

# Risk Management Framework for Infrastructure Projects: A Case Study Approach

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**Abstract:** National highway development projects in India are characterized by large-scale, multiple stakeholders, complex implementation arrangements, and exposure to diverse technical, environmental, financial, and institutional risks. This paper presents a structured risk management framework for infrastructure projects, demonstrated through a case study of the upgradation of National Highway-9 (NH-9) in the state of Maharashtra. The case study focuses on the feasibility-cum-detailed project report (DPR) preparation and implementation planning for capacity augmentation of a 135 km highway corridor to a 2/4-lane configuration with paved shoulders, undertaken under the Engineering, Procurement, and Construction (EPC) mode. The project was commissioned by the Ministry of Road Transport & Highways (MoRT&H), Government of India, with Maharashtra State Road Development Corporation Ltd. (MSRDC) acting as Project Management Consultant and National Highways Authority of India (NHAI) as the employer and executing agency. The analysis covers key project packages with designed lengths of 42.131 km (Package-2) and 46.705 km (Package-3), along with additional widening provisions for palkhi pilgrimage routes. A comprehensive risk identification and assessment process was carried out across project development stages, including feasibility analysis, DPR preparation, land acquisition, environmental and social considerations, design coordination, and EPC structuring. Qualitative and semi-quantitative risk assessment tools, such as risk categorization, probability-impact evaluation, and prioritization matrices, were applied to evaluate critical risks. The findings indicate that early-stage risk identification, integration of regional climatic and demographic factors, and alignment with national highway standards significantly enhance project preparedness and reduce implementation uncertainties. The study demonstrates that the proposed framework provides a systematic and replicable approach for managing risks in large-scale

highway infrastructure projects, contributing to improved decision-making, schedule reliability, and cost control.

**Key Words:** Risk Management Framework; Infrastructure Projects; National Highways; EPC Mode; Project Management Consultancy; Feasibility and DPR; Risk Assessment; NH-9 Maharashtra; Highway Development; India

## I. INTRODUCTION

Infrastructure development plays a critical role in economic growth, regional connectivity, and social integration, particularly in developing economies such as India. Among various infrastructure sectors, road transportation is a key enabler of trade, mobility, and access to essential services. The Government of India, through the Ministry of Road Transport & Highways (MoRT&H), has undertaken extensive national highway development programs to improve capacity, safety, and service levels of existing corridors. However, large-scale highway projects are inherently complex and subject to multiple uncertainties, making effective risk management essential for successful project delivery.

Infrastructure projects, especially national highway projects, face a wide spectrum of risks arising from technical design challenges, land acquisition constraints, environmental and social impacts, financial uncertainties, regulatory approvals, climatic conditions, and coordination among multiple stakeholders. Inadequate identification and management of these risks often result in time overruns, cost escalations, contractual disputes, and compromised quality outcomes (Flyvbjerg et al., 2003; Aven, 2016). Studies indicate that transportation infrastructure projects worldwide frequently exceed

their original budgets and schedules due to insufficient risk planning during early project stages (Love et al., 2019).

Risk management is a systematic process that includes risk identification, analysis, evaluation, mitigation, and continuous monitoring throughout the project life cycle. International standards such as ISO 31000 and project management frameworks such as PMBOK emphasize the integration of risk management into decision-making and governance structures (ISO, 2018; PMI, 2021). In highway projects, early-stage risk management during feasibility and detailed project report (DPR) preparation is particularly critical, as key decisions related to alignment, design standards, land requirements, environmental clearances, and implementation strategy are finalized at this stage.

In India, national highway projects are increasingly implemented through Engineering, Procurement, and Construction (EPC) contracts to reduce private sector risk exposure and improve execution certainty. While EPC mode transfers construction-related risks to contractors, significant risks remain with the employer during project preparation, including design adequacy, statutory approvals, utility shifting, and land acquisition (MoRT&H, 2020). Therefore, a robust risk management framework during project development and structuring becomes essential to ensure smooth implementation under EPC contracts.

This paper presents a structured risk management framework applied to the upgradation of National Highway-9 (NH-9) in the state of Maharashtra. The project involves capacity augmentation of a 135 km corridor to a 2/4-lane configuration with paved shoulders, including Packages 2 and 3 with designed lengths of 42.131 km and 46.705 km respectively, along with widening provisions for palkhi pilgrimage routes. The consultancy assignment for feasibility-cum-DPR preparation was entrusted to Maharashtra State Road Development Corporation Ltd. (MSRDC), with National Highways Authority of India (NHAI) acting as the employer and executing agency.

The selected project corridor traverses regions with varying traffic characteristics, land-use patterns, climatic conditions, and socio-cultural sensitivities. Maharashtra's tropical climate, high population density, and religious tourism activities introduce additional project-specific risks related to construction scheduling, environmental compliance, and

stakeholder management. By adopting a case study approach, this research analyzes risk factors specific to Indian highway projects and demonstrates how a systematic risk management framework can enhance project preparedness and reduce implementation uncertainties.

## II. METHODOLOGY

This study adopts a case study-based analytical research methodology to develop and apply a structured risk management framework for national highway infrastructure projects. The case study approach is considered appropriate due to the complex, context-specific nature of highway development projects, which involve multiple stakeholders, regulatory requirements, and site-dependent uncertainties. The methodology integrates qualitative and semi-quantitative risk assessment techniques and is aligned with internationally recognized standards such as ISO 31000:2018 and the Project Management Institute's PMBOK® Guide, while also incorporating the procedural and contractual requirements of MoRT&H, NHAI, and IRC standards applicable to Indian highway projects. The selected case study pertains to the upgradation of NH-9 in the state of Maharashtra, focusing on Packages 2 and 3 with designed lengths of 42.131 km and 46.705 km respectively. The project scope includes feasibility-cum-detailed project report preparation, capacity augmentation to a 2/4-lane configuration with paved shoulders, and structuring of project implementation under the Engineering, Procurement, and Construction (EPC) mode. The project was commissioned by the Ministry of Road Transport & Highways, with Maharashtra State Road Development Corporation Ltd. acting as the Project Management Consultant and the National Highways Authority of India serving as the employer and executing agency. The selected corridor presents diverse technical, environmental, and socio-cultural conditions, making it suitable for comprehensive risk analysis.

Risk identification was undertaken during the feasibility and DPR preparation stages, as early-stage risks have a significant influence on project outcomes during implementation. A multi-source data collection approach was employed, including review of feasibility reports, DPR documents, alignment drawings, traffic studies, and environmental reports,

along with examination of statutory requirements and previous national highway project records. Expert consultations were conducted with highway engineers, planners, environmental specialists, and project managers involved in similar projects. The identified risks were documented in a structured risk register capturing the nature, source, affected project phase, and potential consequences of each risk.

Following identification, risks were systematically classified into major categories to facilitate structured analysis and effective management. The classification included technical and design risks, land acquisition and right-of-way risks, environmental and social risks, traffic and demand-related risks, construction and implementation risks, financial and cost risks, institutional and contractual risks, and climatic or

force majeure risks. This categorization ensured comprehensive coverage of risk sources specific to national highway projects in the Indian context.

Risk analysis was carried out using a combination of qualitative and semi-quantitative techniques. Each identified risk was evaluated based on its probability of occurrence and potential impact on key project objectives, including cost, schedule, technical performance, and environmental and social compliance. A five-point ordinal scale was adopted for both probability and impact, ranging from very low to very high. The Risk Severity Index (RSI) for each risk was calculated as the product of probability and impact scores, providing a comparative measure of risk criticality across the project.

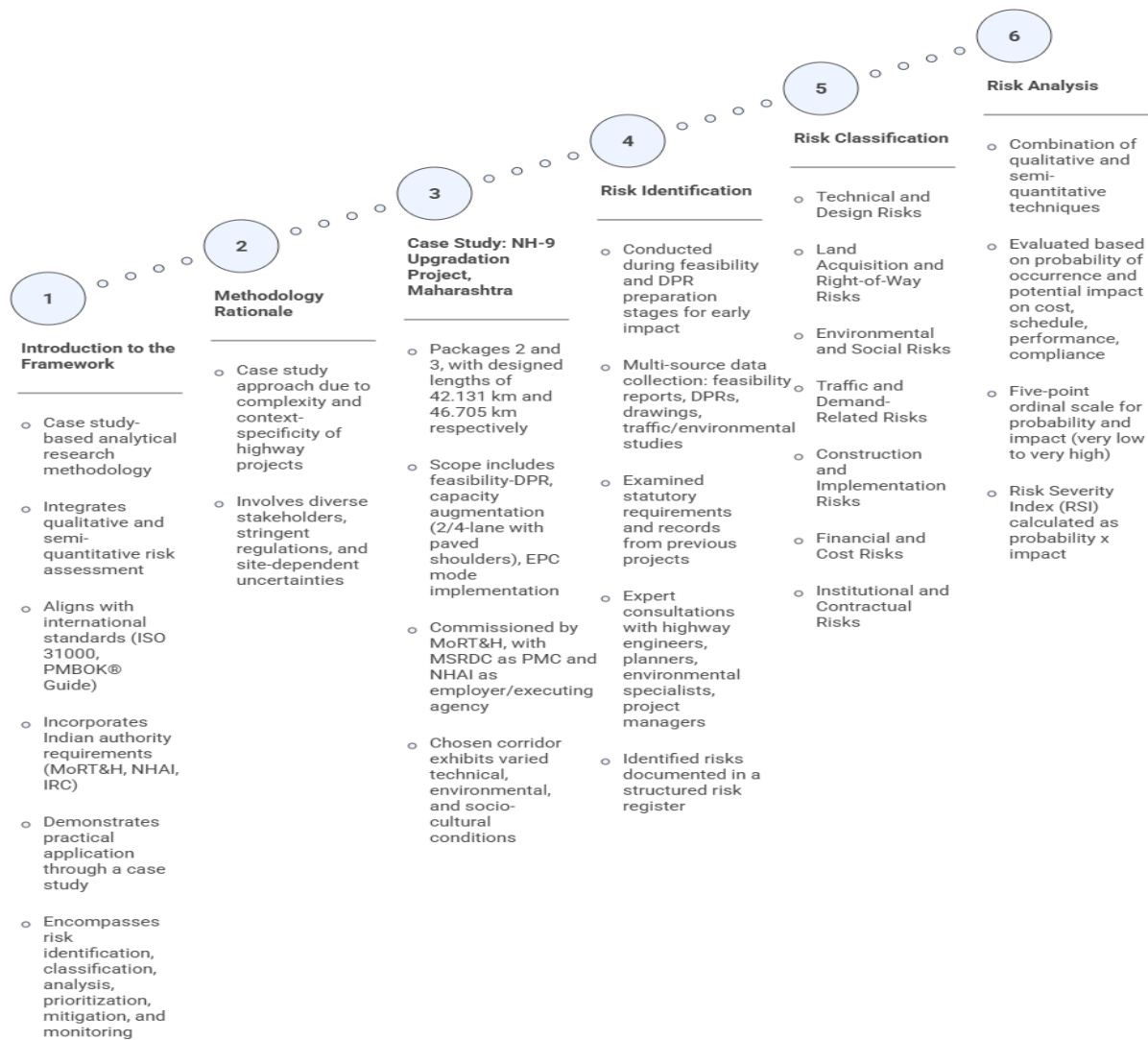


Fig1-Methodological framework adopted for the analysis Risk Management Framework for Infrastructure Projects

The evaluated risks were then prioritized using a probability–impact matrix, enabling classification into high-, medium-, and low-risk categories. High-priority risks, characterized by high RSI values, were identified as requiring immediate attention and proactive mitigation measures, while medium-priority risks were designated for continuous monitoring and contingency planning. Low-priority risks were considered acceptable with routine oversight. This prioritization process allowed focused allocation of management efforts toward risks with the greatest potential impact on project performance.

Risk mitigation strategies were developed for high- and medium-priority risks based on standard risk response options, including risk avoidance, risk reduction, risk transfer, and risk acceptance. Mitigation measures were formulated in accordance with MoRT&H and NHA1 guidelines to ensure practical applicability during EPC implementation. The proposed strategies addressed design optimization, alignment modifications, phased construction planning, contractual risk allocation, and stakeholder engagement measures.

Finally, risk monitoring and review were incorporated as a continuous process throughout the project life cycle. The risk register was designed to be periodically updated to reflect changes in risk status, effectiveness of mitigation actions, and emergence of new risks due to evolving project conditions. Although the methodology relies partly on expert judgment, the use of structured evaluation criteria and multiple data sources enhances the reliability and robustness of the analysis.

### III. RESULT AND DISCUSSION

#### III.1. Direct Cost Optimization – Time and Cost Optimization

Table 5.8 indicates the estimates taken for the proposed case study. The data are collected from Construction of Four Laning with Indapur to Tondle (from Km 84.550 (Design) to Km 131.200 (Design) Section of NH-965G. cost calculated by sixteen activities in optimized time and cost per activity.

Table No. 1 Cost Optimization

Sr No	Description	Cost (RS)	Required Time (Days)	Cost per Activity	Optimized Time (Days)	Average optimized days (Days)	Average Optimized cost per Activity
1	Site clearance and dismantling	12513463	45	278076.9556	13	29	8064231.711
2	Earthwork	815984620	25	32639384.8	10	17.5	571189234
3	Granular subbase and base course	1252717089	40	31317927.23	12	26	814266107.9
4	Bituminous pavement course	1086030640	90	12067007.11	35	62.5	754187944.4
5	Culverts	172878271	65	2659665.708	15	40	106386628.3
6	Bridge	761060325	55	13837460.45	12	33.5	463554925.2
7	Flyovers, Lvups and Vups	1835636590	35	52446759.71	24	29.5	1547179412
8	Drainage and Protective works	712766221	30	23758874.03	22	26	617730724.9
9	Traffic sign, marking and other appurtenances	219439043	30	7314634.767	15	22.5	164579282.3
10	Toll Plaza	157451723	30	5248390.767	20	25	131209769.2
11	Junctions	78566255	45	1745916.778	25	35	61107087.22
12	Truck lay byes	7824294	40	195607.35	25	32.5	6357238.875
13	Bus-Byes	7002827	45	155618.3778	20	32.5	5057597.278
14	Miscellaneous and lighting	62413577	45	1386968.378	20	32.5	45076472.28
15	Utility Shifting	286978390	55	5217788.909	25	40	208711556.4
16	Lumsum provision for Weir (spillway) at major bridge at108+075	150000000	30	5000000	20	25	125000000
	Total	7619263328	705		313	509	5629658211

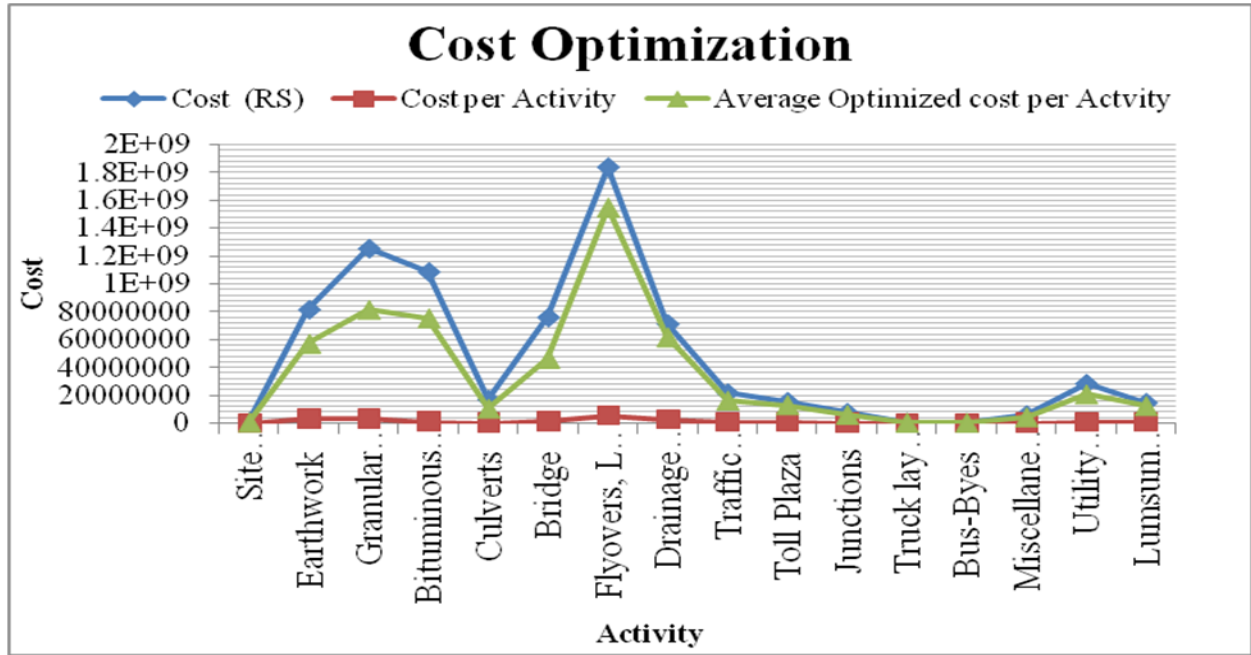


Fig. 1: Cost Optimization

Fig.5.6 shows cost optimization in Construction of Four Laning with Indapur to Tondle (from Km 84.550 (Design) to Km 131.200 (Design) Section of NH-965G of proposed research work. The figure shows activity versus cost values and the average cost per activity. The estimate is taken from the construction of national highway of India Station. The total cost work is 7619263328RS. The result is concluded maximum cost of per activity is Flyovers, Lvups and Vups is 52446759.71 RS and final optimized cost is 1547179412 RS

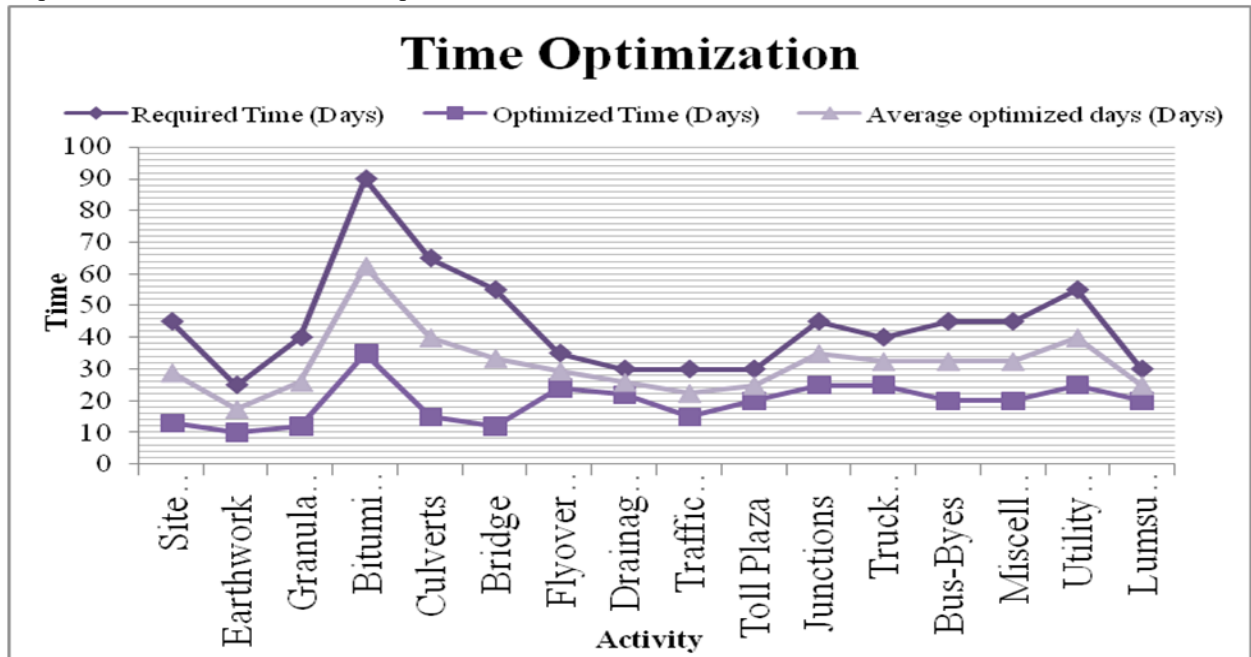


Fig. 2: Time Optimization

Fig. 5.7 shows in time optimization in Construction of Four Laning with Indapur to Tondle (from Km 84.550 (Design) to Km 131.200 (Design) Section of NH-965G of proposed research work. The figure shows activity versus cost values and the average cost per activity. The estimate is taken from the construction of national highway of India Station. The total time required is 705 days. The result is concluded optimized duration per activity is 313 days.

III.2. Percentage Difference Between Times  
 Table 5.9 gives the final time optimization Construction of Four Laning with Indapur to Tondle (from Km 84.550 (Design) to Km 131.200 (Design) Section of NH-965G. This table included construction activity, required time, optimized time and the percentage

difference between required and optimized time. The maximum percentage difference is 78.18 in bridge and the minimum for 26.67 is Drainage and Protective works activity. The total required time is 705 days and reduced to 313 days.

Table No. 2 Percentage difference between Times Construction

Sr No	Description	Required Time (Days)	Optimized Time (Days)	% Diff
1	Site clearance and dismantling	45	13	71.11
2	Earthwork	25	10	60.00
3	Granular subbase and base course	40	12	70.00
4	Bituminous pavement course	90	35	61.11
5	Culverts	65	15	76.92
6	Bridge	55	12	78.18
7	Flyovers, Lvups and Vups	35	24	31.43
8	Drainage and Protective works	30	22	26.67
9	Traffic sign, marking and other appurtenances	30	15	50.00
10	Toll Plaza	30	20	33.33
11	Junctions	45	25	44.44
12	Truck lay byes	40	25	37.50
13	Bus-Byes	45	20	55.56
14	Miscellaneous and lighting	45	20	55.56
15	Utility Shifting	55	25	54.55
16	Lumsum provision for Weir (spillway) at major bridge at108+075	30	20	33.33
	Total Time	705	313	

III.3. Final Cost Optimization  
 Table 5.10 concludes final cost optimization in (+-15 %) of cost per activity in Construction of Four Laning with Indapur to Tondle (from Km 84.550 (Design) to Km 131.200 (Design) Section of NH-965G. This table

included in average optimized time, the average cost per activity. Concluded average optimized days are 509 days and reduced in 433 to 585 days. The total average cost per activity is reduced from 4785209479.7Rs to 6474106943.1 Rs

Table No. 3 Final Cost Optimization

Description	Average Optimized Days	Average Cost Per Activity	Cost Per Activity	Reduced Days (-15%)	Average Cost Per Activity	Reduced Days (+15%)	Average Cost Per Activity
Site clearance and dismantling	29	8064231.711	278076.9556	24.65	6854597.0	33.35	9273866.468
Earthwork	17.5	571189234	32639384.8	14.875	485510848.9	20.125	656867619.1
Granular subbase and base course	26	814266107.9	31317927.23	22.1	692126191.7	29.9	936406024
Bituminous pavement course	62.5	754187944.4	12067007.11	53.125	641059752.8	71.875	867316136.1
Culverts	40	106386628.3	2659665.708	34	90428634.1	46	122344622.6
Bridge	33.5	463554925.2	13837460.45	28.475	394021686.4	38.525	533088164
Flyovers, Lvups and Vups	29.5	1547179412	52446759.71	25.075	1315102499.8	33.925	1779256323
Drainage and Protective works	26	617730724.9	23758874.03	22.1	525071116.1	29.9	710390333.6
Traffic sign, marking and other appurtenances	22.5	164579282.3	7314634.767	19.125	139892389.9	25.875	189266174.6
Toll Plaza	25	131209769.2	5248390.767	21.25	111528303.8	28.75	150891234.5
Junctions	35	61107087.22	1745916.778	29.75	51941024.1	40.25	70273150.31

Truck lay byes	32.5	6357238.875	195607.35	27.625	5403653.0	37.375	7310824.706
Bus-Byes	32.5	5057597.278	155618.3778	27.625	4298957.7	37.375	5816236.869
Miscellaneous and lighting	32.5	45076472.28	1386968.378	27.625	38315001.4	37.375	51837943.12
Utility Shifting	40	208711556.4	5217788.909	34	177404822.9	46	240018289.8
Lumsum provision for Weir (spillway) at major bridge at108+075	25	125000000	5000000	21.25	106250000.0	28.75	143750000
Total Time	509	5629658211		433	4785209479.7	585	6474106943.1

III.4. Indirect Cost Optimization

Table No. 4 Indirect cost

Description	Cost (RS)	Quantity	Indirect Cost	Indirect Cost Per Activity	Optimized Indirect Cost Per Day	Dependability Of Cost
Site clearance and dismantling	12513463	16129.78	403244.5	8960.98889	13904.9828	0.11
Earthwork	815984620	2091917.7	88906502.25	3556260.09	5080371.56	0.62
Granular subbase and base course	1252717089	704441.601	528331200.8	13208280	20320430.8	1.62
Bituminous pavement course	1086030640	3187229.58	6151353087	68348367.6	98421649.4	9.06
Culverts	172878271	20269.117	20269117	311832.569	506727.925	0.29
Bridge	761060325	59526.954	68455997.1	1244654.49	2043462.6	0.27
Flyovers, Lvups and Vups	1835636590	28096.135	19667294.5	561922.7	666687.949	0.04
Drainage and Protective works	712766221	65079.231	81349038.75	2711634.63	3128809.18	0.44
Traffic sign, marking and other appurenances	219439043	67194.805	0	0	0	0.00
Truck lay byes	7824294	939	328650	8216.25	10112.3077	0.13
Bus-Byes	7002827	1092	1092000	24266.6667	33600	0.48
Total	7619263328		6960156132	89984396	130225757	1.71

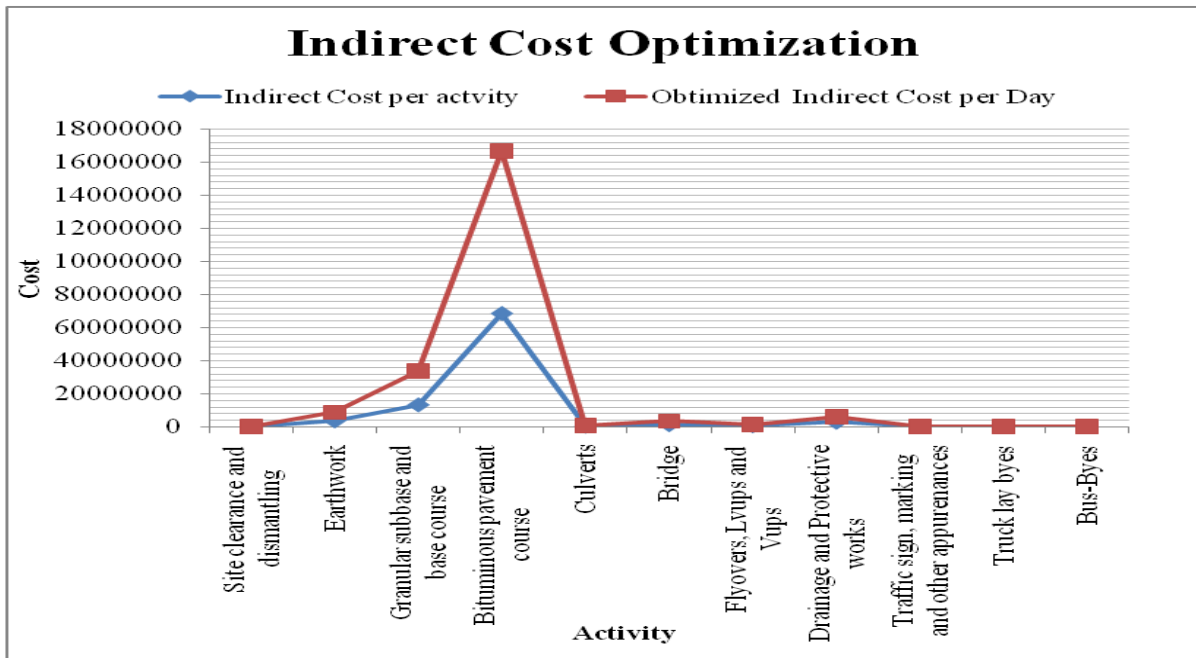


Fig. 3: Indirect Cost Optimization

III.5. Increase in Indirect Cost

Table No. 5 Increase in Indirect Cost

Sr No	Description	Direct Cost	Indirect Cost	% Diff
1	Site clearance and dismantling	12513463	403244.5	96.78
2	Earthwork	815984620	88906502.25	89.10
3	Granular subbase and base course	1252717089	528331200.8	57.83
4	Bituminous pavement course	1086030640	6151353087	82.34
5	Culverts	172878271	20269117	88.28
6	Bridge	761060325	68455997.1	91.01
7	Flyovers, Lvups and Vups	1835636590	19667294.5	98.93
8	Drainage and Protective works	712766221	81349038.75	88.59
12	Truck lay byes	7824294	328650	95.80
13	Bus-Byes	7002827	1092000	84.41
	Total Time	7619263328	6960156132	8.65

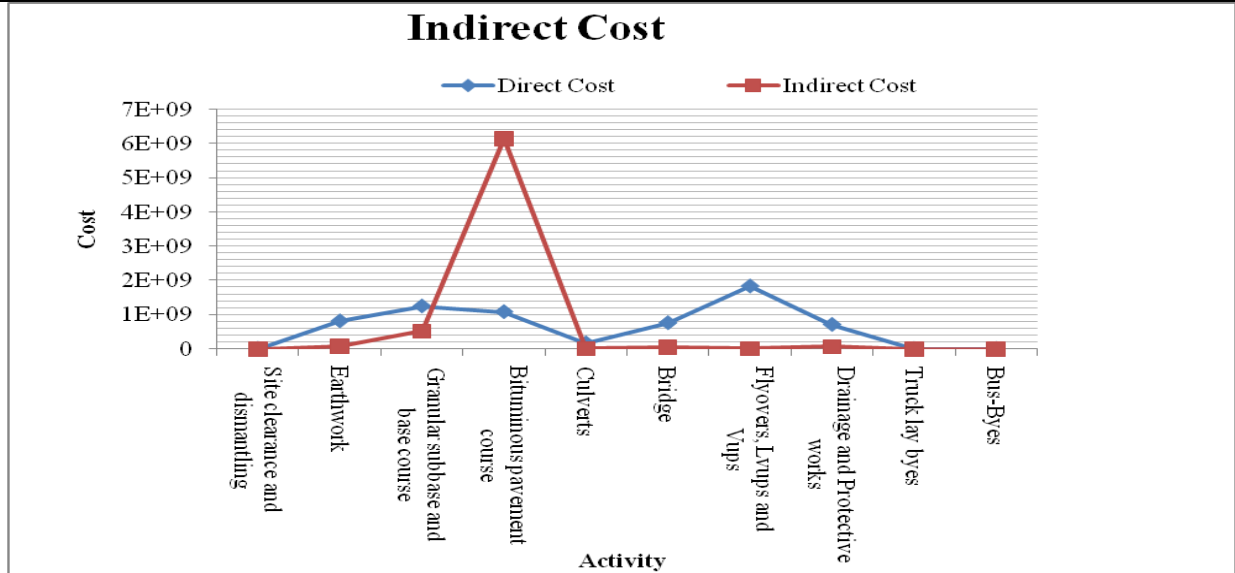


Fig. 4: Increase in Indirect Cost

Figure gives that major indirect coat of construction of four laning with Indapur to Tondle (from Km 84.550 (Design) to Km 131.200 (Design) Section of NH-965G. These figure include in increase in indirect cost with particular activity and calculate percentage difference between direct and indirect cost. Result concludes the

indirect cost increases by approximately 8.65% greater than direct cost.

III.6. Days Optimization In Construction Activity

Table gives the reduction day's reason four lane road project in detail. This table included the original estimate with required and optimized days in a particular activity.

Table No. 6 Days Reduction

Sr No	Description	Required Time (Days)	Average optimized days (Days)	General Remark
1	Site clearance and dismantling	45	29	Extra manpower & machinery using optimized days
2	Earthwork	25	17.5	Labour expensed decreased
3	Granular subbase and base course	40	26	Labour expensed decreased
4	Bituminous pavement course	90	62.5	Unavailability of machinery
5	Culverts	65	40	For curing purpose
6	Bridge	55	33.5	For curing purpose

7	Flyovers, Lvups and Vups	35	29.5	Extra manpower required
8	Drainage and Protective works	30	26	Extra manpower & machinery using optimized 1 days
9	Traffic sign, marking and other appurenances	30	22.5	Using labour charges optimizing days
10	Toll Plaza	30	25	Labour expensed decreased
11	Junctions	45	35	Extra manpower & machinery
12	Truck lay byes	40	32.5	For curing purpose
13	Bus-Byes	45	32.5	Using labour charges optimizing days
14	Miscellaneous and lighting	45	32.5	Extra manpower required
15	Utility Shifting	55	40	Extra manpower & machinery using optimized days
16	Lumsum provision for Weir (spillway) at major bridge at108+075	30	25	Extra manpower & machinery using optimized days
	Total	705	509	

III.7. Mitigation Measures Avoid Risk And Dispute In Construction

Table No. 7 Mitigation Measures

Risk	Possible Mitigation Strategies To Avoid Risk	Risk Factor And Recommendation	Final Recommendation
Risk in defective design	<ol style="list-style-type: none"> <li>Pre-Design &amp; Feasibility Stage                             <ol style="list-style-type: none"> <li>Comprehensive Site Investigation</li> <li>Accurate Traffic &amp; Load Assessment</li> <li>Stakeholder Consultation</li> </ol> </li> <li>Design Stage                             <ol style="list-style-type: none"> <li>Adopt International &amp; National Standards</li> <li>Use Advanced Design Software</li> <li>Perform Peer Review &amp; Independent Audits</li> <li>Incorporate Value Engineering</li> </ol> </li> <li>Construction Stage                             <ol style="list-style-type: none"> <li>Strict Design Compliance Monitoring</li> <li>Address Site-Specific Challenges Promptly</li> </ol> </li> </ol>	<ol style="list-style-type: none"> <li>Inadequate Site Investigations - Conduct geotechnical, hydrological, and environmental studies before design finalization.</li> <li>Non-Compliance with Standards - Follow established road design guidelines and conduct independent reviews</li> <li>Errors in Structural Calculations - Use verified design software and perform peer reviews.</li> <li>Lack of Coordination Between Design &amp; Construction Teams - Hold regular coordination meetings and use BIM tools.</li> </ol>	<ol style="list-style-type: none"> <li>Invest in experienced designers and consultants.</li> <li>Conduct multiple design reviews before approval.</li> <li>Use high-quality materials and standardized construction methods.</li> <li>Incorporate real-time monitoring and adjustments during construction.</li> <li>Ensure legal and environmental compliance from the start.</li> </ol>
Risk change in scope of work	<ol style="list-style-type: none"> <li>Clearly Define the Project Scope                             <ol style="list-style-type: none"> <li>Detailed Project Description</li> <li>Technical Specifications</li> <li>Set Clear Work Boundaries</li> </ol> </li> <li>Improve Planning &amp; Documentation                             <ol style="list-style-type: none"> <li>Work Breakdown Structure</li> <li>Align Scope with Contract &amp; Drawings</li> <li>Use Clear Contract Terms</li> </ol> </li> <li>Effective Stakeholder Communication                             <ol style="list-style-type: none"> <li>Early Involvement of Key Parties</li> <li>Client &amp; Contractor Agreement</li> <li>Regular Scope Review Meetings</li> </ol> </li> <li>Risk Management &amp; Change Control                             <ol style="list-style-type: none"> <li>Identify Potential Risks Early</li> <li>Develop a Change Management Plan</li> </ol> </li> </ol>	<ol style="list-style-type: none"> <li>Unclear Objectives - Ensure SoW is well-documented with defined deliverables.</li> <li>Scope Creep - Implement a strict change control process.</li> <li>Disputes &amp; Misalignment - Conduct stakeholder workshops and ensure signed approvals.</li> <li>Poorly Defined Tasks - Use a Work Breakdown Structure (WBS) for clarity.</li> <li>Legal &amp; Compliance Issues - Align SoW with local laws, permits, and environmental policies.</li> <li>Budget &amp; Timeline Overruns - Include buffer time and contingency costs in planning.</li> <li>Material &amp; Resource Risks - Ensure realistic material sourcing and labor availability estimates.</li> </ol>	<ol style="list-style-type: none"> <li>Start with a Feasibility Study &amp; Detailed Engineering Plan</li> <li>Define Clear Deliverables, Responsibilities &amp; Exclusions Regularly Review Scope with Stakeholders</li> <li>Use Risk Management Tools &amp; Change Control Procedures</li> <li>Monitor Project Progress &amp; Adjust Proactively</li> </ol>
Risk in funding problem for project	<ol style="list-style-type: none"> <li>Ensure Proper Financial Planning                             <ol style="list-style-type: none"> <li>Conduct a Feasibility Study</li> <li>Develop a Detailed Cost Estimate</li> <li>Include Contingency Funds</li> </ol> </li> <li>Secure Reliable Funding Sources                             <ol style="list-style-type: none"> <li>Government Budget Allocation</li> <li>Public-Private Partnerships (PPP)</li> <li>International Funding &amp; Grants</li> <li>Loans &amp; Bonds</li> <li>Alternative Revenue Generation</li> </ol> </li> <li>Strengthen Contract &amp; Payment</li> </ol>	<ol style="list-style-type: none"> <li>Budget Underestimation - Conduct detailed cost estimation and feasibility studies.</li> <li>Delayed Payments - Ensure structured disbursement schedules with milestone-based payments.</li> <li>Overreliance on One Source - Diversify funding through government, PPPs, and grants.</li> <li>Inflation &amp; Price Fluctuations - Include contingency funds and secure</li> </ol>	<ol style="list-style-type: none"> <li>Develop a Robust Financial Plan with Multiple Funding Sources</li> <li>Ensure Proper Budgeting with a Contingency Reserve</li> <li>Monitor Project Costs &amp; Prevent Unnecessary Scope Changes</li> <li>Use Performance-Based Payment Structures</li> <li>Explore Public-Private</li> </ol>

	<p>Management</p> <p>A. Use Performance-Based Contracts</p> <p>B. Ensure Timely Fund Disbursement</p> <p>C. Avoid Overreliance on Single Funding Source</p> <p>4. Manage Cost Overruns &amp; Cash Flow</p> <p>A. Use Cost Control Systems</p> <p>B. Prevent Design Changes</p> <p>C. Optimize Material Procurement</p>	<p>fixed-price contracts where possible.</p> <p>5) Corruption &amp; Mismanagement - Conduct financial audits and enforce strict fund tracking.</p> <p>6) Loan or Grant Delays - Maintain backup funding options and phased implementation plans.</p>	<p>Partnerships &amp; International Grants</p>
<p>Delay in obtaining permits</p>	<p>1. Early Planning &amp; Regulatory Compliance</p> <p>A. Identify Required Permits Early</p> <p>B. Engage Regulatory Authorities</p> <p>C. Conduct Pre-Application Meetings</p> <p>D. Understand Legal &amp; Environmental Regulations</p> <p>2. Efficient Permit Application Process</p> <p>A. Prepare Complete &amp; Accurate Documentation</p> <p>B. Hire Permit Specialists or Legal Consultants</p> <p>C. Submit Applications Early</p> <p>D. Track Permit Progress</p> <p>3. Stakeholder &amp; Government Engagement</p> <p>A. Coordinate with Local Authorities</p> <p>B. Address Community &amp; Environmental Concerns</p>	<p>1) Unclear Regulatory Requirements - Engage authorities early and seek legal guidance.</p> <p>2) Incomplete or Incorrect Documentation - Ensure all applications properly prepared before submission.</p> <p>3) Lengthy Bureaucratic Processes - Follow up regularly and establish good relationships with regulators.</p> <p>4) Community or Environmental Objections - Conduct public consultations and address concerns proactively.</p> <p>5) Last-Minute Applications - Start permit applications early in the project lifecycle.</p> <p>6) Dependency on Multiple Approvals - Request parallel processing of permits where possible.</p>	<p>1) Start the Permit Process Early &amp; Engage Regulators Proactively</p> <p>2) Ensure Compliance with Legal, Environmental &amp; Zoning Laws</p> <p>3) Use Experts to Prepare &amp; Review Permit Applications</p> <p>4) Monitor Approval Timelines &amp; Follow Up Regularly</p> <p>5) Plan for Delays by Allocating Contingency Time</p>
<p>Delay in availability of drawings</p>	<p>1. Effective Planning &amp; Early Design Completion</p> <p>A. Finalize Designs Before Construction Begins</p> <p>B. Set Clear Deadlines for Design Submission</p> <p>C. Prioritize Critical Drawings</p> <p>D. Conduct Thorough Design Reviews</p> <p>2. Improve Communication &amp; Coordination</p> <p>A. Engage Design Consultants Early</p> <p>B. Regular Design Meetings</p> <p>C. Use BIM &amp; CAD Management Systems</p> <p>3. Document Control &amp; Digital Access</p> <p>A. Centralized Document Management System</p> <p>B. Establish Version Control</p> <p>C. Ensure Accessibility</p> <p>4. Contingency Planning for Delays</p> <p>A. Pre-approve Preliminary Drawings</p> <p>B. Allocate Buffer Time for Design Approval</p> <p>C. Develop Alternative Work Plans.</p>	<p>1) Incomplete or Late Design - Finalize designs before project execution begins.</p> <p>2) Poor Coordination Between Teams - Conduct regular design review meetings.</p> <p>3) Multiple Revisions &amp; Changes - Ensure thorough reviews to minimize changes.</p> <p>4) Slow Document Approval Process - Set clear approval timelines with consultants and clients.</p> <p>5) Limited Access to Drawings - Use a digital document control system for instant retrieval.</p> <p>6) Dependency on External Consultants - Monitor progress and enforce deadlines for design submissions.</p>	<p>1) Complete Design Phase Before Construction Starts</p> <p>2) Use Digital Systems for Drawing Management &amp; Access</p> <p>3) Maintain Strict Deadlines for Design Consultants</p> <p>4) Coordinate Between Designers, Engineers &amp; Contractors</p> <p>5) Plan for Delays by Allocating Extra Time for Reviews &amp; Approvals</p>
<p>Risk in change in codes and regulations</p>	<p>1. Stay Updated with Regulatory Changes</p> <p>A. Monitor Government &amp; Regulatory Updates</p> <p>B. Engage Legal &amp; Regulatory Experts</p> <p>C. Attend Industry Workshops &amp; Training</p> <p>2. Early Compliance &amp; Approval Process</p> <p>A. Obtain Permits &amp; Approvals Early</p> <p>B. Conduct Regulatory Risk Assessments</p> <p>C. Align Designs with Future-Proof Standards</p> <p>3. Contract &amp; Project Flexibility</p> <p>A. Include Regulatory Change Clauses in Contracts</p> <p>B. Plan for Contingency Funds</p> <p>C. Maintain Flexible Project Schedules</p> <p>4. Strong Stakeholder Coordination</p> <p>A. Engage Government &amp; Regulatory Bodies</p> <p>B. Collaborate with Industry Associations</p>	<p>1) Unexpected Regulatory Changes - Monitor legal updates and maintain industry engagement.</p> <p>2) Delayed Permits &amp; Approvals - Apply for permits early and conduct regulatory risk assessments.</p> <p>3) High Compliance Costs - Allocate contingency funds and include change clauses in contracts.</p> <p>4) Lack of Awareness Among Teams - Conduct regular training on legal and safety updates.</p> <p>5) Design &amp; Construction Conflicts - Ensure designs comply with both current and future-proof regulations.</p> <p>6) Government Policy Shifts - Maintain strong government and stakeholder relationships.</p>	<p>1) Regularly Monitor Legal &amp; Code Updates</p> <p>2) Secure Permits &amp; Approvals as Early as Possible</p> <p>3) Use Contract Provisions to Manage Regulatory Changes</p> <p>4) Allocate Extra Time &amp; Budget for Compliance Adjustments</p> <p>5) Engage Legal Experts &amp; Train Project Teams on Regulations</p>
<p>Payments delay</p>	<p>1. Strong Financial Planning &amp; Budgeting</p> <p>A. Secure Funding Before Project Starts</p> <p>B. Include Payment Schedules in Contracts</p> <p>2. Clear &amp; Well-Defined Contractual</p>	<p>1) Insufficient Project Funding - Ensure funding is secured before project initiation.</p> <p>2) Unclear Payment Terms in Contracts</p>	<p>1) Secure Project Funding Before Execution</p> <p>2) Clearly Define Payment Terms in Contracts</p>

	<p>Agreements                      A. Include Payment Terms &amp; Timelines in Contracts                      B. Use Performance-Based Payment Systems                      3. Efficient Payment Processing &amp; Monitoring                      A. Use Digital Payment &amp; Invoice Tracking Systems                      B. Follow Up on Pending Payments                      C. Conduct Regular Financial Audits</p>	<p>- Define detailed payment schedules and milestone-based payments.                      3) Delayed Invoice Processing - Use digital payment systems and submit complete documentation.                      4) Government or Client Delays - Maintain strong communication and follow up proactively.                      5) Cash Flow Shortages - Keep contingency funds and establish credit facilities.                      6) Disputes Over Work Quality - Conduct regular inspections and ensure work meets agreed standards.</p>	<p>3) Use Digital Systems for Payment Tracking &amp; Invoice Management                      4) Maintain Cash Flow Reserves &amp; Alternative Financing Options                      5) Engage with Clients &amp; Government Authorities to Ensure Timely Payments</p>
<p>Improper scope of work definition in contract</p>	<p>1. Clearly Define Project Scope in the Contract                      A. Develop a Detailed Scope of Work (SOW)                      B. Specify Technical Requirements                      C. Define Quality Standards &amp; Performance Criteria                      D. Outline Project Deliverables &amp; Timelines                      2. Conduct Thorough Planning &amp; Design Reviews                      A. Engage Engineers, Designers &amp; Contractors Early                      B. Review Drawings, Surveys &amp; Site Conditions                      C. Perform Risk Assessments                      3. Effective Stakeholder Communication &amp; Coordination                      A. Hold Pre-Contract Meetings                      B. Ensure Scope Clarity Among All Parties                      C. Include Dispute Resolution Mechanisms</p>	<p>1) Unclear or Incomplete Scope - Provide a detailed breakdown of work, specifications, and deliverables.                      2) Misalignment Between Stakeholders - Engage engineers, contractors, and legal teams in scope definition.                      3) Frequent Scope Changes - Establish a structured change order process and approval mechanism.                      4) Lack of Compliance with Standards - Use industry-standard contracts like FIDIC or NEC and align with legal requirements.                      5) Poor Documentation &amp; Tracking - Implement digital contract management and real-time project tracking tools.</p>	<p>1) Develop a Clear &amp; Detailed Scope of Work Document                      2) Engage All Stakeholders in Scope Planning &amp; Review                      3) Define Clear Milestones, Quality Standards &amp; Deliverables                      4) Establish a Formal Change Management Process                      5) Use Contract Management Software for Scope Tracking</p>
<p>Accidents/safety during construction</p>	<p>1. Implement a Strong Safety Management System                      A. Develop a Site-Specific Safety Plan (SSSP)                      B. Follow Occupational Health &amp; Safety Regulations                      C. Ensure Proper Site Supervision                      D. Conduct Regular Safety Inspections &amp; Audits                      2. Provide Comprehensive Safety Training                      A. Conduct Safety Inductions for Workers                      B. Offer Specialized Training                      C. Promote Safety Culture                      3. Ensure Proper Use of Personal Protective Equipment (PPE)                      A. Mandate PPE for All Workers                      B. Ensure Proper Fit &amp; Quality                      C. Regularly Inspect &amp; Replace Damaged PPE                      4. Secure the Construction Site &amp; Traffic Management                      A. Use Safety Barriers &amp; Signage                      B. Implement Traffic Control Measures                      C. Ensure Safe Equipment Operation                      5. Emergency Preparedness &amp; First Aid Measures                      A. Establish Emergency Response Plans                      B. Provide First Aid Stations &amp; Medical Kits                      C. Have a Trained First Aid Team On-Site</p>	<p>1) Lack of Safety Planning - Develop and enforce a site-specific safety plan.                      2) Untrained Workforce - Provide regular safety training for all workers.                      3) Poor Traffic Control - Use barriers, warning signs, and trained flaggers.                      4) Inadequate PPE Compliance - Mandate PPE use and conduct regular inspections.                      5) Unsafe Equipment &amp; Machinery Use - Train operators and perform regular maintenance checks.                      6) Emergency Response Deficiencies - Establish emergency plans and first aid stations.</p>	<p>1) Develop &amp; Enforce a Comprehensive Safety Plan                      Provide                      2) Continuous Training &amp; Awareness Programs                      3) Ensure Proper Use of PPE &amp; Equipment Safety                      4) Implement Effective Traffic &amp; Site Management Measures                      5) Establish Emergency Response &amp; First Aid Systems</p>
<p>Risk of bad quality material/equipment</p>	<p>1. Establish a Strong Quality Control System                      A. Develop Material &amp; Equipment Quality Standards                      B. Conduct Pre-Approval Testing                      C. Enforce Strict On-Site Quality Inspections                      D. Monitor Workmanship Standards                      2. Implement a Rigorous Supplier &amp; Procurement Process</p>	<p>1) Low-Quality Materials - Pre-qualify suppliers, enforce strict testing, and conduct third-party audits.                      2) Substandard Equipment - Verify equipment certifications and inspect before deployment.                      3) Lack of Testing &amp; Inspections - Implement laboratory testing and on-site</p>	<p>1) Implement a Strict Quality Control &amp; Testing Program                      2) Source Materials &amp; Equipment from Certified &amp; Reputable Suppliers                      3) Perform Regular Inspections &amp; Third-Party Quality Audits                      4) Use Digital Tracking Systems</p>

	<p>A. Pre-Qualify Suppliers &amp; Manufacturers                  B. Use Certified &amp; Approved Vendors Only                  C. Specify Material Testing &amp; Compliance in Contracts                  D. Ensure Equipment Meets Industry Standards                  3. Conduct Regular Testing &amp; Inspections                  A. Perform Laboratory Tests on Materials                  B. Use Third-Party Quality Audits                  C. Inspect Equipment Before Deployment                  D. Monitor Supplier Performance                  4. Implement a Material Traceability &amp; Documentation System                  A. Maintain Records of All Material Deliveries                  B. Use Digital Procurement &amp; Quality Tracking Software                  C. Establish a Material Rejection Policy</p>	<p>inspections.                  4) Supplier Reliability Issues - Work with certified and experienced vendors only.                  5) Poor Documentation - Maintain complete records of material sources, test reports, and equipment maintenance logs.                  6) Use of Outdated Equipment - Ensure regular maintenance and replacement of worn-out machinery.</p>	<p>for Procurement &amp; Material Compliance                  5) Enforce Strong Contract Terms for Material &amp; Equipment Quality</p>
<p>Risk of insufficient technology</p>	<p>1. Invest in Modern Construction Technology &amp; Equipment                  A. Use Advanced Road Construction Machinery                  B. Adopt Smart Construction Materials                  2. Implement Advanced Software &amp; Digital Tools                  A. Use BIM (Building Information Modeling)                  B. Implement GIS (Geographic Information Systems)                  C. Adopt Project Management Software                  3. Provide Continuous Training &amp; Skill Development                  A. Train Engineers &amp; Workers on New Technologies                  B. Encourage Skill Development Programs</p>	<p>1) Outdated Equipment &amp; Machinery - Invest in advanced construction tools like GPS-controlled equipment and automated pavers.                  2) Lack of Digital Project Management - Implement BIM, GIS, and automated scheduling software.                  3) Untrained Workforce on New Technology - Conduct regular training programs and certification courses.                  4) Inefficient Construction Techniques - Use AI, IoT, and drone-based monitoring for precision and efficiency.                  5) Limited Access to Innovation - Collaborate with technology providers, universities, and research institutions.                  6) High Initial Cost of Technology Adoption - Secure government incentives and partnerships with private sector investors.</p>	<p>1) Invest in Advanced Machinery &amp; Smart Construction Materials                  2) Implement Digital Solutions Like BIM, GIS, and IoT-Based Monitoring                  3) Train Workers &amp; Engineers on Modern Technologies                  4) Collaborate with Technology Providers &amp; Research Institutions                  5) Leverage Government &amp; Private Sector Support for Innovation</p>
<p>Poor performance of subcontractor</p>	<p>1. Implement a Strong Prequalification &amp; Selection Process                  A. Conduct Thorough Prequalification Checks                  B. Verify Certifications &amp; Compliance                  2. Establish Clear Contract Terms &amp; Performance Expectations                  A. Define Scope of Work Clearly                  B. Set Penalties for Non-Performance                  C. Incorporate Quality &amp; Safety Requirements                  3. Monitor Subcontractor Performance Effectively                  A. Conduct Regular Inspections &amp; Audits                  B. Use Performance-Based Payment Systems                  C. Utilize Digital Tracking Tools                  D. Hold Weekly Coordination Meetings                  4. Provide Training &amp; Support for Subcontractors                  A. Offer Technical &amp; Safety Training                  B. Encourage Continuous Improvement</p>	<p>1) Unqualified or Inexperienced Subcontractors - Conduct thorough prequalification and reference checks.                  2) Lack of Contract Clarity - Define scope, deliverables, penalties, and performance expectations clearly.                  3) Failure to Meet Quality Standards - Perform regular inspections, audits, and third-party quality checks.                  4) Delays Due to Poor Management - Use project tracking tools and enforce milestone-based payments.                  5) Safety Violations - Ensure strict adherence to safety training and regulations.                  6) Lack of Communication &amp; Coordination - Hold regular progress meetings and assign a subcontractor liaison.</p>	<p>1) Prequalify &amp; Select Subcontractors Based on Experience &amp; Credentials                  2) Establish Clear Contract Terms, Deliverables &amp; Penalties for Poor Performance                  3) Monitor &amp; Evaluate Subcontractor Work Using Digital Tools &amp; Regular Inspections                  4) Provide Ongoing Training &amp; Support for Performance Improvement                  5) Foster Long-Term Relationships with High-Performing Subcontractors</p>
<p>Poor productivity of plant and equipment</p>	<p>1. Select the Right Equipment for the Job                  A. Match Equipment to Project Needs                  B. Use Advanced &amp; Modern Equipment                  2. Implement a Preventive Maintenance Program                  A. Schedule Regular Maintenance &amp; Inspections                  B. Use Condition Monitoring &amp; Predictive Maintenance                  C. Keep Maintenance Records                  D. Have a Spare Parts Inventory</p>	<p>1) Using Inappropriate Equipment - Select machines based on project needs and capacity.                  2) Frequent Equipment Breakdowns - Implement preventive maintenance and predictive analytics.                  3) Untrained Operators - Conduct regular training and certification programs.                  4) High Fuel Consumption &amp; Inefficiency - Monitor fuel usage and enforce best operational practices.</p>	<p>1) Choose the Right Equipment for Each Task                  2) Implement Preventive &amp; Predictive Maintenance Programs                  3) Train Operators for Efficient &amp; Safe Equipment Handling                  4) Use Telematics &amp; Digital Monitoring for Performance Tracking                  5) Optimize Equipment Scheduling &amp; Reduce Idle Time</p>

	<p>3. Train Operators &amp; Improve Equipment Handling                  A. Provide Operator Training &amp; Certification                  B. Enforce Proper Equipment Usage                  C. Rotate Operators to Prevent Fatigue                  4. Monitor Equipment Performance &amp; Productivity                  A. Use Fleet Management &amp; Telematics Systems                  B. Analyze Data for Continuous Improvement                  5. Optimize Worksite Logistics &amp; Equipment Scheduling                  A. Reduce Idle Time                  B. Ensure Proper Equipment Allocation                  C. Improve Site Layout &amp; Material Flow</p>	<p>5) Long Idle Times &amp; Downtime - Use telematics to track utilization and improve scheduling.                  6) Poor Equipment Scheduling - Plan worksite logistics and allocate machinery efficiently.</p>	
Lack of qualified staff	<p>1. Implement a Strong Recruitment &amp; Hiring Process                  A. Hire Skilled &amp; Certified Professionals                  B. Conduct Rigorous Prequalification Checks                  C. Use Industry Networks &amp; Partnerships                  D. Offer Competitive Salaries &amp; Benefits                  2. Provide Continuous Training &amp; Skill Development                  A. Conduct Regular On-Site Training                  B. Offer Certification &amp; Licensing Programs                  C. Train Supervisors &amp; Managers in Leadership Skills                  D. Use Digital Learning Platforms                  3. Improve Workforce Retention &amp; Motivation                  A. Create a Positive Work Environment.                  B. Provide Career Growth Opportunities                  C. Recognize &amp; Reward High Performers                  D. Ensure Safe &amp; Comfortable Working Conditions                  4. Partner with Training Institutions &amp; Government Programs                  A. Develop Apprenticeship &amp; Internship Programs                  B. Collaborate with Technical &amp; Vocational Schools                  C. Leverage Government &amp; Industry Support                  5. Use Technology to</p>	<p>1) Difficulty in Finding Skilled Workers - Strengthen recruitment partnerships and offer attractive employment packages.                  2) Lack of Training &amp; Certifications - Provide on-the-job training and certification programs.                  3) High Turnover Rates - Improve work conditions, career growth opportunities, and employee recognition programs.                  4) Poor Workforce Planning - Use digital workforce management tools and efficient scheduling.                  5) Limited Access to New Talent - Develop apprenticeship programs with universities and vocational schools.</p>	<p>1) Strengthen Recruitment &amp; Offer Competitive Salaries                  2) Invest in Continuous Training &amp; Certification Programs                  3) Enhance Retention Strategies with Career Growth &amp; Incentives                  4) Partner with Educational &amp; Vocational Institutions for Skilled Labor                  5) Use Workforce Management Software to Optimize Staffing</p>
Shortage of plant and equipment	<p>1. Conduct Detailed Equipment Planning &amp; Forecasting                  A. Perform Early Equipment Requirement Assessment                  B. Develop an Equipment Procurement &amp; Allocation Plan                  2. Secure Reliable Equipment Suppliers &amp; Rental Options                  A. Partner with Trusted Equipment Suppliers &amp; Rental Companies                  B. Use Leasing &amp; Rental Services for Non-Core Equipment                  3. Implement an Effective Equipment Maintenance &amp; Management System                  A. Schedule Preventive Maintenance                  B. Utilize Fleet &amp; Asset Management Software                  C. Ensure Quick Repairs &amp; Spare Parts Availability                  4. Optimize Equipment Utilization &amp; Allocation                  A. Monitor Equipment Productivity &amp; Usage Rates                  B. Implement Shared Equipment Pools                  5. Consider Financial &amp; Budgeting Strategies for Equipment Procurement</p>	<p>1) Poor Equipment Planning - Conduct early assessments and integrate planning into project schedules.                  2) Limited Equipment Availability - Establish partnerships with suppliers and have backup rental options.                  3) Frequent Equipment Breakdowns - Implement preventive maintenance and keep spare parts readily available.                  4) High Equipment Costs - Utilize leasing and rental services for non-essential machinery.                  5) Inefficient Equipment Utilization - Optimize scheduling, monitor usage, and use fleet management software.</p>	<p>1) Conduct Thorough Equipment Planning Before Project Start                  2) Partner with Reliable Suppliers &amp; Establish Rental Agreements                  3) Implement Preventive Maintenance &amp; Keep Spare Parts Available                  4) Use Digital Tools to Monitor Equipment Usage &amp; Allocation                  5) Optimize Equipment Sharing &amp; Scheduling to Maximize Productivity</p>

	<p>A. Allocate Sufficient Budget for Machinery Acquisition                  B. Seek Government &amp; Private Sector Support</p>		
Poor competence and productivity of labor	<p>1. Improve Recruitment and Selection Processes                  A. Hire Skilled &amp; Certified Workers                  B. Conduct Skill Assessments &amp; Background Checks                  C. Collaborate with Training Institutes &amp; Vocational Schools.                  2. Implement Comprehensive Training Programs                  A. Provide On-Site Technical Training                  B. Ensure Safety &amp; Compliance Training                  C. Develop Mentorship Programs                  D. Offer Digital Learning Tools                  3. Enhance Labor Productivity Through Efficient Management                  A. Use Workforce Scheduling &amp; Monitoring Tools.                  B. Set Clear Work Targets &amp; Performance Standards                  C. Reduce Idle Time &amp; Optimize Workflows                  4. Improve Worksite Conditions &amp; Labor Welfare                  A. Ensure Comfortable &amp; Safe Working Environments                  B. Offer Competitive Salaries &amp; Benefits                  C. Encourage Teamwork &amp; Motivation                  5. Optimize Technology &amp; Automation for Better Productivity                  A. Use Mechanization to Reduce Manual Labor Needs                  B. Leverage Digital Performance Monitoring Tools                  C. Implement AI &amp; Robotics in Repetitive Task</p>	<p>1) Unskilled Workforce - Conduct regular training and mentorship programs.                  2) Lack of Motivation &amp; Engagement - Provide performance incentives, recognition, and career growth opportunities.                  3) Poor Labor Management &amp; Scheduling - Use digital workforce management tools to optimize productivity.                  4) Safety Violations &amp; Workplace Hazards- Enforce strict compliance with safety standards and regulations.                  5) High Turnover Rates - Offer competitive salaries, benefits, and a positive work environment.</p>	<p>1) Strengthen Hiring &amp; Recruitment for Skilled Labor                  2) Invest in Training &amp; Certification Programs                  3) Enhance Workforce Motivation &amp; Retention Strategies                  4) Implement Digital Tools for Scheduling &amp; Productivity Monitoring                  5) Use Mechanization &amp; Automation to Reduce Manual Errors</p>
Third party delays	<p>1. Invest in Modern Construction Technology &amp; Equipment                  A. Use Advanced Road Construction Machinery                  B. Adopt Smart Construction Materials                  C. Implement Digital Twin Technology                  2. Implement Advanced Software &amp; Digital Tools                  A. Use BIM (Building Information Modeling)                  B. Implement GIS (Geographic Information Systems)                  C. Adopt Automated Project Management Software                  3. Provide Continuous Training &amp; Skill Development                  A. Train Engineers &amp; Workers on New Technologies                  B. Encourage Skill Development Programs                  4. Collaborate with Technology Providers &amp; Research Institutions                  A. Partner with Equipment Manufacturers                  B. Leverage Government &amp; Industry Support                  C. Engage in R&amp;D for Sustainable Road Technologies</p>	<p>1) Delays from Government Permits &amp; Approvals - Initiate applications early and assign a dedicated approvals team.                  2) Unreliable Suppliers &amp; Subcontractors -Prequalify vendors, use backup suppliers, and set performance-based contracts.                  3) Material Shortages &amp; Late Deliveries - Maintain contingency stock and track supply chain logistics digitally.                  4) Slow Response from Utility Providers - Engage early with utility companies and set up clear service agreements.                  5) Lack of Coordination Among Stakeholders - Establish regular meetings, digital tracking, and escalation mechanisms.</p>	<p>1) Engage with Key Third Parties Early &amp; Maintain Strong Communication                  2) Use Performance-Based Contracts &amp; Delay Penalty Clauses                  3) Optimize Supply Chain &amp; Logistics with Digital Tracking                  4) Ensure Timely Permit Approvals Through Early Regulatory Engagement                  5) Implement a Robust Project Monitoring &amp; Risk Management System</p>
Risk of defective material from supplier	<p>1. Implement a Robust Supplier Prequalification Process                  A. Request Certifications &amp; Compliance Documents                  B. Conduct Factory &amp; Supplier Audits                  C. Check Past Performance &amp; Reviews                  2. Strengthen Material Testing &amp; Quality Control Procedures</p>	<p>1) Unreliable Suppliers - Prequalify vendors, conduct audits, and request compliance certifications.                  2) Defective or Substandard Materials-Implement strict material testing before and after delivery.                  3) Lack of Supplier Accountability - Include warranty and defect liability</p>	<p>1) Prequalify &amp; Audit Suppliers Before Procurement                  2) Enforce Strict Material Testing &amp; Compliance Verification                  3) Include Warranty &amp; Replacement Clauses in Supplier Contracts                  4) Optimize Storage &amp;</p>

<p>A. Conduct Pre-Delivery Material Testing                  B. Perform On-Site Testing Before Use                  C. Use Third-Party Testing Agencies                  D. Implement Batch Sampling &amp; Random Inspections                  3. Optimize Procurement &amp; Contractual Safeguards                  A. Specify Material Standards in Contracts                  B. Include Defect Liability &amp; Warranty Clauses                  4. Improve Logistics &amp; Storage to Maintain Material Integrity                  A. Ensure Proper Transportation Conditions                  B. Store Materials in Controlled Environments.                  5. Utilize Digital Tools for Supply Chain &amp; Quality Management                  A. Use Procurement Management Software                  B. Deploy RFID &amp; Barcode Tracking                  C. Automate Quality Control Reporting.</p>	<p>clauses in contracts.                  4) Material Damage During Transportation - Use proper handling, packaging, and storage practices.                  5) Poor Supply Chain Visibility - Implement digital tracking systems for real-time monitoring.</p>	<p>Transportation to Prevent Material Degradation                  5) Leverage Digital Tools for Quality Control &amp; Supplier Management</p>
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IV. CONCLUSION

- Overall Project Performance Improvement - The study demonstrates that systematic time-cost optimization combined with structured risk management significantly improves the performance of large-scale highway infrastructure projects executed under EPC mode. The case study of the Indapur-Tondle section of NH-965G confirms the effectiveness of the proposed framework in achieving measurable reductions in project duration and cost.
- Time Optimization Outcomes - The original estimated construction duration of 705 days was reduced to 313 days at the optimized activity level and to 509 days on an average optimized basis. Significant reductions were achieved in activities such as bridge construction, culverts, earthwork, and pavement works through optimized resource deployment, parallel execution, and improved planning.
- Direct Cost Optimization Results - Direct construction costs were reduced from ₹7,619.26 crore to approximately ₹5,629.66 crore after optimization. Structural components such as flyovers, LVUPs, and VUPs were identified as the most cost-intensive activities, highlighting the need for focused cost control and efficient execution strategies for major structures.
- Sensitivity Analysis of Cost Variation - The final cost optimization analysis within a ±15% variation in activity duration demonstrated that adherence to optimized schedules leads to substantial cost

savings, while deviations result in significant cost escalation. This confirms the strong interdependence between time and cost in highway construction projects.

- Indirect Cost Implications - Although direct costs were reduced, indirect costs increased by approximately 8.65% due to extended overheads, supervision, equipment standby, and administrative expenses. This finding emphasizes the importance of controlling indirect costs through efficient project governance, reduction of idle resources, and streamlined decision-making.
- Key Factors Contributing to Time Reduction - Time reductions were primarily achieved through increased manpower and machinery deployment, improved labor productivity, optimized scheduling, and better coordination among project stakeholders. However, constraints such as machinery unavailability in bituminous works indicate the need for improved equipment planning.
- Risk Identification and Mitigation Effectiveness - The study identified critical risks related to defective design, scope changes, funding constraints, permit delays, material quality, safety, subcontractor performance, labor productivity, and third-party dependencies. A comprehensive set of mitigation measures was proposed to address these risks at planning, design, and construction stages.
- Dispute Avoidance and Project Stability - The implementation of proactive risk mitigation strategies, clear scope definition, robust contract management, and performance-based payment

mechanisms significantly reduces the likelihood of disputes, claims, and project delays.

- Adoption of Technology and Digital Tools - The findings highlight the importance of adopting modern construction technologies, BIM, GIS, digital project management systems, and real-time monitoring tools to enhance productivity, improve coordination, and support informed decision-making.
- Practical Applicability of the Framework - The proposed time–cost–risk optimization framework is practical, scalable, and replicable for similar national highway projects in India, particularly those implemented under EPC contracts and governed by MoRT&H and NHA standards.
- Contribution to Infrastructure Project Management Practice - This research contributes to improved project planning and execution practices by integrating quantitative optimization with qualitative risk management, offering valuable insights for project owners, consultants, and contractors.
- Scope for Future Research - Future studies may incorporate advanced quantitative risk analysis techniques such as Monte Carlo simulation, life-cycle cost analysis, and multi-objective optimization models to further enhance decision-making in highway infrastructure projects.

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