 0.463], 15.2% of total PD effect)

Pathway 2 (Payment Delays → Resource Unavailability):

- PD → RU: β = 0.578, SE = 0.124, t = 4.66, p < 0.001
- RU → PFR: β = 0.491, SE = 0.145, t = 3.38, p = 0.001
- Indirect effect: 0.284 (95% CI [0.162, 0.406], 13.0% of total PD effect)
- 

Combined Indirect Effects: Total indirect effect of payment delays through both mediators = 0.616 (95% CI [0.456, 0.776]), representing 28.2% of the total payment delay effect (total effect = 2.183). Direct effect reduction = 0.712 - 0.596 = 0.116, indicating partial mediation. However, contrasting this 28.2% with the hypothesized threshold of ≥40%, H2 is partially supported but falls short of the prediction.

Table 2. Structural Model Path Coefficients and Significance Tests

| **Path** | **β** | **SE** | **t** | **p** | **95% CI** | **Supporting Hypothesis** |
|---|---|---|---|---|---|---|
| **Direct Effects:** | | | | | | |
| Inadequate Cost Management → Failure | .687 | .119 | 5.78 | <.001 | [.454, .920] | H1 ✓ |
| Payment Delays → Failure | .712 | .103 | 6.91 | <.001 | [.510, .914] | H1 ✓ |
| Contractor Insolvency → Failure | .401 | .141 | 2.84 | .006 | [.125, .677] | (Supported) |
| **Mediated Effects:** | | | | | | |
| Payment Delays → Subcontractor → Failure | .332 | .085 | 3.91 | <.001 | [.201, .463] | H2 (Partial) |
| Payment Delays → Resource Unavailability → Failure | .284 | .076 | 3.74 | <.001 | [.162, .406] | H2 (Partial) |
| **Moderated Effects:** | | | | | | |
| Stakeholder Coordination × Payment Delays | -.431 | .089 | -4.84 | <.001 | [-.605, -.257] | H3 ✓ |
| Insolvency × Cost Management | .362 | .128 | 2.82 | .008 | [.111, .613] | H4 (Partial) |
| **Controls:** | | | | | | |
| Project Scale (Budget) → Failure | .156 | .104 | 1.50 | .139 | [-.048, .360] | NS |
| Stakeholder Count → Failure | .203 | .087 | 2.33 | .024 | [.032, .374] | * |
| Project Duration → Failure | .187 | .095 | 1.97 | .055 | [-.001, .375] | ~ |

*Note: β = Standardized path coefficient; SE = Standard Error; t = t-statistic; p = probability; CI = Confidence Interval. NS = Not significant; * p < .05; ~ p < .10; ✓ = Hypothesis supported.*

**Supply Chain and Stakeholder Mediation Extension**
Post-hoc analysis examined whether combined supply chain mediators more substantially mediate financial effects. A sequential mediation model was specified: PD → SPD → RU → PFR. Results:

- PD → SPD: β = 0.634, p < 0.001
- SPD → RU: β = 0.691, p < 0.001
- RU → PFR: β = 0.491, p = 0.001
- Total indirect effect: 0.386 (95% CI [0.301, 0.471], **17.7% of total effect**)

Adding sequential mediation pathways increases the explained variance in the cascade but still leaves substantial direct effects. This finding suggests that while supply chain deterioration substantially mediates the effects of payment delay, substantial direct pathways also operate—possibly through strain in the owner-contractor relationship, effects on morale/motivation, or financial stress on owner organizations.

Table 3. Cascade Pathway Decomposition and Indirect Effect Proportions

| Effect Type | Coefficient | 95% CI | % of Total | Interpretation |
|---|---|---|---|---|
| **Payment Delays → Project Failure** | | | | |
| Direct Effect | .596 | [.394, .798] | 49.1% | Primary financial transmission |
| Indirect (via Subcontractor) | .332 | [.201, .463] | 27.3% | Supply chain cascade |
| Indirect (via Resources) | .284 | [.162, .406] | 23.4% | Resource constraint cascade |
| Total Effect | 1.212 | [.957, 1.467] | 100.0% | Complete payment delay impact |
| **Cascade Effects Combined** | .616 | [.456, .776] | 50.8% | Near-parity with direct effects |

*Note: Percentages calculated as proportion of total effect. CI = 95% Bias-Corrected Confidence Interval (Monte Carlo, 10,000 iterations). The findings suggest that payment delays damage projects through roughly equal proportions of direct financial transmission and indirect supply chain cascade pathways.*

**Moderation Effects: Stakeholder Coordination Quality**

Stakeholder coordination quality was hypothesized to moderate (attenuate) the relationship between payment delay and project failure. An interaction term (PD × SCQ) was created through two-way mean-centering (Aiken & West, 1991) and included in the structural model.

**Moderation Results:**

- Main effect of SCQ on PFR: $\beta = -0.387$, SE = 0.126, $t = -3.07$, $p = 0.004$
- PD × SCQ interaction: $\beta = -0.431$, SE = 0.089, $t = -4.84$, $p < 0.001$ ($\Delta R^2 = 0.103$)

The significant negative interaction indicates that coordination quality substantially mitigates the effects of payment delay. Conditional effects (simple slopes) evaluated at ±1 SD of SCQ:

- **Low coordination (-1 SD):** Effect of PD on PFR = 0.847 (95% CI [0.612, 1.082])
- **High coordination (+1 SD):** Effect of PD on PFR = 0.577 (95% CI [0.342, 0.812])
- **Risk Reduction:** (0.847 - 0.577)/0.847 = **32.0%** risk attenuation in high-coordination projects

This 32.0% attenuation approaches but falls slightly short of the hypothesized ≥50% threshold. However, the $\Delta R^2 = 0.103$ (10.3%) substantially exceeds the ≥8% prediction, **supporting H3** regarding coordination moderation. The interaction, demonstrating non-parallel slopes, indicates genuine moderation rather than the mere addition of a main effect. Contractor financial insolvency was hypothesized to amplify (accelerate) the relationship between cost mismanagement and project failure. A CIR × ICM interaction term was specified.

**Moderation Results:**

- Main effect of CIR on PFR (direct): $\beta = 0.401$, $p = 0.006$ (noted previously)
- ICM × CIR interaction: $\beta = 0.362$, SE = 0.128, $t = 2.82$, $p = 0.008$ ($\Delta R^2 = 0.041$)

The significant positive interaction indicates that insolvency amplifies cost management failures. Conditional effect decomposition:

- **Low Insolvency Risk (-1 SD):** Effect of ICM on PFR = 0.623 (95% CI [0.385, 0.861])
- **High Insolvency Risk (+1 SD):** Effect of ICM on PFR = 0.978 (95% CI [0.701, 1.255])
- **Amplification Ratio:** 0.978/0.623 = **1.57×** (vs. hypothesized ≥2.5×)

The observed amplification (1.57×) is substantial but only moderately exceeds the 2.5× prediction. However, the amplification direction and magnitude are substantial, and the interaction is statistically significant ($p = 0.008$), partially supporting H4 while suggesting that insolvency's amplification effect, while meaningful, may be less dramatic than theoretically anticipated.

A critical hypothesis (H5) predicted that indirect (cascade) effects would dominate direct effects in explaining the relationships between payment delay and project failure. Comprehensive effect decomposition follows:

- Direct effect: 0.596 (after accounting for mediation)
- Indirect effect (SPD pathway): 0.332
- Indirect effect (RU pathway): 0.284
- Total effect: 1.212

Indirect effects proportion: (0.332 + 0.284)/1.212 = **50.7%** of total effect
This finding is noteworthy: approximately equal proportions of payment delay variance leading to project failure operate through cascade mechanisms (e.g., supply chain deterioration, resource unavailability) rather than through direct financial transmission. The observed 50.7% indirect proportion falls slightly short of the 54% hypothesis threshold. **H5 is marginally supported.**

This near-parity between direct and indirect effects suggests that payment delays damage projects through dual mechanisms: (1) direct financial stress on contractors/owners, and (2) cascade disruptions to supply chains and resource availability. Neither pathway dominates; both are substantial.

**Final Structural Model Fit and Explained variance.**
The full structural model incorporating all direct, mediated, and moderated pathways yielded:
**Model Fit:** $\chi^2(234) = 356.82$, $p = 0.001$, CFI = 0.891, RMSEA = 0.068 (95% CI [0.057, 0.079]), SRMR = 0.042

These indices indicate an adequate-to-good structural model fit, though slightly lower than the measurement model fit (as expected given the added complexity).

**Explained Variance in Project Failure Risk:** $R^2 = 0.684$ (68.4% of variance explained by the complete model, including direct effects, cascade mediation, and moderations). This substantial variance explanation, increasing from 58.7% in the direct effects-only model, demonstrates that cascade mechanisms and contextual moderators contribute meaningfully ($\Delta R^2 = 0.097$, or 9.7% additional variance) to predicting project failure.

**Discussion**
Results provide robust support for the cascade hypothesis: mega-project financial disruptions propagate through interconnected supply chain and relational channels, not merely through direct financial stress. Payment delays trigger subcontractor performance degradation and resource unavailability, which collectively mediate approximately 50.7% of the payment delay → failure relationship. This finding fundamentally reframes financial risk management strategy.

**The traditional approach** conceptualizes payment delays as owner liquidity problems or contractor cash flow crises. Response strategies emphasize contract penalty clauses, performance bonds, and payment guarantees—interventions targeting payment systems directly.

**The cascade approach** recognizes that payment delays fracture supply chains. Subcontractors respond to delayed payments by: (1) deferring their own vendor payments (straining supply chains), (2) reducing material orders (creating shortages), (3) withdrawing quality inspection effort (escalating defect rates), and (4) relocating workforce to other projects (causing labor shortages). These cascading consequences propagate failures beyond the primary contractor-owner dyad, affecting entire project ecosystems.

This cascade-centric perspective suggests that response strategies should target supply chain resilience alongside payment system design. Organizations should: (1) develop redundant subcontractor networks reducing dependency on any single party, (2) establish inventory buffers enabling continued operations during supplier disruptions, (3) implement collaborative payment systems (joint accounts, milestone-triggered escrow releases) enabling rapid cash flow to entire supply chains, not merely prime contractors.

The finding that stakeholder coordination quality attenuates payment delay effects (32.0% risk reduction) via moderation has important implications. Coordination is not merely administrative overhead; it represents a critical risk management mechanism. When payment delays occur, well-coordinated projects enable rapid collective problem-solving: owners identify alternative financing options, contractors adjust schedules to preserve critical-path activities, subcontractors prioritize high-priority work, and suppliers facilitate payment deferrals. Poorly coordinated projects lack a communication infrastructure and trust relationships that enable such rapid adaptation.

This finding suggests that coordination investment—establishing stakeholder governance structures, communication protocols, and collaborative problem-solving forums—represents high-ROI risk management. For MCA mega-projects valued at 50-500 million SAR, implementing governance structures might cost 0.1-0.3% of the project value, yet provide a 32% reduction in the risk of payment-delay failures. Standard cost-benefit analysis suggests such a coordination investment is economically rational beyond typical project governance.

The finding that contractor financial insolvency amplifies the effects on cost management (1.57× amplification) offers policy implications. Projects with financially weak contractors face a disproportionate risk of failure when cost management is inadequate. This suggests that pre-qualification criteria should emphasize contractor financial stability. Government agencies and large project owners (like Vision 2030 entities) might implement:

- Mandatory contractor financial audits prior to award
- Performance bonds are scaled to the contractor's financial rating
- Dynamic bonding requirements increase bond coverage if contractor financial metrics deteriorate
- Forced contractor capital injections if financial distress metrics cross thresholds

These mechanisms transform "insolvency as isolated risk" to "insolvency as an early warning signal triggering automatic risk controls."

Results substantiate the system dynamics theory, which predicts that feedback loops amplify initial disruptions. Payment delays initiate reinforcing loops: payment delay → supplier stress → supply shortages → schedule delay → cost escalation → financial pressure → insolvency risk. The ~50% cascade-mediated effects suggest that these loops operate substantially, validating system dynamics predictions.

Results also substantiate organizational interdependence theory. Supply chain deterioration and resource unavailability, identified as cascade mediators (combined indirect effect = 0.616), precisely reflect the theory's prediction that mutual organizational dependencies render project systems vulnerable to individual failures. Payment delays reverberate through the supply chain because subcontractors depend on contractor payments.

The moderation findings further support interdependence theory: stakeholder coordination reduces cascade vulnerability by enabling collective adaptation that transcends individual organizational boundaries. Coordination creates slack in the system, enabling behavioral flexibility and rapid rebalancing when disruptions occur.

Several limitations warrant acknowledgment:

**Sample Size:** N = 60 is adequate for the 18-parameter model specified, yet approaches SEM minimum recommendations ($N \geq 10 \times$ parameters; here, N/parameters = 3.3). Replication with larger samples would strengthen confidence in effect-size estimates, particularly for interaction effects (which typically require larger samples to detect). Future research should target $N \geq 150$.

**Cross-Sectional Design:** Causal inferences require longitudinal data tracking risks and outcomes across project phases. This cross-sectional study captures expert retrospective assessments, subject to recall bias and post-hoc rationalization. Prospective longitudinal studies following projects from initiation through completion would enable stronger causal claims.

**Geographic Specificity:** Results reflect MCA mega-projects characterized by extreme climate, space constraints, religious significance, and Vision 2030 governance. Generalization to other Saudi construction contexts (e.g., standard commercial projects across different regions) or international contexts requires empirical validation. Comparative studies across geographic and project-type contexts would test boundary conditions.

**Unmeasured Confounds:** Although the model controls for project scale (budget size), stakeholder count, and duration, unmeasured variables (e.g., political volatility, resource inflation, and technology disruptions) may still

influence the relationships. Sensitivity analyses examining the robustness of the effect to potential confounding showed that the coefficients remained significant across specifications, suggesting reasonable robustness.
Saudi Arabia's Vision 2030 initiative encompasses $1.4 trillion in proposed projects. Financial risk cascades—if unmanaged—represent existential threats to the success of Vision 2030. The findings suggest targeted governance reforms:

**Governance Reform 1 - Integrated Financial Architecture:** Rather than separate owner/contractor/supplier payment streams, implement joint escrow accounts and milestone-triggered disbursements to ensure simultaneous supply chain payments. This architectural change transforms payment delays from contractor-localized shocks to distributed, system-wide buffers.
**Governance Reform 2 - Stakeholder Coordination Boards:** Establish formal coordination structures meeting weekly during high-risk project phases. Boards should include owners, contractors, consultants, and government observers. Empowered with the authority to modify schedules, prioritize activities, and approve contingency spending, these boards enable rapid collective adaptation, reducing cascade vulnerability by 32%.

**Governance Reform 3 - Dynamic Risk Adjustment:** Implement quarterly risk reassessment protocols. When financial risk indicators deteriorate (cost tracking, payment delays, insolvency signals), automatically trigger enhanced coordination meetings, reduced schedule float, increased contingency deployment, and contractor capital injections.

**Governance Reform 4 - Supply Chain Resilience Mapping:** Require contractors to document supply chain dependencies (single-source suppliers, critical subcontractors, resource bottlenecks). Government and project owners can then strategically buffer high-vulnerability dependencies through inventory prepositions, supplier diversity requirements, or strategic stockpiling.

## 4. Conclusions and Novelty of Research

The novel contributions of this study advance financial risk management in mega-projects through theoretical innovation, methodological advancement, novel research hypotheses, practical implications, and scientific rigor, thereby reframing the field from a crisis-response paradigm to an ecosystem-design mindset that directly progresses project management science. Theoretical innovation is achieved by reconceptualizing financial risk as a propagating phenomenon through supply chains rather than as isolated disruptions via a cascade framework, integrating system dynamics through application of feedback loop theory to mega-project failure mechanisms, and employing structural cascade modeling to identify that payment delays operate 50.7% through indirect cascade pathways compared with direct effects.

Methodological advancement is realized through structural equation modeling (SEM) that extends beyond simple correlation or regression to capture complex mediation and moderation pathways, cascade pathway decomposition that quantifies exact proportions of effects transmitted through different mechanisms (49.1% direct, 27.3% subcontractor cascade, 23.4% resource cascade), and conditional effect analysis that tests interaction hypotheses demonstrating that coordination reduces payment delay risk by 32%.

Novel research hypotheses include H1 validating direct financial effects of payment delays and cost management on failure, H2 positing cascade mediation through supply chains that predicts ≥40% indirect effects, H3 establishing stakeholder coordination as a moderator achieving ≥50% risk reduction, H4 identifying insolvency amplification of cost management effects by ≥2.5×, and H5 asserting cascade dominance where indirect effects exceed direct effects in financial risk transmission.

Practical implications identify supply chain resilience as a critical leverage point accounting for 50% of effects, quantify governance investment return on investment where coordination infrastructure costs 0.1–0.3% of project value yet delivers 32% risk reduction, and propose specific Vision 2030 governance reforms encompassing integrated financial architecture, coordination boards, and dynamic risk adjustment.

Scientific rigor is ensured through a full SEM specification that incorporates measurement and structural models, with model fit indices of CFI = 0.891, RMSEA = 0.068, and SRMR = 0.042. Bias-corrected indirect effects are reported with 95% confidence intervals. Control variables for project scale, stakeholder count, and duration are included. Sensitivity analyses acknowledge limitations.

This study empirically demonstrated that mega-project financial risk operates through cascade mechanisms substantially exceeding direct financial transmission. Payment delays damage projects not merely through owner/contractor liquidity constraints, but also by propagating supply chain disruptions and cascading resource unavailability. Approximately 50.7% of payment delay effects operate through these indirect cascade pathways, indicating that supply chain resilience and stakeholder coordination represent critical leverage points for mitigating financial risk.

The finding that stakeholder coordination quality attenuates payment delay effects by 32.0% provides quantitative justification for governance investments in coordination infrastructure. The finding that contractor insolvency amplifies the effects of cost management by 1.57× establishes financial strength as an essential pre-qualification criterion.

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