International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 6, 2025
https://theaspd.com/index.php

Cost And Revenue Estimation Methods In Road Infrastructure Projects: A Comparative Study Of Projects

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ABSTRACT
This paper examines the use of the Cost and Revenue Estimation Model in road infrastructure projects, focusing on four distinct projects. The study aims to assess the effectiveness of this model in accurately forecasting project costs, revenues, and the overall financial viability of each project over a given period. Using DPRs as the primary source, this research highlights trends, challenges, and key factors influencing project performance and also evaluating the influence of variables such as project scale, location, and time period on estimation methods. Ultimately, the study provides valuable insights into best practices for infrastructure cost estimation, with recommendations for improving model reliability and risk assessment in future projects.
Key Words: *Detailed Project Reports (DPRs), Cost and Revenue Model, Road Infrastructure Projects, Risk Assessment, Financial Viability, Build-Operate-Transfer (BOT), Design-Build-Finance-Operate-Transfer (DBFOT), Wholesale Price Index (WPI), Public-Private Partnerships (PPP).*

INTRODUCTION

The estimation of costs and revenues in road infrastructure projects is a critical factor in determining project feasibility, financial sustainability, and long-term value creation. Road infrastructure projects, especially those developed under BOT and DBFO T models, require a sophisticated understanding of cost elements, revenue streams, traffic projections, tolling mechanisms, and risk-sharing arrangements. These models have gained global acceptance due to their potential to transfer risk to the private sector, while ensuring that infrastructure needs are met through public-private collaboration. (Ravinder, 2021). However, the success of these projects' hinges on accurate cost and revenue projections, as well as flexible financial structures that can accommodate variabilities in project timelines and traffic patterns.
The need for precise estimation methods arises due to the contrasting financial performances of various road projects, which can be attributed to differences in concession periods, escalation rates, and toll rate structures. For instance, projects with shorter concession terms, face significant challenges in recouping initial costs due to moderate traffic growth projections and fixed toll rate structures. Conversely, longer concession periods, allow for greater flexibility in cost recovery, especially when concession extensions are included to offset traffic variability. (Joshi, 2019). Such mechanisms align well with the BOT model's objective to mitigate revenue risk by transferring it to the concessionaire, particularly in cases of unanticipated reductions in traffic volumes.
Cost escalations in these projects often follow standard inflation rates indexed to the WPI, which provides a degree of financial predictability. However, variances in the escalation percentages can impact overall project costs. For example, a 5% escalation rate, by averaging it annually to manage construction and operational costs. Similarly, other projects integrate a routine maintenance cost estimation based on anticipated wear, such as a 5% area coverage for pothole repair. Effective cost estimations, especially for routine maintenance and toll operation expenses, are essential for sustaining project performance (Sharma & Ghosh, 2020).
Furthermore, each project's tolling mechanism significantly affects revenue streams. Some projects employ WPI-indexed toll rate increases, allowing for revenue adjustments in line with inflation. Additionally, these projects include extensions to the concession period if traffic projections fall below

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expectations, offering risk-sharing provisions that stabilize revenue expectations over time. Such mechanisms are particularly advantageous in scenarios of fluctuating traffic volumes, ensuring that concessionaires can meet financial obligations even during periods of reduced traffic. (Mohanty, 2020). This study seeks to critically evaluate and compare the cost and revenue estimation methodologies used across the selected four major road projects, analysing the impact of varied concession models, toll rate structures, escalation strategies, and traffic projections.

he objective of this research is to analyse how BOT and DBFOT models adapt to financial and operational realities in diverse contexts and to provide a comparative understanding of the effectiveness of these methods in ensuring project viability. (Banerjee, 2018). By examining the financial structures, cost breakdowns, escalation assumptions, and toll revenue mechanisms used in five selected road projects, this study aims to identify best practices and common challenges in cost and revenue estimation for infrastructure projects, particularly in emerging markets where such infrastructure is essential for economic growth.

LITERATURE REVIEW

The application of PPP model in large-scale infrastructure projects, particularly those related to transportation, has gained significant attention globally. Thailand, with its long-standing history of adopting PPP frameworks, predominantly utilizes BOT and Build-Transfer-Operate (BTO) models for transportation infrastructure (Kokkaew, 2020). In the research paper, author prepares models, allocate design, finance, construction, and operational risks to private concessionaires, a strategy that has been widely employed in highway and road infrastructure projects. The study also introduces the concept of the Public Sector Comparator (PSC), which can be utilized as a benchmark during negotiations with concessionaires. The PSC provides an estimate of the financial implications of public sector operation versus the continued involvement of the private sector. The author also added the existing literature by providing a practical tool for evaluating BOT infrastructure projects. Their approach, which incorporates risk-adjusted analysis and the PSC benchmark, offers valuable insights for both public agencies and private concessionaires when renegotiating or extending BOT contracts in transportation infrastructure.

(Meng, 2013) The concept of the Private Finance Initiative (PFI), later evolved into PPP, was introduced in the UK during the early 1990s as a model for delivering public infrastructure projects. Under this scheme, the private sector, often through a Special Purpose Vehicle (SPV), assumes responsibility for designing, financing, building, and operating public projects, typically over a period of 20-30 years. The life costing (WLC) or life cycle costing (LCC) approaches have become essential in these long-term agreements due to the need to optimize expenditure over the entire project lifespan. However, despite the widespread use of PFI/PPP, limited empirical research has explored the application of WLC/LCC within this context.

(Zhang, 2016) proposes a novel quantitative model to determine the optimal project life span and concession period, maximizing benefits for both stakeholders. The model integrates economic and social factors, offering a more holistic approach than previous methods, which have typically treated concession period determination as exogenous and sequential. This advancement is crucial for improving financial viability and benefit distribution, considering uncertain social benefits and costs.

In the field of transportation infrastructure, PPPs have garnered significant attention due to their ability to involve private-sector participation beyond traditional methods. The study conducted by (Ramsey, 2020) focuses on quantifying the cost and schedule performance of transportation. PPP projects in the United States are a relatively unexplored area in the current body of knowledge. Their research emphasizes two major PPP delivery methods: Design-Build-Finance (DBF) and Design-Build-Finance-Operate-Maintain (DBFOM). By analysing 75 projects completed between 1995 and 2015, aggregating approximately $39 billion, the authors provide a robust quantitative assessment of project performance. The findings reveal that PPP projects exhibit a notable cost performance, with an average cost change of 3.04%, compared to 9% for similar projects utilizing traditional design-build (DB) methods. Additionally, the average schedule change was found to be 1.38%, demonstrating a marked improvement over conventional approach. These results underscore the efficiency gains associated with PPP models in terms of both cost and time management. The paper also highlights the increasing adoption of DBF and

DBFOM methods, which contribute to enhanced governance, financial management, and sustainability in transportation infrastructure projects.

(Parrado, 2021) explores the balance between procedural and results-driven accountability in PPPs in both the Netherlands and Spain. This research addresses a gap in the literature concerning how administrative traditions influence accountability frameworks within PPP contracts. The authors argue that the distinct administrative traditions of these two countries — legalistic in Spain and managerial in the Netherlands — lead to different emphasis on process versus outcome accountability. Dutch officials, adhering to relational governance principles, focus on results-based accountability. In contrast, Spanish administrators, particularly in non-clinical services, prioritize procedural accountability, while in clinical services, they adopt a results-driven approach. Further the study offers valuable insights, stressing the importance of establishing clear result-oriented objectives at the outset of PPP contracts. Furthermore, it highlights that results-based accountability demands competencies that are often lacking in legalistic public sectors. This gap in capabilities is critical for ensuring effective contract oversight and maximizing the performance outcomes of PPPs. Thus, the research underscores the need for adaptive governance structures that integrate both procedural and results-driven accountability to optimize public service delivery.

(De Marco, 2012) investigates the factors influencing the equity share in BOT projects, a common structure within PPPs. Their research, focused on toll road projects, aims to identify the key determinants of equity participation in relation to the project's risk profile. By utilizing regression analysis, the authors examine the relationship between various risk factors and the capital structure of BOT contracts. Their findings suggest that critical variables such as the inflation rate, the size of the investment, the length of the construction period, the stability of the SPV, and the organizational structure of the project significantly affect the equity portion of the financing. The study offers practical insights for project promoters by helping them understand factors that can lead to higher debt leverage. It also provides valuable information to lending institutions on determining the appropriate debt resources for BOT projects. The research contributes to the growing body of knowledge on PPP capital structures and helps refine financing methods for BOT initiatives.

(Koppenjan, 2015) examines the complexities involved in using PPPs for green infrastructure development, particularly low-carbon, climate-resilient (LCCR) projects. The paper highlights the potential of Design, Build, Finance, Maintain, and Operate (DBFMO) contracts in advancing LCCR infrastructure, but also underscores significant tensions, arising from the misalignment between the economic-driven objectives of traditional PPPs and the environmental goals of sustainability projects. The study calls for a transformation in PPP regulatory frameworks to accommodate green infrastructure goals, stressing the need for governments to adopt strong LCCR policies, ensure investment returns, and develop contract management expertise.

(Chi, 2017) explores the cost-benefit analysis of privately operated toll roads by examining the impact and risk allocation to the public from both government and private sector perspectives. They use a synthesized toll tunnel project case to investigate how tolls are treated either as transfer payments or end-user costs. Their analysis employs the Monte Carlo simulation approach to assess the risks associated with variables, highlighting that both perspectives - public and private - are valid. The study offers insights into decision-making based on the impacts and risks from the host government's standpoint, contributing to the project evaluations of toll road initiatives involving private operators.

(Kagne, 2020) examines the financial risks associated with PPP road projects in India, emphasizing the BOT model. The paper discusses how the Indian government relies on PPPs for infrastructure development, particularly in the road sector, which accounts for 80% of all PPP projects. Financial risks in PPP projects, especially those related to long-term commitments, are critical. The authors propose a Net Present Value (NPV)-at-risk method for evaluating these risks, integrating Monte Carlo simulation to address uncertainty in risk parameters. The model developed serves as a decision-making tool for risk assessment and financial return estimation, offering a method to mitigate financial risks in privately financed infrastructure projects.

(Fathi, 2021) conducted an exploratory study on the funding and financial performance of PPP highway projects in the United States. Their study addressed a gap in the literature by examining the distribution of funding between the public and private sectors in PPP agreements, specifically in Design-Build-Finance-Operate-Maintenance (DBFOM) and Design-Build-Finance-Maintenance (DBFM) projects. The findings indicated that projects with less than 35% private funding had better cost-growth performance compared to those with greater private funding. Moreover, DBFM projects exhibited superior cost performance relative to DBFOM projects. This research highlights the importance of the type of PPP arrangement and the funding source distribution in influencing the cost performance of highway infrastructure projects.
(Bayat, 2020) proposed a financial conflict resolution model for BOT contracts using bargaining game theory. The study developed a financial model to determine the optimal concession period and capital structure while considering the conflicting financial interests of the sponsor, government, and lender. Using fuzzy set theory, the model accounted for risks and uncertainties. The research highlighted that being the first proposer in the negotiation could affect the concession period, but not the equity level. Furthermore, the inclusion of income tax as part of the government's financial benefits increased the concession period length. This model offers a practical tool to reach fair and efficient agreements, preventing negotiation failures and costly renegotiations.
(Shaw, 2010) emphasizes the integration of container terminal design and construction with operational planning to mitigate project delivery costs and reduce scheduling delays. The paper highlights the advantages of collaboration between design, construction, and operations teams in container terminal projects. This integrated approach allows for concurrent development processes that traditionally occur in isolation, leading to time and cost savings. Shaw notes that this methodology fosters efficiency by streamlining the construction phase while simultaneously preparing for operational readiness, thus reducing the overall project lifecycle. The insights provided are valuable for large-scale infrastructure projects, particularly those related to maritime port development.
(Abdel Aziz, 2007) explores the payment mechanisms employed in transportation DBFO projects in British Columbia. The study provides an in-depth analysis of different payment approaches, focusing on their application within the PPP framework and based on the project's specific conditions, promoting financial sustainability and effective risk management for both the public and private sectors. By surveying transportation projects, the author highlights the importance of selecting appropriate payment mechanisms to manage risks and ensure financial viability. Various mechanisms, including availability-based payments and toll-based systems, are discussed in relation to their impact on the project's overall performance and risk allocation.
(PPPs., 2015) The NEC (New Engineering Contract) is recognized for its adaptability and simplicity, making it a preferred choice for various contracts including work supply, physical services, and professional services. Widely used in the UK, South Africa, and to a lesser extent in New Zealand and Hong Kong, the NEC's structured flexibility is attractive to international financing institutions. Patterson and Trebes (2015) explore its use in DBFO contracts within PPPs, emphasizing how it serves as a valuable tool in project finance deals. The authors highlight NEC's potential as a superior alternative to the traditionally used Federation International des Ingenieurs-Conseils (FIDIC) contracts in global PPP infrastructure projects.
(Kasemsukh, 2020) assess the financial implications of construction delays in BOT infrastructure projects, particularly in Thailand where the BOT model is widely used for PPPs. Their study emphasizes the construction phase as the most risk-prone, often leading to delays that can result in severe financial consequences, including contract termination. Using a hypothetical financial model, the authors conduct a risk analysis through Monte Carlo simulation to quantify the risks faced by project sponsors. The findings suggest the necessity for both public and private sectors to collaboratively develop risk mitigation strategies to ensure more balanced and resilient BOT contracts in future infrastructure projects.
(Acerete, 2010) analyses the financial implications of using private finance mechanisms for road infrastructure in Spain and the UK. The study highlights the challenges associated with the high costs of risk transfer in private finance arrangements. It also emphasizes the difficulty in obtaining comprehensive assessments due to the lack of transparency, as much of the financial information is restricted by commercial sensitivity. The authors argue that the risks associated with these projects are

disproportionately borne by the public sector, while the private sector reaps the benefits. The findings suggest that private financing for roads may lead to a transfer of costs to the state, undermining the intended efficiency of such projects.

(Fernandes, 1999) examines Portugal's experience with private financing of road infrastructure through the DBFO model. Faced with a substandard road network relative to other European nations, Portugal sought to incorporate private investment to bridge the gap. Six DBFO contracts covering 830 km of roadways were issued, where private contractors would construct and maintain the roads for 30 years. Payments to the concessionaires were based on shadow tolls, reflecting vehicle kilometres driven. Early assessments of this model indicated both public and private sector benefits, with continuous monitoring to optimize the DBFO approach. This suggests that private financing may be a sustainable option for large infrastructure projects in Portugal.

COMPARATIVE ANALYSIS OF MODELS IN INFRASTRUCTURE PROJECTS AND CHALLENGES IN ROAD INFRASTRUCTURE COST ESTIMATION

PPPs have emerged as an effective model for financing, developing, and maintaining large-scale infrastructure projects globally. The two most common forms of PPP, particularly in road infrastructure, are the BOT and DBFOT models. Both models involve private sector participation, but they differ in terms of risk allocation, concession terms, and financial structures. A comparative analysis of these models across different countries and project contexts reveals significant insights into their advantages, challenges, and overall effectiveness in managing infrastructure projects, particularly in transportation.

➢ **BOT Model**

The BOT model has been widely adopted in countries like India, Thailand and Spain for financing road projects. Under the BOT framework, private concessionaires are responsible for the construction and operation of a project for a fixed concession period, after which the asset is transferred back to the public sector (Kokkaew, 2020; Acerete, 2010). The BOT model has the ability to leverage private sector efficiency in both the construction and operation phases, as well as for minimizing upfront public capital expenditure. However, a significant challenge associated with BOT projects is the high financial risk borne by private concessionaires, particularly in terms of demand risk and construction delays. The authors noted that such delays often lead to severe financial penalties or contract termination, underscoring the need for effective risk management strategies.

➢ **DBFOT Model**

The DBFOT model has been used in many countries, where private firms are responsible for the design, construction, financing, and long-term operation of road infrastructure (Fernandes & Viegas, 1999). In the DBFOT model, the private sector not only finances and operates the project but also typically earns revenue through tolls or availability payments based on performance metrics. The model has shown promising results in terms of early project delivery and efficient operation, largely due to the continuous monitoring systems that allow both the public and private sectors to optimize the process. Nevertheless, challenges persist, particularly in the accurate estimation of shadow tolls and their correlation with traffic volume.

Challenges in Road Infrastructure Cost Estimation

Cost estimation in road infrastructure projects, whether under BOT or DBFOT models, presents several challenges. One major issue is the inherent difficulty in accurately forecasting project costs due to uncertainties in construction risks, demand variability, and macroeconomic factors such as inflation and interest rates. For example, De Marco (2012) identified critical risk factors influencing the capital structure of BOT projects, including inflation rates, construction period lengths, and the organizational structure of the Special Purpose Vehicle (SPV). These variables often lead to cost overruns and financial strain on both private concessionaires and public authorities.

Additionally, Acerete (2010) emphasized the complexities associated with risk transfer in private finance mechanisms, particularly in road infrastructure projects in Spain and the UK. The study noted that the costs of risk transfer are often underestimated, leading to financial burdens on the public sector. This challenge is compounded by the lack of transparency in financial information due to commercial sensitivity, which makes it difficult for public authorities to objectively assess the long-term financial implications of PPP projects. The authors concluded that in many cases, the risks are disproportionately borne by the public sector, while the private sector reaps the financial benefits (Acerete, 2010).

Another challenge relates to the estimation of long-term maintenance and operational costs. In PPP agreements where the private sector is responsible for the operation and maintenance of infrastructure, discrepancies often arise between the estimated and actual costs of maintaining the asset over its life cycle. For instance, Ramsey (2020) quantified the cost and schedule performance of transportation PPP projects in the United States, finding that while PPP projects exhibited notable cost performance improvements over traditional models, the estimation of long-term operational costs remained a significant challenge.

The comparative analysis of BOT and DBFOT models in road infrastructure projects reveals both advantages and challenges. While both models have been successful in leveraging private sector expertise and financing, they are not without risks. BOT projects, particularly in countries like Thailand and India, face significant financial risks related to demand and construction delays, while DBFOT projects like in Europe have shown promise in reducing upfront public expenditure but present challenges in accurately forecasting long-term costs. Addressing these challenges will require more refined cost estimation models, better risk-sharing mechanisms, and increased transparency between public and private sectors to ensure the long-term sustainability of road infrastructure projects under PPP frameworks.

RESEARCH METHODOLOGY

This section details the research methodology employed in analysing four selected road infrastructure projects, with a particular focus on cost estimation and revenue models. The methodology is based on secondary data collection through the review of technical reports and project documentation. The research follows a comparative approach to evaluate the cost and revenue structures, primarily focusing on the BOT model and related toll-based revenue recovery mechanisms.

Data Collection – Secondary Data

Technical reports and project documentation of following four road infrastructure projects, carried out under the PPP framework, particularly using the BOT model are considered:

- ➢ Ujjain-Jaora Highways
- ➢ Satna-Chitrakoot Highways
- ➢ Mangawan to UP Border, Section of NH-27
- ➢ Satna-Bela, Section of NH-75

Their technical reports provide detailed information on the design, financial structure, construction timelines, operational frameworks, and revenue models for each project. Additionally, the cost estimation methodologies, concession agreements, and traffic projections are carefully reviewed to assess their influence on the financial viability of the projects.

Cost and Revenue Model Employed

Each of the road infrastructure projects utilizes a distinct cost and revenue model based on its contractual and financial structure. The primary focus of this study is on the revenue generation mechanisms, which are largely dependent on toll collection as per the concession agreements. These models include variations such as BOT and DBFOT, which shape the risk-sharing agreements between the public and private sectors. Below is a detailed analysis of each project's cost and revenue model:

➢ **Ujjain-Jaora Highways**

Project Model: DBFOT (Design-Build-Finance-Operate-Transfer)

Cost & Revenue Model: This project operates under a toll-based revenue recovery model. The concessionaire is responsible for financing, constructing, and operating the highway for a specified concession period. Revenue is generated by toll collection based on traffic projections. A detailed traffic assessment model is employed to estimate the toll collection rate and ensure the project's financial viability. This model includes periodic reviews of traffic flow to account for fluctuations in revenue generation.

➢ **Satna-Chitrakoot Highways**

Project Model: BOT DBFOT (Design-Build-Finance-Operate-Transfer)

Cost & Revenue Model: Similar to the Ujjain-Jaora Highways, this project relies on toll-based revenue collection. The concessionaire is permitted to recover costs through tolls at concession rates over the project's life cycle. The project's financial model includes assumptions on traffic growth rates, inflation adjustments, and toll rate escalations based on pre-defined clauses in the concession agreement. The revenue model is closely linked to the expected traffic volume and growth over the concession period.

- **Satna-Bela Road Project (NH-75)**

Project Model: BOT (Build -Operate-Transfer)

Cost & Revenue Model: This section of the Satna-Bela Road project follows a BOT model with cost recovery through toll collection. The toll is set at concession rates that allow the concessionaire to recoup the project costs over a fixed period. The project timeline and cost structure are closely aligned with traffic assessments to ensure that the toll rates can sustain operational and maintenance costs while providing adequate returns on investment for the private entity involved.

- **Mangawan to UP Border, Section of NH-27**

Project Model: BOT (Build-Operate-Transfer)

Cost & Revenue Model: As with the previous projects, this section operates on a toll-based revenue recovery system under the BOT framework. The project involves significant upfront capital investment, which is to be recovered through tolls. The concessionaire bears the financial risk, with revenue models structured to account for variations in traffic patterns and potential economic factors that may affect toll revenue. The concession agreement outlines the toll escalation procedures, ensuring that the revenue stream adjusts to inflation and economic changes over time.

Cost Estimation Model

The cost estimation models employed across these projects are largely influenced by the project's financial and operational structures. The methodology involves analysing the following key factors:

- **Time Periods**: The concession period for each project is carefully examined to understand its influence on cost recovery. Most projects involve a concession period ranging from 15 to 30 years, during which the concessionaire is expected to recover the initial capital investment through toll collection and other associated revenue streams.
- **Construction Schedules**: The construction timeline for each project is a critical parameter in estimating costs. Delays or deviations from the proposed schedule can significantly affect the financial outcomes. The cost estimation includes considerations for construction risk, material cost fluctuations, and labour costs over the project lifecycle.
- **Traffic Projections and Revenue Forecasting**: Traffic assessments are central to the revenue models in these road infrastructure projects. The financial models rely on accurate projections of traffic flow and growth over time. The data used for these projections include historical traffic patterns, population growth rates, and economic activity in the region. Sensitivity analyses are also conducted to assess the potential impact of deviations from the expected traffic volumes on the revenue generation capacity.
- **Concession Agreements and Financial Liabilities**: The analysis of concession agreements provides insights into the financial obligations and liabilities borne by the private entities. These agreements often include clauses related to toll escalation, revenue-sharing with the government, and penalties for non-compliance with construction or operational benchmarks. The financial risks are closely tied to the conditions set forth in these agreements, which significantly influence cost estimation models.

Data Analysis and Interpretation

Data analysis and interpretation process involves systematic examination of data obtained from various surveys, inventories, cost estimations, and traffic forecasts to establish the feasibility of the project over its concession period. This analysis incorporates detailed cost breakdowns, traffic projections, toll revenue calculations, and discounted cash flow (DCF) analysis. Each element provides insight into both the current value and future earnings potential of the project.

Given the substantial capital expenditure, supported by a revenue model based solely on toll collection, it is essential to evaluate projected revenues accurately. This is done by factoring the initial traffic volume estimates, anticipated annual growth rates, and the toll rate per vehicle. Further, the application of a discounting rate enables a realistic appraisal of future revenues, converting them to their present value to reflect the project's financial worth over the 10-year operational period. The BOT model is widely employed for infrastructure projects as it enables private sector participation by allowing the private entity to finance, build, operate, and maintain the project over a specific period. This analysis evaluates the BOT model's applicability to the significant initial costs, primarily directed at extensive roadworks, drainage, and structures, and revenue from toll collection.

Firstly, in data analysis, we compare and analyse the two projects – Mangawan to MP/UP Border (Section of NH-27) and Satna-Bela (Section of NH-75).

Both projects involve the construction and maintenance of highway sections within Madhya Pradesh, structured to be funded, constructed, and operated by private entities under the BOT model. Despite similarities in their BOT framework, the projects differ in cost allocation, project length, traffic projections, and infrastructure requirements. A detailed comparative analysis reveals the financial and operational considerations of each project. The Mangawan project spans 52.074 km, with a total EPC cost of ₹458.06 crores. In comparison, the Satna-Bela project covers a slightly shorter distance of 48.040 km, with a lower EPC cost of ₹419.7 crores. Both projects allocate their costs across key construction categories; however, the Mangawan project emphasizes on surface courses and bridge construction, while the Satna-Bela project allocates a relatively larger portion of costs to earthwork and service road construction.

Cost Distribution and Infrastructure Components

The two projects distribute their costs among similar construction elements, yet with different weightages based on individual project needs:

- **Road Construction and Surface Courses**: In both projects, a significant portion of the budget is dedicated to road construction and surface layers, underscoring their necessity for traffic durability and safety. The Mangawan project allocates 30.55% of its budget to bases and surface courses, whereas the Satna-Bela project allocates 27.27%.
- **Earthwork and Drainage**: Earthwork is essential for stability, particularly in areas requiring extensive groundwork. The Satna-Bela project allocates 11.68% of its budget to earthwork compared to the Mangawan project's 8.26%, potentially indicating greater terrain preparation needs. Drainage costs, critical for managing water flow, are similar across both projects, reflecting a shared focus on infrastructure resilience.
- **Bridge and Culvert Construction**: The construction of cross-drainage structures, such as minor and major bridges, is essential for connectivity and accounts for significant expenditure in both projects. The Mangawan project allocates a higher combined percentage to bridge and culvert construction, with 9.68% for minor bridges and 5.54% for major bridges, while Satna-Bela allocates 8.62% for minor bridges and 5.96% for major bridges, indicating similar prioritization.

Traffic and Revenue Projections

Traffic volume and toll collection, which directly impact revenue, are crucial for the financial sustainability of both BOT projects, thereby making forecasting accuracy essential:

- **Initial Traffic Volume and Growth Rate**: Both projects estimate daily traffic volume, with a 5% annual growth rate. The Mangawan project begins with an initial traffic estimate of 10,000 vehicles daily, while a similar projection for the Satna-Bela project is implied based on design and cost assumptions.
- **Revenue Model**: Assuming an average toll rate of ₹50 per vehicle, revenue is anticipated to compound annually due to projected traffic growth. Over a 10-year period, this compounding results in cumulative toll revenues, with Mangawan reaching approximately ₹28.31 crores annually by Year 10. However, given similar traffic assumptions, the Satna-Bela project would yield slightly lower revenues due to its lower toll infrastructure and shorter length.

Discounted Cash Flow (DCF) Analysis and Financial Viability

DCF analysis evaluates the present value of toll revenues over the concession period by applying a discount rate of 10%, reflecting the time value of money and risk over time:

- **Present Value of Toll Revenue**: For the Mangawan project, the present value of future toll revenues is estimated at ₹135.78 crores over 10 years. In contrast, the Satna-Bela project, with a similar discount rate and projected revenue, is expected to yield a slightly lower present value due to its shorter route length and lower traffic density.

- **Net Present Value (NPV) and Profitability**: Both projects display a significant financial gap between their EPC costs and NPV of toll revenue, with the Mangawan project showing a shortfall of approximately ₹322.28 crores and the Satna-Bela project also likely falling short, albeit with a marginally smaller deficit due to a reduced cost base. These NPV outcomes suggest that neither project achieves full cost recovery within the 10-year concession period based on toll revenue alone, underscoring the limitations of toll-only revenue models, necessitating a higher concession period.

Comparative Interpretation and Conclusions

Both the Mangawan and Satna-Bela BOT projects illustrate the challenges of funding infrastructure via toll revenues within a limited concession period. The analysis reveals that both projects face substantial financial shortfalls, when the EPC costs are compared to the NPV of projected revenues, indicating the need for alternative revenue streams or adjustments to financial structuring:

- **Revenue Model Limitations**: The reliance on toll revenues alone is insufficient to cover the initial investment for both projects. To enhance financial feasibility, stakeholders may consider extending the concession period beyond 10 years, which would allow for additional toll collection periods to bridge the revenue gap.
- **Alternative Revenue Sources**: Both projects could explore supplementary revenue streams, such as commercial development along the highway or public-private financing options, including viability gap funding (VGF) from the government.
- **Financial Structuring Adjustments**: Given the high capital intensity, adjustments such as increased toll rates or gradual toll escalation tied to inflation, based on Wholesale Price Index, could improve revenue recovery without significantly impacting traffic.

The comparative analysis indicates that while both projects are viable under BOT frameworks, financial adjustments and extended revenue sources are essential for achieving full cost recovery and sustainable profitability. This analysis highlights the importance of comprehensive financial modelling and adaptive revenue strategies in ensuring the long-term viability of BOT highway infrastructure projects.

In comparing the Mangawan-MP/UP Border, Satna-Bela, Satna-Chitrakut and Ujjain-Jaora Road projects, each of which is implemented either under BOT or DBFOT models, a detailed examination of project costs, revenue projections, toll collection methodologies, and concession terms provides insight into each project's financial structure, operational approach, and viability within its set concession period.

Project Scope and Model

- **Mangawan-MP/UP Border (NH-27):**

Implemented on a DBFOT basis, this project spans 52.074 kilometres. The total EPC cost is ₹458.06 crores, with a 10-year concession period and an initial toll rate set at ₹50 per vehicle, increasing with traffic at 5% per annum.

With a shorter concession period of only 10 years, this project faces challenges in achieving cost recovery solely through toll revenue.

- **Satna-Bela (NH-75):**

This DBFOT project, covering 48.040 kilometers, also features a design and build approach with a total EPC cost estimated at ₹419.7 crores, slightly above a conservative third-party estimate of ₹406.74 crores. The project's toll rate increment is based on a 5% annual escalation, with estimated work progress rates and escalations factored over three years.

- **Ujjain-Jaora Highway:**

A 95-kilometer BOT project with a 25-year concession period, this project adopts an open toll collection system. A unique feature is its pass issuance at a flat ₹50 rate, providing an alternative revenue stream and simplifying tolling for frequent users.

The concession period includes provisions to extend by 1.5% for every 1% decrease in actual traffic, reflecting traffic-dependent flexibility that aligns revenue streams with real-world conditions.

Cost Structure and Financial Viability

- **Mangawan-MP/UP Border Project:**

The project's costs are heavily weighted toward roadwork components, with 30.55% directed at bituminous and concrete surface courses and an additional 10.28% toward sub-bases.
Traffic growth at 5% per year yields an NPV of approximately ₹135.78 crores over the 10-year concession period, leaving a significant financial gap of ₹322.28 crores. This shortfall emphasizes the need for additional revenue streams or extended concession terms, as the toll-revenue-only approach is insufficient

- **Satna-Bela Project:**

With a cost distribution similar to the Mangawan-MP/UP Border project, this project also sees significant investments in road surfaces (27.27% of total costs) and earthwork (11.68%).
Escalation costs are calculated based on semi-annual increments averaged at 8.10% annually. Though projections suggest that the total EPC estimate is in line with conservative cost assumptions, the escalation mechanism helps address inflationary impacts over a prolonged construction period, adding a layer of financial flexibility.

- **Ujjain-Jaora Project:**

Though larger in scale, this project's 25-year concession period allows for greater revenue accumulation, making the BOT model more feasible. The toll pass option provides consistent revenue, and flexible concession extensions based on traffic help to offset the risks of traffic underperformance.
The project's long-term viability is underscored by projected toll revenues reaching ₹100 crores, underscoring a more balanced relationship between toll revenues and initial investment costs.

Revenue Projections and Risk Assessment

Revenue Projections:

- **Mangawan-MP/UP Border** relies solely on toll revenue but encounters challenges with a 10-year concession, where a 5% annual traffic increase is insufficient to offset high upfront costs. A discounted cash flow analysis shows that even with projected increases, the financial gap remains significant.

- **Satna-Bela** project benefits from escalated cost projections and a semi-automated toll collection system, which simplifies operations while adjusting revenues in line with gradual traffic growth.

- **Ujjain-Jaora** benefits from a 25-year concession, providing ample time for toll revenue to offset costs. Traffic underperformance provisions in the concession agreement add a layer of protection against revenue shortfalls.

Risk Mitigation:

- For **Mangawan-MP/UP Border**, risk is elevated due to the toll-dependent revenue model and constrained concession term, necessitating either government support (e.g., viability gap funding) or extended concession periods to bridge the financial gap.
- **Satna-Bela**'s escalated cost adjustments and maintenance provisions mitigate inflationary risks but would benefit from a concession term reassessment, given the high capital requirements.
- **Ujjain-Jaora**'s flexible concession model adjusts in response to actual traffic performance, offering resilience against demand risk and aligning cost recovery with realistic traffic trends.

Once the data from the technical reports and project documentation were collected, a comparative analysis was conducted to identify the commonalities and differences in the cost and revenue models of each project. The analysis focused on the following:

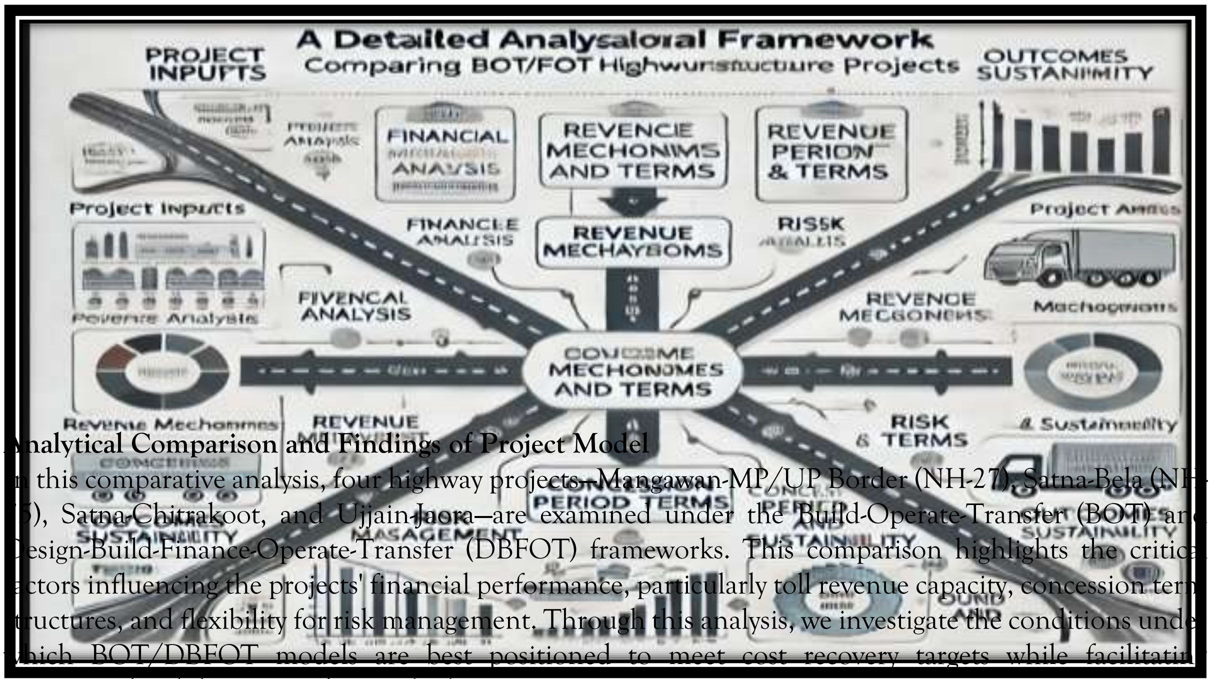
- **Risk Allocation**: A key component of the cost and revenue model is the allocation of risks between the public and private entities. In all five projects, the financial risk associated with construction costs and traffic uncertainties is largely borne by the concessionaire, while the government ensures regulatoy oversight and provides minimal financial guarantees.
- **Financial Viability**: The financial models of the projects are evaluated in terms of their viability based on toll collection rates and projected traffic flows. Each project's financial viability is contingent upon accurate traffic forecasts, toll rate flexibility, and effective risk management strategies.

A comparison of the cost and revenue models across the projects reveals that while the BOT model remains the predominant framework, variations in traffic projections and financial structures lead to differing levels of success in cost recovery. Projects that integrate more sophisticated traffic forecasting tools and flexible toll rate structures tend to perform better in terms of financial sustainability.

Overall, the comparison of these three projects reveals that the BOT/DBFOT models' success is deeply influenced by how well concession terms and tolling mechanisms align with the financial realities specific to each project. The Mangawan-MP/UP Border project demonstrates the challenges of a shorter concession period, where moderate toll revenue growth is insufficient to cover substantial capital costs. In contrast, the Ujjain-Jaora project exemplifies a more balanced financial framework; its extended concession term and flexible adjustments based on actual traffic conditions provide a stable foundation for cost recovery. This adaptability in concession terms serves as a safeguard against revenue shortfalls, enabling the project to better match costs with revenue over an extended timeframe.

The Satna-Bela project, though benefiting from escalated cost projections and a semi-automated toll collection system, faces limitations in revenue generation due to its shorter term. Adjustments to concession length or tolling mechanisms would likely enhance its viability, ensuring a revenue structure better suited to the financial demands of the project. In these findings illustrate that while BOT/DBFOT models are effective, their viability depends on nuanced project design that accommodates the unique demands of capital costs, expected traffic growth, and operational flexibility. Properly aligned, these elements collectively support a sustainable revenue base, mitigating financial risks and ensuring the success of infrastructure projects under concession frameworks.

Diagram: 1 Detailed analytical framework diagram for comparing BOT/DBFOT highway infrastructure projects (*Source: Author*)



Analytical Comparison and Findings of Project Model

In this comparative analysis, four highway projects—Mangawan-MP/UP Border (NH-27), Satna-Bela (NH-75), Satna-Chitrakoot, and Ujjain-Jaora—are examined under the Build-Operate-Transfer (BOT) and Design-Build-Finance-Operate-Transfer (DBFOT) frameworks. This comparison highlights the critical factors influencing the projects' financial performance, particularly toll revenue capacity, concession term structures, and flexibility for risk management. Through this analysis, we investigate the conditions under which BOT/DBFOT models are best positioned to meet cost recovery targets while facilitating operational viability across distinct highway projects.

- **Mangawan-MP/UP Border (NH-27) Project**

The Mangawan-MP/UP Border project, spanning a 52.074-kilometer section on NH-27, employs a DBFOT framework with a concession period of 10 years. Given an estimated EPC cost of ₹458.06 crore, the project depends significantly on toll revenue, with toll rates commencing at ₹50 per vehicle and increasing annually by 5%. However, the relatively short 10-year concession period creates a stringent timeline for cost recovery. Traffic growth is projected at a moderate 5% annually, which, when analysed through discounted cash flow (DCF) methods, results in an NPV of approximately ₹135.78 crore — substantially below the initial capital investment, with a shortfall of ₹322.28 crore.

The constrained revenue-generating timeframe, combined with high upfront costs, highlights the potential for financial underperformance. This project illustrates the limitations of shorter concession terms within the DBFOT structure, particularly in the context of moderate traffic growth and fixed toll rate escalations. To mitigate revenue shortfall risks, alternative financing measures, such as government-backed viability gap funding (VGF) or an extension of the concession term, may be required. The Mangawan-MP/UP Border project demonstrates the necessity of aligning concession terms with both projected revenue cycles and the capital demands of road infrastructure projects to secure financial sustainability.

➢ **Satna-Bela (NH-75) Project**

The Satna-Bela project covers a 48.040-kilometer stretch on NH-75, implemented under a DBFOT model. With a total capital cost of approximately ₹419.7 crore, the project integrates a 5% annual toll rate escalation and considers a bulk cost escalation of 8.10% annually, calculated semi-annually. The toll revenue potential, coupled with structured escalation, contributes to a realistic capital recovery path. However, the project's concession period remains limited, requiring strategic adjustments to optimize revenue.

Although close alignment between conservative capital estimates (₹406.74 crore) and the projected EPC cost (₹419.7 crore) suggests reasonable accuracy in cost assessment, financial viability may benefit from additional revenue mechanisms or an extended concession period. For instance, enhancing toll rates slightly above the scheduled 5% or prolonging the concession period could ensure cost recovery and financial sustainability within the DBFOT model. This case underscores the role of flexible tolling structures in projects with short concession terms and high initial costs, supporting sustainable revenue generation amid rising operational expenses.

➢ **Satna-Chitrakoot Project**

The Satna-Chitrakoot project spans 75 kilometres, structured under a BOT model with a 25-year concession period. The longer term provides a substantial timeframe for cost recovery, allowing toll adjustments to better align with anticipated traffic patterns. The toll rate increases at an annual rate of 5%, following the Wholesale Price Index (WPI), creating a steady revenue base while incorporating potential inflationary adjustments. The longer concession term effectively balances toll revenue generation with the projected cost escalations, contributing to a cumulative toll revenue projection of ₹484.77 crore over 10–15 years.

An additional feature of this project is the provision for concession extensions, wherein for every 1% shortfall in traffic relative to projections, the concession period is extendable by 1.5%. This adaptability to real-time traffic data mitigates demand risk, thereby stabilizing cash flow and ensuring that the revenue structure can absorb traffic fluctuations. The Satna-Chitrakoot project thus demonstrates the financial resilience achievable with extended concession periods, where flexibility in the revenue framework effectively manages traffic variance and demand risk.

➢ **Ujjain-Jaora Highway Project**

The Ujjain-Jaora project, covering 95 kilometres, operates under a BOT structure with a 25-year concession period. The project adopts an open toll collection system, supplemented by pass issuance at ₹50 per pass, which enhances toll collection efficiency and serves as an additional revenue stream. This system is particularly advantageous given the extended concession period, where revenues are projected to reach approximately ₹100 crore, indicating a strong alignment between the project's revenue potential and capital expenditure requirements.

In line with the Satna-Chitrakoot project, the Ujjain-Jaora project includes concession flexibility, enabling the concession period to extend by 1.5% for every 1% traffic shortfall. This adaptive framework mitigates revenue risks associated with lower-than-expected traffic volumes, promoting financial stability over the concession period. The 25-year BOT model, reinforced by adaptable concession terms, ensures that the project can maintain its operational viability in fluctuating traffic conditions while balancing initial costs and toll-based revenue generation.

Comparative Analysis and Findings

This comparative assessment of the Mangawan-MP/UP Border, Satna-Bela, Satna-Chitrakoot, and Ujjain-Jaora projects reveals key insights into the financial dynamics of BOT and DBFOT models:

- **Concession Term Alignment**: Extended concession periods, as seen in the Satna-Chitrakoot and Ujjain-Jaora projects, fosters a robust framework for cost recovery and risk mitigation, particularly in BOT models. The additional timeframe allows for revenue adjustments and flexibility in toll rate escalations, effectively aligning revenue potential with long-term financial obligations.
- **Revenue Risk Mitigation**: Both the Satna-Chitrakoot and Ujjain-Jaora projects incorporate flexible concession terms, enabling extensions based on actual traffic shortfalls. This adaptability safeguards toll revenue stability against unforeseen fluctuations in demand, ensuring that revenue cycles match capital and operational costs over time. Projects with shorter concession periods, such as Mangawan-MP/UP Border and Satna-Bela, could benefit from similar mechanisms to mitigate revenue volatility.
- **Toll Rate and Cost Escalation Adjustments**: Regular toll rate increments, such as the 5% annual increase utilized across the projects, serve as effective tools to account for inflationary pressures. However, projects with shorter concession terms, such as Mangawan-MP/UP Border, may require more aggressive toll escalation or supplementary funding to secure financial sustainability.
- **Demand Responsiveness**: The Satna-Bela and Mangawan-MP/UP Border projects, despite shorter terms, illustrate the potential benefits of revising tolling strategies based on traffic responsiveness. Adapting toll rate structures or incorporating supplementary fees (e.g., open toll systems or pass issuance) could significantly enhance revenue flows and ensure sustainable capital recovery.

CONCLUSION AND RECOMMENDATIONS

The comparative analysis of the Mangawan-MP/UP Border, Satna-Bela, Satna-Chitrakoot, and Ujjain-Jaora highway projects elucidates several critical insights regarding the financial performance and sustainability of road infrastructure initiatives under the Build-Operate-Transfer (BOT) and Design-Build-Finance-Operate-Transfer (DBFOT) models. It is evident that the success of these projects' hinges on a multifaceted approach that considers not only the projected traffic patterns and revenue generation potential but also the strategic alignment of concession periods, toll structures, and risk management mechanisms.

Projects characterized by extended concession periods, such as Satna-Chitrakoot and Ujjain-Jaora, exhibit a greater capacity for cost recovery and financial resilience. The flexibility to adjust toll rates in response to inflation and traffic dynamics significantly contributes to their operational viability. In contrast, the Mangawan-MP/UP Border and Satna-Bela projects face inherent challenges related to shorter concession terms, which constrain their revenue-generating capabilities, especially amidst moderate traffic growth projections. The resultant financial shortfalls underscore the critical need for aligning concession terms with realistic traffic forecasts and capital requirements.

Moreover, the analysis reveals the importance of adaptive revenue mechanisms in mitigating demand risks. The inclusion of flexible concession terms that allow for extensions in the event of traffic shortfalls, as seen in the Satna-Chitrakoot and Ujjain-Jaora projects, provides a safeguard against fluctuations in revenue streams. This adaptability not only stabilizes cash flow but also ensures that the financial structure can accommodate unforeseen challenges, ultimately enhancing the long-term viability of these projects.

In light of these findings, it is imperative to recommend strategic actions that can enhance the financial sustainability of road infrastructure projects.

There some of the recommendations from the present study are as follows:

- **Adopt Flexible Concession Structures**: It is recommended that project developers and policymakers consider implementing flexible concession terms that allow for extensions based on actual traffic performance. This adaptability can significantly mitigate revenue risks and enhance the financial stability of projects, particularly those with shorter concession periods.
- **Incorporate Dynamic Tolling Mechanisms**: To ensure adequate revenue generation, projects should explore dynamic tolling mechanisms that allow for more aggressive adjustments based on market

conditions and traffic patterns. This could include variable toll rates during peak and off-peak periods or supplementary fees to enhance cash flow.

- **Utilize Viability Gap Funding (VGF)**: For projects facing substantial initial capital demands and moderate traffic projections, the provision of government-backed VGF should be considered. Such funding can bridge financial gaps and support the upfront costs associated with road infrastructure development, facilitating more robust financial planning.
- **Enhance Traffic Projection Models**: Stakeholders should invest in sophisticated traffic forecasting models that account for various economic and demographic factors influencing road usage. Improved accuracy in traffic projections will enable more informed decision-making regarding concession periods and toll rate structures, ultimately supporting financial sustainability.
- **Implement Routine Monitoring and Evaluation**: Establishing a systematic framework for ongoing monitoring and evaluation of financial performance, traffic trends, and operational efficiencies is essential. Regular assessments can help identify potential risks early, allowing for timely adjustments to revenue strategies and operational plans.
- **Engage Stakeholders in Revenue Planning**: Involving local stakeholders, including community representatives and transport authorities, in the planning and implementation phases can yield valuable insights into traffic behaviour and revenue optimization. Collaborative approaches can enhance the acceptance of toll structures and encourage usage.
- **Promote Research and Development in Cost Estimation**: Further research should be undertaken to develop refined cost estimation methodologies that better account for variable escalation rates, maintenance costs, and unforeseen expenditures. A more nuanced understanding of cost dynamics will spport better financial planning and project viability.

Lastly the application of these recommendations can significantly enhance the financial robustness and operational viability of road infrastructure projects within the BOT and DBFOT frameworks. By aligning concession terms, tolling strategies, and revenue mechanisms with the realities of traffic demand and operational costs, stakeholders can ensure the successful delivery and sustainability of essential infrastructure projects, ultimately contributing to economic growth and public welfare.

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