

An Analytical Study On Construction Equipment Utilization And Its Influence On Highway Project Performance

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Abstract

A key factor in determining the success of major highway infrastructure projects is the effective use of construction equipment. Using Package-I (Km 0+000 to 38+775) of the NH-561A rehabilitation and upgrade project in Maharashtra as a case study, this study investigated the function of equipment deployment and its effect on project performance. Key performance indicators such as equipment usage patterns, idle time, breakdown frequency, cost variations, and schedule adherence were examined by the research using a combination of primary data (surveys, interviews, and site observations) and secondary data (project progress reports, equipment logs). The results showed that inefficient equipment, especially in bitumen pavers and dumpers, caused to delays and higher operating expenses. On the other hand, machinery such as excavators and batching plants that were properly maintained and used increased total production. The study found that, in order to improve project outcomes in highway building under the Hybrid Annuity Model (HAM), strategic planning, routine maintenance, operator training, and real-time monitoring of construction machinery are crucial.

Keywords: Construction Equipment Utilization, Highway Project Performance, NH-561A, Infrastructure Management, Hybrid Annuity Model, Equipment Efficiency, Project Cost and Time Overruns, Road Construction, Preventive Maintenance.

1. INTRODUCTION

The engineer must be well-versed in the equipment available to them and know how to use it for a particular purpose in order to complete any job. The project's overall development will depend on how quickly the task is finished. Therefore, it is necessary to consider all aspects of the site's operational conditions when selecting the equipment. Therefore, proper planning and administration are necessary to ensure that the equipment is used effectively, economically, and productively.

The equipment can be selected based on the type they need. When selecting the excavation tools, the state of the site, the duration of the equipment's use, and the overall cost must all be taken into account. Prioritizing the main task that requires the machine—such as block excavation, piling, etc.—is crucial when choosing excavation equipment. To avoid mistakes and problems on the job site, prior experience with machine selection is essential. The quality of the work is controlled by the devices used.



Fig 1.1 Tips for equipment management

1.1. Tips for equipment management

Since it reduces administrative costs, reduces devices, enhances quality, boosts productivity, and supplies the right equipment, it is a crucial method for achieving business goals and objectives. Construction equipment requires a variety of maintenance procedures, including predictive maintenance, preventive maintenance, and repair for poor working conditions. Maintaining high performance and routine maintenance of engineering knowledge, facilities, and equipment is the real goal of predictive or preventive maintenance in order to ensure and reduce their rates. The primary goal of the devices' operation is to make sure they meet regulatory requirements. This enables 'only timely' devices to be made available by enabling the devices to function with more sophisticated and pure prediction models.

Proper Planning

For highway building projects to be completed successfully, careful planning is necessary. Determining project requirements, choosing the degree of automation, and coordinating equipment utilization with project objectives are the first steps in effective equipment management. By foreseeing problems and efficiently allocating resources, careful planning reduces expenses and enhances project performance.

Equipment Selection

For a project to be completed on schedule and under budget, selecting the appropriate construction equipment is essential. The newest technologies, local maintenance skills, and prior project experiences should all be taken into account while making this choice. Planning teams and equipment managers work together to pick equipment, which frequently entails determining whether to buy, rent, or lease equipment in light of the company's financial and strategic standing.

Optimum Utilization

Equipment needs to be properly maintained and operated in order to enhance output. Preventive maintenance improves operational uptime and decreases malfunctions. Equipment managers are in charge of hiring qualified operators, making sure everyone is safe, and keeping thorough records. Higher utilization rates can also be attributed to proper equipment placement and use.

1.2. Construction Equipment Maintenance

Maintenance is a crucial component of equipment management since construction machinery downtime can result in large financial losses. Up to 37% of a machine's life-cycle expenditures may be attributed to maintenance and repairs. Performance and costs are affected by the quality of service, whether it is owned or leased. Equipment condition is maintained and project continuity is guaranteed by routine inspections, timely maintenance, and repairs.

Equipment Manager's Role

Coordination of equipment planning, deployment, employee training, maintenance, and financial management is mostly the responsibility of the equipment manager. Profitability is significantly impacted by effective equipment management, particularly in the road construction industry where profit margins are usually narrow. Delays, cost overruns, and safety hazards can result from inadequate oversight.

2. LITERATURE REVIEW

Deep et al. (2022) carried out an empirical assessment of the key elements influencing the performance of highway projects. According to their research, major factors that influence project success include financial resource management, human capabilities, and equipment planning. They emphasized the need for a systematic project management approach by pointing out that poor planning frequently results in inefficiencies, delays, and cost overruns.

Fashina et al. (2021) investigated the reasons behind Hargeisa construction project delays and discovered that limited funding, inadequate equipment maintenance, and poor stakeholder coordination were the key factors. Their research demonstrated the ongoing worldwide problem of construction time and cost management, particularly in emerging nations.

Van and Quoc (2021) investigated research trends in the use of machine learning in construction management by conducting a scientometric study. According to their findings, the adoption of data-driven techniques for resource allocation, schedule forecasting, and equipment optimization has significantly

increased. They came to the conclusion that project planning and execution may be completely transformed by machine learning tools.

Alkhawaja and Varouqa (2023) examined the effects of service risks associated with infrastructure on the financial results of road projects in Jordan. They discovered that insufficient risk mitigation frequently resulted in unanticipated service interruptions and higher project expenses. The significance of integrating formal risk assessment tools into infrastructure design procedures was underscored by their research.

Patel and Ruparathna (2023), who put forth a paradigm for evaluating the life cycle sustainability of road projects that is based on Building Information Modeling (BIM). Their study showed how BIM technology analyzes energy use, material selection, and long-term maintenance techniques to help make informed decisions. They maintained that implementing BIM may greatly improve infrastructure projects' economic and environmental sustainability.

MATERIALS AND METHOD

2.1. Research Design

This study used an analytical research design based on case studies, with a focus on Package-I (Km 0+000 to Km 38+775) of the NH-561A upgrade project. The strategy integrated qualitative information obtained from important project stakeholders with quantitative performance metrics, such as equipment operating hours and maintenance frequency. A thorough assessment of equipment-related efficiency and its direct or indirect effects on the execution of highway projects was made possible by this mixed-method approach.

2.2. Study Area Details

The study's foundation was the A'nagar-Tembhurni Road (NH-561A) Rehabilitation and Upgrade, notably Package-I, which covered the Maharashtra state's Km 0+000 to Km 38+775 segment. The project was carried out at a sanctioned cost of ₹627 crore using the Hybrid Annuity Mode (HAM). Ahmednagar Ghogargaon Road Projects Pvt. Ltd. was the concessionaire, while Dhruv Consultancy was the independent engineer. The National Highways Authority of India (NHAI) commissioned the project, while Teck Konnect served as the design consultant.

2.3. Sampling and Respondent Profile

Participants directly involved in equipment deployment and monitoring were chosen using a purposive sample technique. Project engineers, site supervisors, plant managers, and equipment operators were among the 25 important employees that made up the sample. By representing both the concessionaire and the consulting firms, these responders made sure the study's data pool was large and pertinent.

2.4. Data Collection Techniques

The study relied on both **primary** and **secondary** data sources.

- **Primary data** were gathered utilizing structured questionnaires that concentrated on important variables such maintenance schedules, idle time, fuel consumption, downtime, and equipment usage rates. Furthermore, qualitative insights into logistical and strategic concerns were obtained through in-depth interviews with project managers and equipment supervisors. To evaluate the actual use of machinery including excavators, rollers, pavers, and batching plants, on-site observations were also made.
- **Secondary data** comprised the concessionaire's daily equipment logs, Monthly Progress Reports (MPRs), and Detailed Project Reports (DPRs). In order to determine benchmark usage levels, information was also gathered from Dhruv Consultancy's performance monitoring reports and equipment manufacturer reference manuals.

Key Variables

The study identified a clear set of **independent** and **dependent variables**:

- **Independent Variables:** These included operator skill levels, breakdown and maintenance intervals, average daily working hours, fuel/resource consumption efficiency, and the kind and quantity of equipment deployed.
- **Dependent Variables:** These included quality performance as determined by independent audits and QC/QA reports, cost variations (planned vs. actual expenditure), and timeframe adherence (planned vs. actual completion).

Data Analysis Methods

The collected data were subjected to various **analytical techniques**:

- **Descriptive statistics** were used to summarize patterns of equipment deployment and performance metrics.
- **Pearson correlation analysis** was conducted to identify relationships between equipment utilization and key project performance indicators (KPIs).
- **Multiple regression analysis** was applied to model the influence of utilization variables on time and cost overruns.
- A **comparative analysis** was also performed to evaluate the differences between planned milestones and actual achievements over the project duration.

2.5. Reliability and Validity

The instruments were pre-tested on comparable HAM-based highway projects in Maharashtra to guarantee the authenticity and dependability of the research findings. Triangulation was used in the study by contrasting the results of observations, interviews, and official reports. This increased the data's believability. Cronbach's Alpha was used to validate the survey instrument's internal consistency dependability; the result was 0.82, indicating high reliability.

3. RESULTS AND DISCUSSION

This section's findings were derived from primary and secondary data gathered from Package-I (Km 0+000 to Km 38+775) of the Maharashtra NH-561A highway upgrade project. The analysis's main goal was to determine how much and how well construction equipment is used, as well as how this affects project performance. In addition to qualitative inputs from site observations and interviews, quantitative data from field logs, progress reports, and equipment records were statistically examined. To obtain actionable insights, equipment-related variables were associated with key project performance metrics like schedule adherence, cost deviation, and quality compliance.

3.1. Equipment Deployment and Utilization Pattern

During the busiest construction times, 32 big equipment units were deployed. Pavers, batching plants, tippers, excavators, loaders, and compactors made up the majority of the equipment deployment mix. Depending on the site's conditions and the type of equipment, the average daily working hours varied from six to ten hours.

Table 1: Summary of Equipment Utilization (Average Values for Peak Periods)

Equipment Type	Total Units Deployed	Avg. Daily Working Hours	Idle Time (%)	Breakdown Frequency/Month	Maintenance Frequency
Excavators	6	9	10%	2	Every 300 hrs
Wheel Loaders	3	8	15%	1	Every 250 hrs
Vibratory Rollers	5	7.5	12%	1.5	Every 200 hrs
Bitumen Pavers	2	6.5	20%	3	Weekly
Batching Plants	2	10	5%	1	Every 500 hrs
Dumpers/Trucks	14	8	18%	2.5	Every 3000 km

Bitumen pavers and dumpers were seen to have longer idle times, which are frequently ascribed to delays in coordination and material availability. Better utilization and fewer breakdowns were observed in excavators and batching plants, suggesting that preventive maintenance procedures were working. Operational efficiency was impacted by an increase in the frequency of breakdowns in older equipment (over 4 years old).

Impact on Time Performance

The original scheduled timeline for Package-I was 24 months. Based on monthly progress reports, a cumulative delay of approximately **3.5 months (15%)** was observed at the time of assessment.

Table 2: Time Performance Metrics

Project Segment (Km)	Planned Completion (Months)	Actual Completion (Months)	Delay (Months)	Primary Delay Factors
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Km 0+000 – Km 10+000	6	7.2	1.2	Late equipment mobilization
Km 10+000 – Km 25+000	9	10.8	1.8	Paver breakdown, monsoon delay
Km 25+000 – Km 38+775	9	9.5	0.5	Operator shortage

Longer delays were seen in segments with a high frequency of equipment failures and a shortage of qualified operators. Sections that mostly relied on asphalt operations and bitumen paving were especially vulnerable to equipment failure. By moving more equipment and using double-shift operations in the last stage, the delay was somewhat reduced.

Impact on Cost Performance

While the overall project was within sanctioned cost limits, specific heads such as **fuel consumption** and **equipment repair/maintenance** showed upward deviations.

Table 3: Cost Comparison – Equipment-Related Heads

Cost Head	Budgeted Cost (INR Cr.)	Actual Cost (INR Cr.)	Deviation (%)
Fuel & Lubricants	8.5	10.2	+20%
Equipment Maintenance	2.2	2.9	+31.8%
Equipment Hire & Leasing	5.6	5.4	-3.5%
Total Equipment-Linked Cost	16.3	18.5	+13.5%

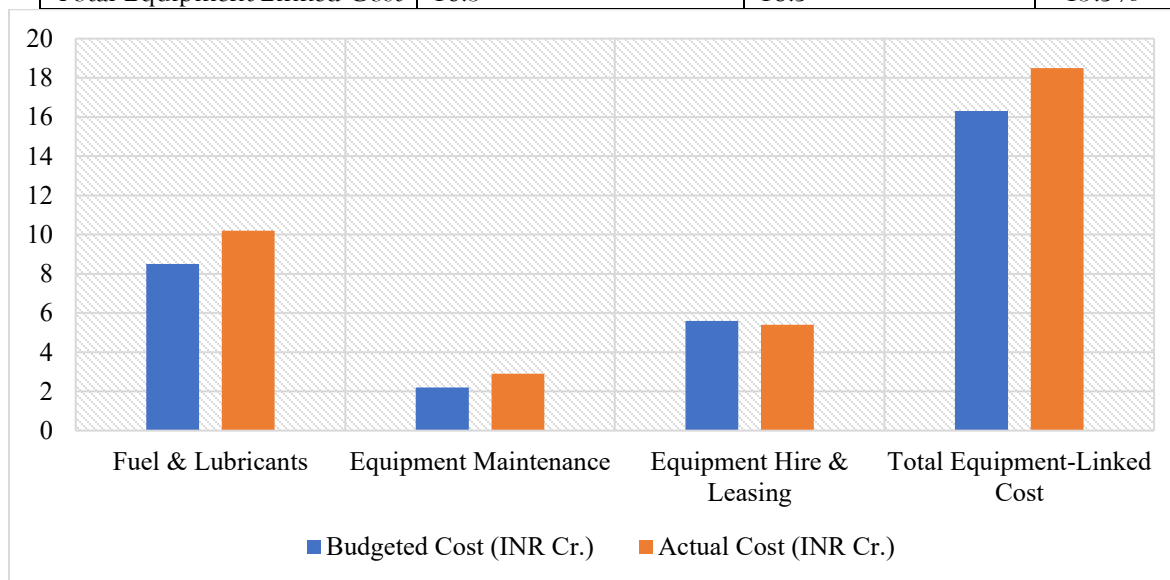


Figure 1: Cost Comparison – Equipment-Related Heads

Underutilized or inefficiently operated machinery was closely associated with fuel and maintenance cost overruns. For other operations, the concessionaire used rented equipment, which was somewhat more economical because there were fewer repair commitments. Cost increases were also caused by mechanic overtime and higher-than-expected use of spare components.

3.2. Quality Performance

Quality performance was measured through independent engineer audits and compliance reports.

Table 4: Quality Indicators and Non-Conformance Observations

Work Item	No. of Inspections	Non-Conformance Reports	Compliance Timeframe (Avg.)	Root Cause (Where Applicable)
Subgrade Preparation	12	1	5 days	Compaction defect – roller downtime
Bituminous Layer Laying	10	2	7–10 days	Uneven surface – paver error

Concrete Drain Casting	8	0	NA	NA
Embankment Work	9	1	3 days	Watering tanker delay

While the quality of civil work was generally acceptable, paver-related non-conformances emerged as a notable concern. Inspections revealed that improper levelling and inconsistent output were traced back to equipment calibration errors and insufficient operator training. However, all issues were resolved within acceptable timeframes and did not lead to permanent defects.

4. CONCLUSION

The analysis came to the conclusion that the use of construction equipment significantly affected the NH-561A highway project's (Package-I) overall performance, especially with regard to time efficiency, cost management, and quality assurance. Although there was a sufficient amount of equipment available, inefficiencies like idle time, frequent malfunctions, postponed maintenance, and a shortage of skilled operators caused schedule delays and mild cost overruns. Although they were few, quality problems were frequently attributed to inappropriate handling or malfunctioning equipment. To increase efficiency and lower project risks, the results emphasized the necessity of improved planning, predictive maintenance, operator training, and real-time equipment monitoring. Under the Hybrid Annuity Model, effective and strategic equipment management is essential to the successful completion of highway development projects.

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