

Risk Assessment and Management in Build Operate Transfer (BOT) Infrastructure Projects

Dr. Prathmesh Vilas Patil¹, Mr. Rohan Dnyandev More², Mr. Milind N. Telavane³

¹Associate Professor, Civil Engineering Department, Atma Malik Institute of Technology & Research, Shahapur, Dist. Thane, Maharashtra, India, 421601. Email: prathmeshpatil19@gmail.com

²Assistant Professor and HOD, Civil Engineering and Planning, Pravin Rohidas Patil College of Engineering and Technology. Email: rohanmore2003@gmail.com

³Assistant Professor, Civil Engineering Department, Shivajirao S Jondhale College of Engineering and Technology, Asangaon, Dist. Thane, Maharashtra, India, 421601. Email: milindssjp20@gmail.com

ABSTRACT

Build Operate Transfer infrastructure contracts expose public authorities, concessionaires and lenders to interacting construction, revenue and financing uncertainties. This article develops a simulation-based framework for screening risks, assessing financial consequences and comparing mitigation measures in an illustrative toll-road concession. No field survey or operating-project dataset is used. Eight risk categories are screened using assumed occurrence probabilities and conditional impacts. A reproducible Monte Carlo model generates 10,000 paired scenarios for capital expenditure, demand, operating cost, borrowing rates and commissioning delay. The baseline probability of stabilized debt-service coverage falling below unity is 42.2%, compared with 24.3% under an assumed mitigation package. Median project net present value changes from INR -308.6 crore to INR -233.8 crore after including an incremental mitigation cost. Demand and capital expenditure emerge as influential drivers of debt-service coverage within the specified model. The findings demonstrate a transparent assessment method rather than observed project performance. Contract-specific calibration, cash-flow scheduling and independent validation are required before applying the framework to investment or concession decisions.

Keywords: Build Operate Transfer; Infrastructure risk; Monte Carlo simulation; Risk allocation; Debt-service coverage

I. INTRODUCTION

BOT arrangements combine infrastructure delivery, long-term operation and eventual asset transfer within a concession structure. Project feasibility depends on construction performance, service demand, expenditure control and financing terms throughout that period. A project can appear satisfactory under a central forecast yet face repayment stress when moderate changes in several variables occur together. Risk assessment therefore needs to connect individual uncertainties to outcomes that matter to the concessionaire, lender and public authority.

This article considers an illustrative user-paid toll road. Its analytical focus is the relationship between uncertainty in capital cost, stabilized revenue, operating expenditure, debt pricing and delay. The chosen setting supports a clear demonstration of risk assessment without asserting that a particular road was surveyed, constructed or evaluated. All numerical assumptions and resulting outputs are synthetic. The distinction is essential because plausible model outputs do not constitute evidence about the frequency or severity of risks in actual BOT projects.

A useful assessment should produce more than a list of hazards. It should specify who controls each risk, how exposure is measured, which response changes the underlying cash flows, and what residual risk remains. This study links an illustrative risk register to a financial simulation and compares a baseline concession with a paired mitigation scenario. The comparison is intended to support methodological understanding and the design of a future project-specific study.

II. OBJECTIVES

- Identify major BOT risks across preparation, construction, operation and transfer.
- Demonstrate a transparent probability–impact screening procedure using disclosed assumptions.
- Quantify simulated distributions of stabilized DSCR and project NPV.
- Compare a specified mitigation package using common random numbers.
- Develop allocation and monitoring proposals consistent with the limitations of the model.

III. LITERATURE SURVEY

The World Bank guidance distinguishes site, demand and other project uncertainties and describes risk allocation as part of PPP structuring [1–3]. These resources establish categories for a risk register; they do not supply the probabilities used in this article. Demand concerns service use and revenue, while site exposure includes land availability and related development conditions. The present study adopts those distinctions to avoid combining commercially different events under one broad risk label.

The Asian Development Bank PPP Handbook provides an institutional framework for infrastructure partnerships [4]. The PPP Risk Allocation Tool offers a reference for allocation decisions [5], while ADB guidance on private-sector engagement stresses clearly defined responsibilities [6]. Together, these sources motivate the separate treatment of assessment, allocation and monitoring. They are guidance documents rather than validation datasets for the numerical model presented here.

The methodological contribution is a compact worked analysis in which distribution assumptions, financial equations and mitigation transformations are disclosed together. Risk ranking, repayment stress and economic attractiveness are kept distinct. A high screening score need not imply the greatest cash-flow influence, and a positive project NPV does not guarantee adequate annual debt coverage. These relationships can be evaluated explicitly instead of being inferred from qualitative rankings alone.

IV. METHODOLOGY

Study design and scope

The study is a computational simulation with 10,000 scenarios and pseudorandom seed 20261003. Each scenario represents a stylized concession outcome rather than a respondent or an observed project. The concession is assumed to contain 25 operating years at the planned opening date, with delay reducing the remaining operating window. Values are expressed in INR crore. Debt is assumed to fund 70% of realized capital expenditure and to amortize through equal annual payments over 15 operating years. The analysis evaluates stabilized coverage, not the minimum DSCR across a fully scheduled loan life.

Table 1. Illustrative project assumptions

Parameter	Assumed value
Base capital expenditure	INR 1,000 crore
Stabilized annual revenue	INR 160 crore
Stabilized annual O&M cost	INR 40 crore
Debt share / repayment period	70% / 15 years
Operating concession window	25 years minus delay
Project discount rate	11% annually
Mitigation cost	INR 20 crore paid initially
Simulation	10,000 paired draws; seed 20261003

The model excludes taxes, depreciation, tariff escalation, ramp-up, working capital, interest during construction, reserve accounts, refinancing, salvage value and explicit handback expenditure. Their exclusion keeps the financial demonstration auditable but prevents the outputs from serving as a bankable financial appraisal. Capital expenditure is represented at the valuation date; operating cash flows begin after the sampled delay. The simplification does not model a detailed construction drawdown schedule.

Risk screening and stochastic inputs

For screening, $S = 100 \times p \times i$, where p is an assumed occurrence probability and i is an assumed conditional fractional impact. The impact is a generic screening severity, not a calibrated financial loss. Screening scores cannot be summed into an expected project loss because the categories can overlap and use different practical consequences. High scores identify items deserving investigation, not established risk frequencies.

Table 2. Assumed risk probabilities and screening scores

Risk	p	i	Score
Demand shortfall	0.42	0.35	14.70
Land acquisition delay	0.38	0.30	11.40
Construction cost overrun	0.36	0.28	10.08
Approval delay	0.32	0.24	7.68
Interest rate increase	0.30	0.22	6.60
O&M cost escalation	0.34	0.16	5.44
Contractual dispute	0.22	0.23	5.06
Handback deficiency	0.20	0.18	3.60

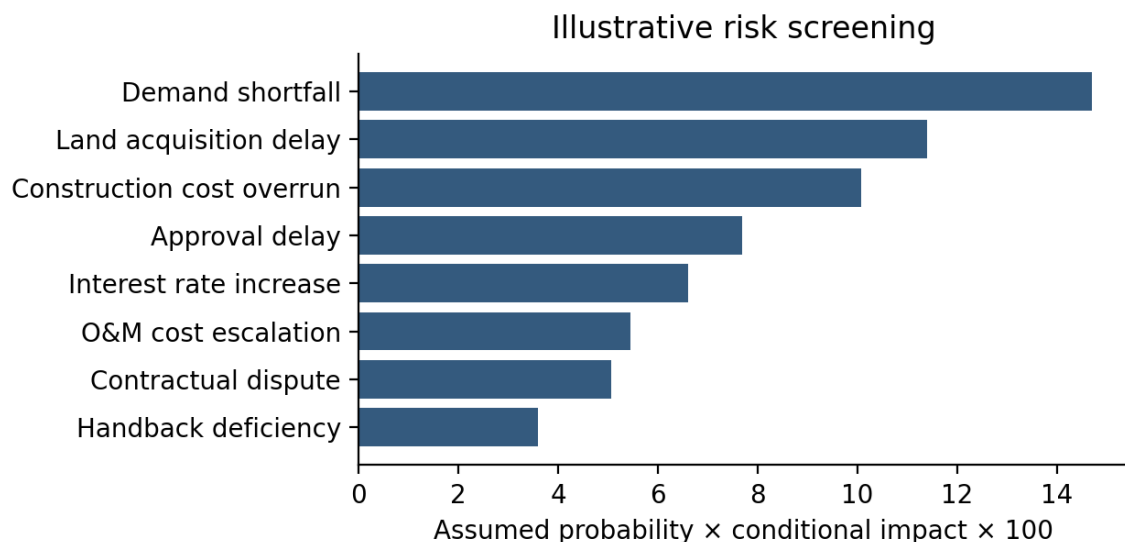


Fig. 1. Risk screening scores calculated from illustrative assumptions.

Table 3. Triangular distributions used in the simulation

Variable	Minimum	Mode	Maximum
Capital cost multiplier	.95	1.08	1.35
Revenue demand multiplier	.65	.95	1.20
O&M multiplier	.95	1.05	1.25
Annual borrowing rate	.080	.095	.120
Opening delay in years	0	.5	2

Inputs are drawn independently from triangular distributions. The lower and upper limits define bounded scenarios, while the mode represents the most likely assumed input. These distributions are analyst-selected and are not fitted to observed data. Independence can understate compound shocks; construction delay and cost escalation, for example, may be positively associated in real projects. The risk register and simulation therefore have different purposes: the register broadens governance coverage, whereas the financial model quantifies five selected drivers.

Financial equations and mitigation scenario

Realized capital cost $C = 1,000c$, annual revenue $R = 160t$, annual operating cost $O = 40o$, and debt principal $D = 0.70C$. Here c , t and o are the sampled multipliers. Annual debt service $A = Dr/[1 - (1 + r)^{-15}]$, where r is the sampled borrowing rate. Cash flow available for debt service is approximated by $F = R - O$, and stabilized $DSCR = F/A$. $DSCR$ below 1.00 indicates insufficient stabilized cash flow to meet the modelled annual debt payment.

Project NPV = $F[1 - (1.11)^{-(25-l)}]/0.11/(1.11)^l - C$, where l is the sampled opening delay. Fractional operating years are treated through the annuity expression as an analytical approximation. This is an unlevered project metric, distinct from equity NPV. Interest rates affect $DSCR$ through debt service but do not affect this project NPV because the project discount rate is fixed. Delay affects NPV and does not affect stabilized $DSCR$ in the specified equations.

The mitigation package transforms the same draws using $c' = 1 + 0.65(c - 1)$, $t' = 1 + 0.80(t - 1)$, $o' = 1 + 0.75(o - 1)$, $r' = \min(r, 0.1025)$, and $l' = 0.65l$. These transformations narrow cost, revenue and operating uncertainty, cap borrowing rates and shorten delay. They represent hypothetical effectiveness of preparation, contract controls and financial protection; they are not measured treatment effects. An incremental INR 20 crore is subtracted from mitigation NPV, funded outside the assumed debt principal. Stabilized $DSCR$ excludes that initial expenditure.

Common random numbers hold underlying shocks constant across the two scenarios. Differences therefore reflect the disclosed transformations rather than unrelated samples. Summary measures comprise the 5th, 50th and 95th percentiles, the proportion with $DSCR$ below unity, and the proportion with negative NPV. Spearman rank correlations describe monotonic association between inputs and baseline $DSCR$; they do not establish causal effects or quantify risk interaction.

Statistical analysis

The numerical analysis was rerun and verified using Python 3.12.14, NumPy 2.3.5, SciPy 1.17.0 and Matplotlib 3.10.8. NumPy default_rng, using the PCG64 generator and seed 20261003, generated 10,000 independent scenarios. Baseline and mitigation outcomes used the same sampled inputs. Continuous outcomes were summarized by the 5th, 50th and 95th percentiles, calculated using the linear interpolation method. Scenario proportions were calculated as the number satisfying the specified threshold divided by 10,000 and multiplied by 100.

Spearman rank correlation coefficients were calculated with `scipy.stats.spearmanr` between each sampled input and baseline stabilized $DSCR$. These coefficients are descriptive sensitivity measures for the simulated scenarios. No inferential hypothesis tests or population-level significance claims were made; therefore, an alpha significance threshold and inferential p-values are not applicable. Increasing the number of simulated scenarios does not provide empirical validation of the assumed distributions. Exact calculated coefficients, rounded to six decimal places, are reported in Table 4a alongside Fig. 4.

V. RESULTS AND DISCUSSION

Simulated financial outcomes

Table 4. Simulated outcomes from 10,000 paired scenarios

Measure	Baseline	Mitigation
DSCR P5	0.711	0.846
DSCR P50	1.040	1.122
DSCR P95	1.378	1.391
Project NPV (INR crore) P5	-595.912	-458.693
Project NPV (INR crore) P50	-308.583	-233.837
Project NPV (INR crore) P95	-42.960	-29.209
DSCR < 1.00 (%)	42.19	24.33
NPV < 0 (%)	97.48	97.32

The median stabilized DSCR is 1.040 in the baseline and 1.122 after the mitigation transformations. The simulated shortfall proportion declines by 17.86 percentage points. These values apply only to the selected parameter ranges. They should not be described as a forecast of default because the model contains no reserve mechanism, restructuring behaviour or time-series liquidity assessment.

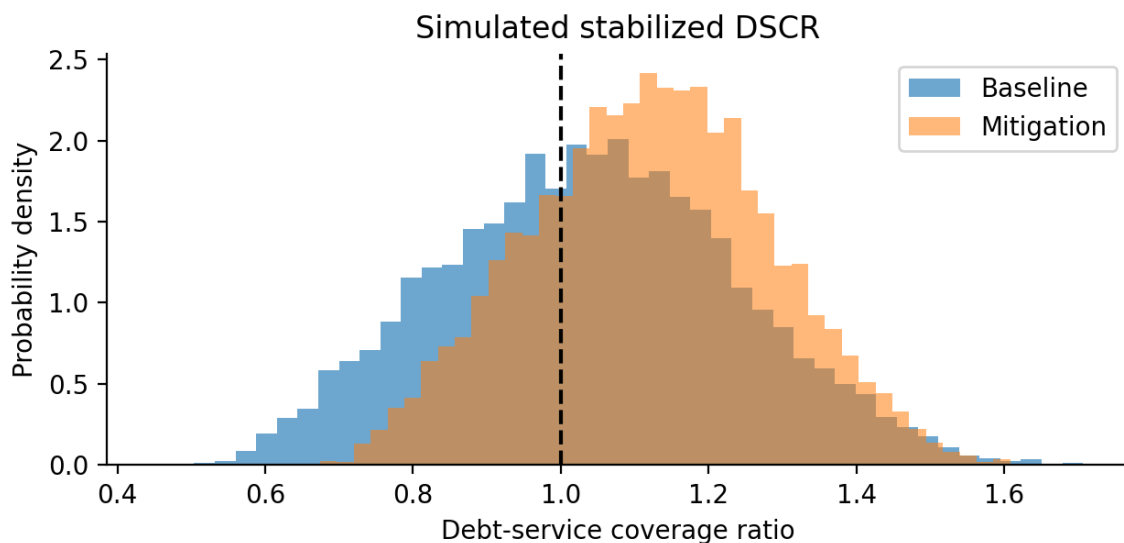


Fig. 2. Simulated DSCR distributions; the dashed line marks coverage of 1.00.

The distribution comparison is more informative than the median alone. A higher central outcome may coexist with a material lower tail, particularly where demand remains uncertain. The mitigation package mechanically limits several adverse realizations; its apparent benefit depends on those assumed effectiveness factors. Contract provisions should be evaluated for enforceability and implementation cost before treating any distributional narrowing as achievable.

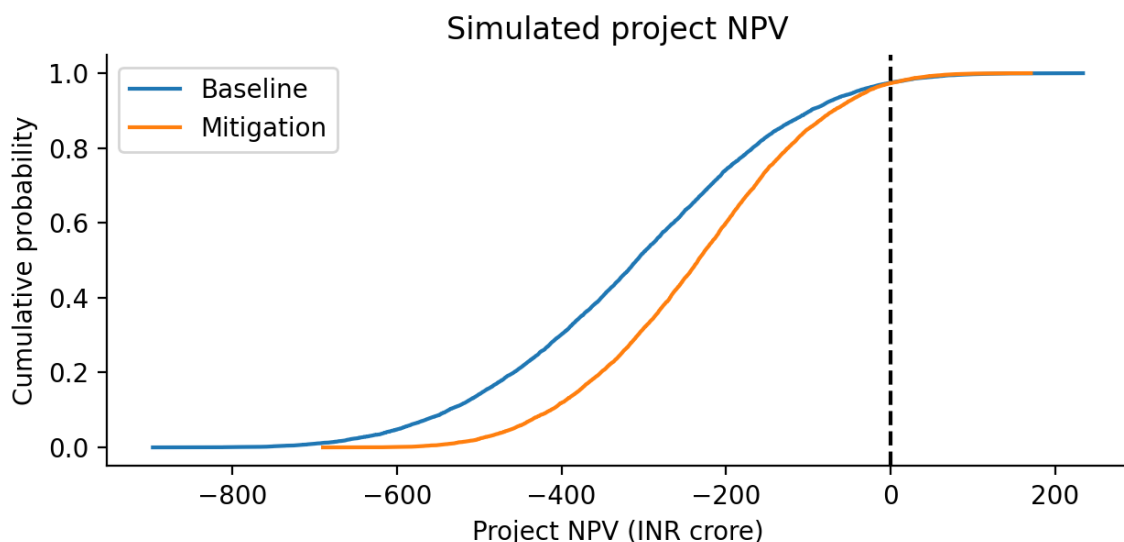


Fig. 3. Empirical cumulative distributions of simulated project NPV.

Negative project NPV occurs in 97.48% of baseline scenarios and 97.32% of mitigation scenarios. The incremental mitigation cost is included in this comparison. Because no demand growth or tariff escalation is assumed, the model treats stabilized annual cash flow as constant throughout the shortened concession. Its NPV output consequently reflects a restrictive illustrative operating profile rather than a complete road-project valuation.

Drivers and interpretation

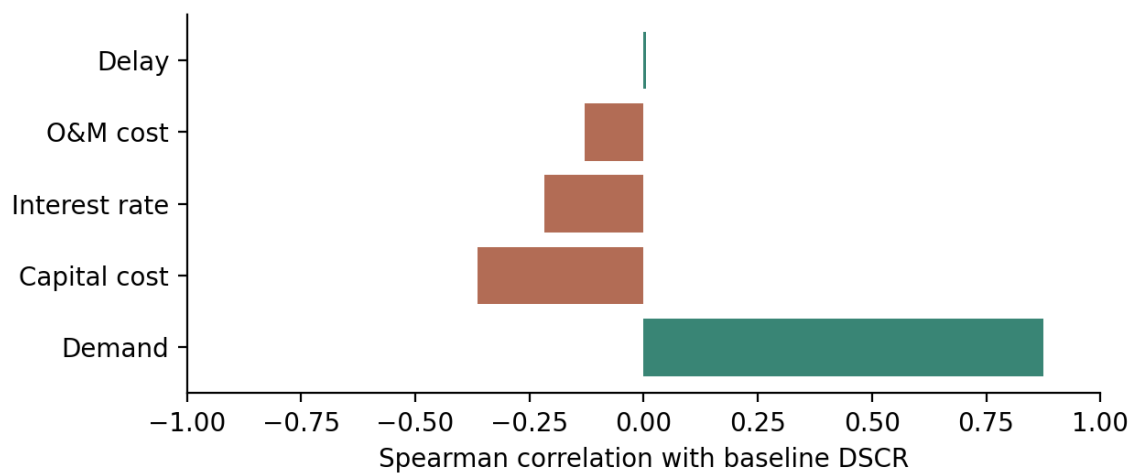


Fig. 4. Spearman correlations with simulated baseline stabilized DSCR.

Table 4a. Calculated Spearman correlations with simulated baseline stabilized DSCR

Sampled input	Spearman rho
Demand multiplier	0.876173
Capital cost multiplier	-0.363943
Annual borrowing rate	-0.218283
O&M cost multiplier	-0.129923
Opening delay	0.004955

Revenue variation raises coverage, while higher capital expenditure, borrowing rates and operating costs reduce it. Delay has no direct DSCR pathway in the model, so any small sample correlation with that metric is random variation. This structural limitation should not be interpreted as evidence that delay is financially unimportant. Delay changes NPV and would also change debt balances or repayment timing in a construction-period financing model.

The risk screening assigns high priority to demand shortfall and land acquisition delay. The financial sensitivity exercise separately evaluates the variables actually represented in the cash-flow equations. The two outputs should be used together: governance items omitted from a simplified financial model still require contractual controls. A contractual dispute, for example, can affect revenue collection or expenditure even though no standalone dispute variable is sampled.

Risk allocation and management implications

Table 5. Proposed allocation and monitoring framework for project-specific review

Risk	Proposed responsibility	Control and indicator
Land and access	Public authority before works	Verified possession; unresolved parcels
Design and construction	Concessionaire / EPC contractor	Design checks; cost and milestone variance
Demand and collection	Concessionaire; explicit sharing if agreed	Independent forecasts; traffic and receipts
Public approvals	Relevant authority / defined interface	Approval schedule; overdue decisions
Finance and rates	Concessionaire / lenders	Rate protection; coverage and reserves
Operations and maintenance	Concessionaire / operator	Service indicators; maintenance backlog
Exceptional events	Defined contract sharing / insurance	Coverage review; recovery arrangements
Handback condition	Concessionaire under contract	Periodic condition survey; funded plan

The proposed allocation should be reviewed against control, insurability and the ability to absorb loss. Assigning a risk to a party does not remove its economic consequences. For example, a construction contractor may accept a price commitment yet become unable to perform after an extreme shock. Financial capacity, security instruments and performance monitoring therefore matter alongside the wording of the contract.

A practical register should record the owner, cause, consequence, trigger, response, budget and review date for every material item. Preparation controls should precede financial close where possible. During construction, schedule and cost reporting should distinguish approved scope changes from unexplained variance. During operation, traffic, collections and maintenance performance should be compared with forecasts using agreed definitions. The framework is a proposal for implementation, not a report of controls applied to an actual concession.

Limitations and validation needs

The main limitation is absence of real project observations. Neither the risk probabilities nor the mitigation factors have empirical calibration. The simulation sample size reduces Monte Carlo noise but does not resolve uncertainty about the assumptions. No confidence interval for an observed population is appropriate because there is no population sample. Simulated scenario frequencies represent conditional model probabilities only.

A future empirical study should obtain concession agreements, financial-close forecasts, construction expenditure records, annual traffic receipts, maintenance accounts and debt schedules with suitable permissions. It should fit distributions to relevant evidence, test correlated stress scenarios and compare predictions with withheld operating years. Separate comparisons are needed for user-paid BOT, annuity concessions and availability-payment arrangements because their revenue risks differ. A complete appraisal should also include construction interest, tax, escalation, reserves, handback obligations and fiscal exposure.

VI. CONCLUSION

The article demonstrates a reproducible method for connecting a BOT risk register with simulated financial performance. The paired analysis shows improved coverage and project valuation under the explicitly assumed mitigation transformations, while preserving residual uncertainty. Demand, capital cost and financing conditions directly affect stabilized repayment capacity in the model. Delay remains relevant to valuation even though it has no direct stabilized DSCR effect in the simplified formulation.

The principal practical contribution is transparency: each ranking, distribution and financial result can be traced to a disclosed assumption. The numerical outcomes are illustrative and cannot support claims about actual BOT project success or default rates. Project-specific evidence and independent validation are necessary before the framework informs concession design, lender appraisal or public financial commitments.

DECLARATIONS

Study status and ethics: This is a simulation study. No human participants, field survey or identifiable project records were used. No empirical ethics approval is claimed. Data availability: All input distributions, equations, mitigation transformations, sample size and random seed are specified in the methodology. Funding: Author confirmation required. Competing interests: Author confirmation required. Author contributions: Author confirmation required. Corresponding author: To be confirmed by the authors.

REFERENCES

1. World Bank. Identifying Risks. Available: <https://ppp.worldbank.org/identifying-risks>. Accessed: 3 October 2026.
2. World Bank. Allocating Risks. Available: <https://ppp.worldbank.org/allocating-risks>. Accessed: 3 October 2026.
3. Prathmesh Vilas Patil, & Dr. Ambadas Dhuraji Lodhe. (2025). Innovative Approaches To Water Conservation In Rajasthan: Challenges And Solutions. Journal of Scientific Research and Technology, 3(2), 5–16. <https://doi.org/10.61808/jsrt164>
4. World Bank. Structuring PPP Projects. Available: <https://ppp.worldbank.org/structuring-ppp-projects>. Accessed: 3 October 2026.
5. Asian Development Bank. Public–Private Partnership (PPP) Handbook. Available: <https://www.adb.org/documents/public-private-partnership-ppp-handbook>. Accessed: 3 October 2026.

6. World Bank PPP Resource Center. PPP Risk Allocation Tool (2019). Available: <https://ppp.worldbank.org/library/ppp-risk-allocation-tool-2019>. Accessed: 3 October 2026.
7. Asian Development Bank. Engaging the Private Sector in Public–Private Partnerships. Available: <https://www.adb.org/publications/engaging-private-sector-public-private-partnerships>. Accessed: 3 October 2026.
8. Menon S, Patil PV, Singh L, Sharma T, Pawar KP, Verma CS. Optimization of bamboo fiber reinforced polymers for sustainable mechanical applications: A comparative analysis of bioplastics and traditional materials. *Journal of Composite Materials*. 2026;0(0). doi:10.1177/00219983261472102
9. PATIL, P. V. (2025). Risk analysis for a build operate transfer (bot) projects. *International Journal of Scientific Research in Engineering and Management*, 9(7). <https://doi.org/10.55041/IJSREM51508>
10. Bing, L., Akintoye, A., Edwards, P. J., and Hardcastle, C. (2005). The allocation of risk in PPP/PFI construction projects in the UK. *International Journal of Project Management*, 23(1), 25–35. DOI: 10.1016/j.ijproman.2004.04.006.
11. Grimsey, D., and Lewis, M. K. (2002). Evaluating the risks of public private partnerships for infrastructure projects. *International Journal of Project Management*, 20(2), 107–118. DOI: 10.1016/S0263-7863(00)00040-5.
12. Ke, Y., Wang, S. Q., Chan, A. P. C., and Lam, P. T. I. (2010). Preferred risk allocation in China’s public–private partnership (PPP) projects. *International Journal of Project Management*, 28(5), 482–492. DOI: 10.1016/j.ijproman.2009.08.007.
13. Wang, S. Q., Tiong, R. L. K., Ting, S. K., and Ashley, D. (2000). Evaluation and management of political risks in China’s BOT projects. *Journal of Construction Engineering and Management*, 126(3), 242–250. DOI: 10.1061/(ASCE)0733-9364(2000)126:3(242).
14. Li, B., Akintoye, A., Edwards, P. J., and Hardcastle, C. (2005). Critical success factors for PPP/PFI projects in the UK construction industry. *Construction Management and Economics*, 23(5), 459–471. DOI: 10.1080/01446190500041537.