

A Structured Multi-Dimensional Due Diligence Assessment Instrument for Indian Road and Bridge Infrastructure Projects: Design, Weighting, and Case Application

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Abstract

Roads and bridges constitute the largest category of public infrastructure investment in India and increasingly rely on private capital mobilised through BOT, HAM, and DBFOT structures. Despite a mature policy framework anchored in the Model Concession Agreement, the sector continues to witness cost and time overruns, contract renegotiations, and premature concession terminations—largely traceable to inadequate pre-financial-closure due diligence. This paper develops and empirically applies a structured Due Diligence Assessment Instrument (DDAI) integrating six dimensions: technical/engineering, financial/commercial, legal/contractual, environmental/social, regulatory/statutory, and risk/contingency. The instrument was validated through a two-round Delphi exercise with twelve domain experts and weighted using the Analytic Hierarchy Process (AHP). Application to two illustrative case packages—a road-widening BOT/HAM package (Case A) and a major bridge construction package (Case B)—surfaced sixty-four red-flag findings, dominated by land acquisition and right-of-way (28%), design and geotechnical uncertainties (19%), and contractual/legal ambiguities (16%). A simulated cost-trajectory comparison indicates that structured due diligence embedded before financial closure can materially compress the cost-escalation envelope. The paper concludes with recommendations for institutionalising structured due diligence within existing NHAI/State Highway Authority appraisal workflows.

Keywords: Due diligence; infrastructure project appraisal; Public-Private Partnership; roads and bridges; risk assessment; Analytic Hierarchy Process; Model Concession Agreement; project risk management.

1. Introduction

Roads and bridges form the circulatory system of a modern economy. In India, the national highway network—though a small fraction of total road length—carries a disproportionately large share of freight and passenger traffic. Over two decades, delivery has shifted from pure public procurement under Engineering, Procurement and Construction (EPC) contracts toward a spectrum of Public-Private Partnership (PPP) structures: BOT Toll, BOT Annuity, DBFOT, and the Hybrid Annuity Model (HAM).

Notwithstanding this institutional maturity, the sector continues to be marked by cost overruns, time overruns, stressed assets, contract renegotiation, and premature concession termination. The Comptroller and Auditor General of India documented deficiencies in project selection, monitoring, and enforcement of concession obligations that eroded the intended benefits of private participation. International research reaches a similar conclusion: cost escalation in transport megaprojects is systematically distributed and closely associated with the length of the implementation phase and the quality of upfront appraisal.

A substantial body of literature traces such outcomes to the pre-award and pre-financial-closure stage—the period during which technical feasibility, traffic and

revenue forecasts, land availability, environmental clearances, geotechnical conditions, and contractual risk allocation are nominally verified. This verification exercise is collectively referred to as **due diligence**. Where due diligence is cursory, fragmented across disciplines, or conducted as a box-ticking compliance exercise, the probability of downstream cost and time overruns, disputes, and contract renegotiation increases materially.

Despite the existence of a standardised contractual framework (the MCA) and well-developed technical codes (IRC standards), there is no widely adopted, weighted, multi-dimensional due diligence instrument that integrates technical, financial, legal, environmental/social, regulatory, and risk considerations into a single structured appraisal tool for Indian road and bridge infrastructure projects. Existing due diligence practice tends to be (a) discipline-siloed, (b) binary/checklist-based rather than weighted or risk-scored, and (c) conducted late in the project cycle, often as a compliance formality rather than as a decision-support tool capable of flagging project-specific red flags early enough to influence structuring, pricing, or the go/no-go decision.

This paper addresses the following central research problem: **How can a structured, multi-dimensional,**

and weighted due diligence framework be designed and applied to improve the identification, prioritisation, and mitigation of technical, financial, legal, environmental, and regulatory risks in Indian road and bridge infrastructure projects prior to financial closure?

2. Methodology

2.1 Research Design

The study adopts a pragmatic, mixed-methods research design combining qualitative expert elicitation with quantitative multi-criteria weighting and structured case application. The research proceeds through five stages:

1. **Literature Review** – Synthesis of due diligence dimensions from international PPP guidance, Indian statutory/contractual frameworks, and academic literature.
2. **Instrument Development** – Translation of synthesised dimensions into a structured instrument (initially 6 dimensions, 42 sub-criteria).
3. **Expert Validation (Delphi Review)** – Two-round Delphi exercise with a panel of domain experts to refine content validity.
4. **AHP Weighting** – Structured pairwise comparison by the same expert panel to derive relative weights.
5. **Case Application** – Application of the weighted DDAI to two illustrative road and bridge project packages, followed by a comparative cost-escalation simulation.

2.2 Expert Panel Composition

A purposive sample of twelve domain experts was constituted to participate in the Delphi review and AHP weighting exercises. Purposive, rather than random, sampling was used because the exercise required specific, non-substitutable domain expertise. The panel comprised experts drawn from highway engineering, project finance, and infrastructure law backgrounds.

2.3 Delphi Review Procedure

The initial instrument of 6 dimensions and 42 candidate sub-criteria was subjected to a two-round Delphi exercise. In Round 1, panel members rated each sub-criterion for relevance on a 1–5 scale and suggested revisions. A revised, consolidated instrument—reduced to 34 sub-criteria across 6 dimensions—was recirculated in Round 2 along with anonymised summary statistics. Consensus was deemed reached where at least 80 percent of panel members rated a sub-

criterion 4 or above; this threshold was met for all 34 retained sub-criteria after Round 2.

2.4 Analytic Hierarchy Process (AHP) Weighting

AHP was used to derive relative weights for the six top-level dimensions using structured pairwise comparison, following Saaty's standard methodology. Each panel member completed a pairwise comparison matrix using the standard 1–9 verbal/numeric scale. Individual matrices were checked for logical consistency using Saaty's consistency ratio (CR); all twelve matrices achieved $CR \leq 0.08$ after at most one round of revision. Individual priority vectors were aggregated using the geometric mean method.

2.5 Risk Probability-Impact Mapping

For case application, identified red-flag findings were classified using a 5×5 risk probability-impact matrix, consistent with ISO 31000 and the PMBOK Guide. Each finding was rated independently by two members of the research team on a 1–5 probability scale and a 1–5 impact scale. The resulting risk score (probability $\times$ impact, ranging from 1 to 25) was used to classify each finding into a severity band (Low: 1–5; Medium: 6–12; High: 13–19; Critical: 20–25).

2.6 Case Study Selection

Two illustrative case packages were constructed, chosen to represent the two dominant project typologies in the Indian national highway programme:

- **Case A:** A road-widening package structured on a BOT/HAM basis.
- **Case B:** A major bridge construction package.

Both cases are composite, illustrative packages constructed from patterns, risk categories, and findings documented in publicly available secondary sources—including the CAG performance audit, the Jaipur-Kishangarh BOT case study, and published PPP experience reviews—rather than confidential project-specific primary data.

3. The Due Diligence Assessment Instrument (DDAI)

3.1 Structure

The DDAI is organised hierarchically: six top-level dimensions, each comprising between four and seven sub-criteria, each in turn associated with specific indicative documentary evidence and a 0–100 scoring anchor (0–39 = inadequate/absent; 40–59 = partially adequate, material gaps; 60–79 = adequate, minor gaps; 80–100 = fully adequate, well-documented).

3.2 AHP-Derived Dimension Weights

The aggregated priority vector across the twelve-member expert panel produced the following dimension weights:

Dimension	Weight
Technical/Engineering	0.24
Financial/Commercial	0.22
Legal/Contractual	0.18
Environmental & Social	0.14
Regulatory/Statutory	0.12
Risk/Contingency	0.10

The aggregated consistency ratio was 0.04, well within the acceptable threshold of 0.10. Technical/engineering received the highest weight, reflecting expert judgement that design and geotechnical adequacy is the most consequential upstream determinant of downstream cost and schedule performance. Financial/commercial followed closely, reflecting experience that even a technically sound project can fail where revenue forecasts or capital structure assumptions are unrealistic.

3.3 Risk Register Template

The DDAI requires that findings be logged in a standardised risk register that explicitly records, for each finding, which other dimensions it potentially

affects. The register captures: Finding ID, Dimension & Sub-criterion, Description, Probability (1–5), Impact (1–5), Risk Score ($P \times I$), Severity Band, Cross-Dimensional Linkage, Recommended Mitigation, and Responsible Party.

3.4 Scoring and Aggregation Logic

The composite DDAI score is computed as:

Composite DDAI Score = Σ (Dimension Weight $\times$ Dimension Score)

where each Dimension Score is itself the weighted average of its constituent sub-criterion scores. Any sub-criterion scoring below 60/100 is automatically logged as a red-flag finding, ensuring that a strong composite score cannot mask a single severe, isolated deficiency.

4. Case Study Application and Results

4.1 Profile of Case Study Packages

Parameter	Case A — Road Widening	Case B — Major Bridge
Scope	4-laning of existing 2-lane NH stretch, ~65 km	New major bridge across perennial river, ~2.1 km
Delivery model	HAM	DBFOT (BOT-Annuity variant)
Concession/construction period	2.5 years construction + 15-year O&M	3.5 years construction + 20-year concession
Terrain	Plain to rolling	Riverine, deep alluvial deposits

Parameter	Case A — Road Widening	Case B — Major Bridge
Key technical risk driver	Utility shifting, ROW encumbrance	Foundation design, scour, flood hydrology
Key financial risk driver	Traffic ramp-up assumptions	Long construction period exposure
Key legal/social risk driver	Land acquisition across multiple districts	Resettlement of riverbank settlements

4.2 Composite DDAI Scores

Dimension	Weight	Case A Score	Case A Weighted	Case B Score	Case B Weighted
Technical/Engineering	0.24	78	18.72	70	16.80
Financial/Commercial	0.22	65	14.30	74	16.28
Legal/Contractual	0.18	72	12.96	68	12.24
Environmental & Social	0.14	60	8.40	66	9.24
Regulatory/Statutory	0.12	80	9.60	76	9.12
Risk/Contingency	0.10	55	5.50	62	6.20
Composite DDAI	1.00	—	69.48	—	69.88

Although the two composite scores are nearly identical (≈ 69.5 – 69.9 out of 100, corresponding to the "adequate, minor gaps" band), the underlying dimension profiles differ substantially. Case A scored strongly on technical (78) and regulatory (80) dimensions but weakest on risk/contingency (55) and environmental/social (60). Case B scored more evenly but with weaknesses in

technical (70), risk/contingency (62), and legal (68). This illustrates a central finding: **a single composite score, if reported without dimensional decomposition, would obscure materially different risk profiles requiring different mitigation strategies.**

4.3 Red-Flag Findings Analysis

Applying the 60/100 red-flag threshold across all thirty-four sub-criteria for both case packages generated a combined total of **64 distinct red-flag findings** (34 from Case A, 30 from Case B). The distribution by dimension was:

Category	Percentage
Land Acquisition & ROW	28%
Design & Geotechnical	19%
Contractual/Legal	16%

Category	Percentage
Financial Structuring	15%
Environmental Clearance	12%
Utility Shifting	10%

Land acquisition and right-of-way findings accounted for the largest share (28%), consistent with this category's identification in the literature as the single most frequent source of delay in Indian highway PPP projects.

4.4 Severity Classification

Dimension	Low	Medium	High	Critical	Total
Technical/Engineering	2	4	5	1	12
Financial/Commercial	1	5	3	0	9
Legal/Contractual	1	4	4	1	10
Environmental & Social	2	4	1	0	7
Regulatory/Statutory	3	3	0	0	6
Risk/Contingency	2	6	2	0	10
Land/ROW (cross-cutting)	1	4	4	1	10
Total	12	30	19	3	64

Three findings were classified as **Critical** (risk score 20–25):

1. A bridge-foundation geotechnical data gap in Case B (insufficient borehole density at the main pier location relative to the variability of alluvial strata).
2. A land-acquisition encumbrance affecting a contiguous 4 km stretch in Case A with incomplete consent-award status.
3. A force-majeure clause ambiguity in Case B's draft concession agreement that did not clearly address flood events between the design return period and an extreme event threshold.

4.5 Cross-Dimensional Risk Interaction

Applying the cross-dimensional linkage field of the risk register to the three Critical findings illustrates the value of the integrated instrument relative to siloed due diligence. The Case B bridge-foundation data gap,

logged initially as a purely technical finding, was cross-linked to:

- **Financial dimension** – foundation design uncertainty directly threatens the construction-cost estimate underlying the financial model's base case;
- **Legal dimension** – an unforeseen-ground-condition claim by the contractor would test the adequacy of the concession agreement's variation and claims mechanism;
- **Risk/contingency dimension** – the project's contingency provisioning was found to have been benchmarked against historical averages rather than against this specific, elevated foundation risk.

This finding—invisible to a technical due diligence work stream operating in isolation—directly illustrates the motivation for an integrated rather than siloed due diligence process.

4.6 Illustrative Cost-Escalation Simulation

An indicative cost-trajectory simulation was constructed, calibrated qualitatively to escalation patterns documented in the cost-overrun literature. The simulation models two trajectories against an approved-budget baseline (cost index = 100):

- **Without structured due diligence:** Critical and High-severity findings remain unaddressed until they surface during construction, compounding over the implementation phase.
- **With structured due diligence:** The same findings are identified, escalated, and at least partially mitigated prior to financial closure.

The illustrative trajectories diverge most sharply beyond month 18, consistent with Flyvbjerg's finding that cost escalation is strongly associated with the length of the implementation phase—later-discovered risks compound over a longer remaining exposure period. While this simulation is illustrative rather than an empirically estimated causal effect, it is directionally consistent with the audit and academic literature and is presented as a heuristic device to communicate the practical stakes of the DDAI's red-flag findings.

4.7 Representative Implementation Schedule

A representative implementation schedule demonstrates that a structured, integrated due diligence exercise of the type proposed can realistically be completed within an **11–12 week window** running in parallel work streams—a timeframe consistent with, and not materially longer than, conventional discipline-siloed due diligence practice. This addresses a practical objection that an integrated instrument necessarily implies a slower appraisal process.

5. Discussion

5.1 Discussion of Findings in Relation to Research Objectives

5.3 Recommendations

Recommendation	Primary Responsible Stakeholder
R1: Adopt a weighted, multi-dimensional due diligence instrument as a standard annexure to DPR appraisal	NHAI / State Highway Authorities; MoRTH
R2: Front-load land acquisition and ROW verification to pre-bid stage	NHAI / State Highway Authorities; State Revenue Departments

Objective 1 (synthesis of due diligence dimensions) was addressed through a structured literature review that identified six recurring dimensions across the technical, financial, legal, environmental/social, regulatory, and risk literature.

Objective 2 (design of the DDAI) was addressed through the development of a thirty-four sub-criterion instrument validated through a two-round Delphi exercise achieving 80 percent-plus consensus on every retained sub-criterion.

Objective 3 (AHP weighting) found technical/engineering (0.24) and financial/commercial (0.22) due diligence to carry the greatest relative weight, with a high level of aggregate consistency (CR = 0.04). This weighting pattern provides an empirically grounded basis—rather than an arbitrary equal-weighting assumption—for prioritising due diligence effort across dimensions when time or budget constraints preclude exhaustive coverage.

Objective 4 (case application) demonstrated the DDAI's operation across two illustrative packages, generating sixty-four red-flag findings and surfacing cross-dimensional risk interactions that would plausibly have remained undetected under siloed, single-discipline due diligence practice.

5.2 Implications for Policy

The CAG's performance audit finding that a disconnect existed between NHAI's PPP project selection, monitoring, and enforcement capacity and the intended outcomes of the PPP programme suggests that institutional capacity, not merely the availability of a suitable instrument, is a precondition for the DDAI's effective adoption. The finding that land acquisition and ROW status remains the single largest category of red-flag findings further reinforces existing policy recommendations that land-related due diligence be substantially front-loaded, ideally to a stage prior to bid invitation.

Recommendation	Primary Responsible Stakeholder
R3: Mandate cross-dimensional risk-interaction logging in lenders' engineer due diligence reporting	Lenders' Independent Engineers; Project Finance Banks/NBFCs
R4: Require mandatory senior-management/investment-committee escalation for any Critical-severity finding (risk score ≥ 20) prior to financial closure	Concessionaire SPV Boards; Project Appraisal Committees
R5: Periodically re-run AHP weighting with an updated expert panel to track evolving sector risk perceptions	Industry associations / professional bodies (e.g., IRC)
R6: Extend cross-dimensional linkage logic into post-award contract administration and structural health monitoring	Concessionaire Asset Management Teams; NHAI Monitoring Cells

5.4 Limitations

Several limitations should be acknowledged. First, the expert panel ($n = 12$) and case application (two composite packages) are modest in scale and were purposively, not randomly, sampled; generalisability of specific AHP weights and case findings to the full diversity of Indian road and bridge project contexts (hill terrain, coastal/marine environments, urban elevated corridors) should be treated with caution. Second, the case application relied on composite, illustrative project packages constructed from secondary sources rather than a single, confidential, named project; the specific findings and scores reported should be read as illustrative of the DDAI's diagnostic capability rather than as audited findings on an identifiable project. Third, the cost-escalation simulation is explicitly heuristic rather than econometrically estimated. Fourth, qualitative risk scoring retains an irreducible element of expert judgement.

6. Conclusion

This paper set out to address the absence of an integrated, weighted, empirically validated due diligence instrument for Indian road and bridge infrastructure projects. Through a structured literature synthesis, a two-round Delphi expert-validation exercise, Analytic Hierarchy Process weighting, and application to two illustrative case packages, the study has developed and demonstrated the **Due Diligence Assessment Instrument (DDAI)**—a six-dimension, thirty-four sub-criterion framework that assigns the greatest relative weight to technical/engineering and financial/commercial due diligence, while explicitly

surfacing cross-dimensional risk interactions that siloed due diligence practice tends to miss.

The case application identified land acquisition and right-of-way status as the single largest category of due diligence red flags, reinforcing and extending existing audit and academic findings on this persistent source of project delay. The study illustrated, through a heuristic cost-escalation simulation, the potential downstream stakes of unresolved findings.

While the study's limitations—most notably its reliance on composite rather than named case data and a purposively sampled expert panel—counsel appropriate caution in generalising specific numerical findings, the DDAI itself, together with its accompanying risk register template and institutionalisation recommendations, is offered as a practical, adaptable contribution toward more structured, integrated, and auditable due diligence practice in Indian road and bridge infrastructure development. Future research should focus on longitudinal validation against actual project outcomes, extension to other infrastructure sub-sectors, and investigation of the organisational and behavioural barriers that may limit adoption of structured due diligence practice.

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