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Research on Maintenance Cost Management of an Expressway Project

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Abstract: With the vigorous advancement of expressway construction, China now boasts extensive highway coverage nationwide. However, most expressways have entered maintenance phases, making it imperative to balance high-quality transportation services with effective cost control in highway maintenance. This study focuses on the an Expressway Project, analyzing current maintenance cost control practices and identifying existing challenges. Through systematic evaluation of maintenance design, material procurement, construction implementation, and inventory management processes, we propose optimized cost control strategies. The research provides methodological guidance and theoretical support for cost management in A Expressway projects, enhancing their competitive edge and sustainable development. Additionally, the analytical framework developed for A Expressway maintenance cost control is expected to offer valuable insights for other expressway maintenance cost control models.
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1. Introduction

In recent years, with the rapid development of China's economy, the construction of expressway networks has made significant progress. By 2024, the total length of expressways in China had reached 183,600 kilometers, ranking first in the world. Expressways have significantly improved transportation capacity, optimized the road grade structure, and offer advantages such as speed, convenience, safety, and strong traffic flow capacity.

With the passage of time and increasing mileage, most expressways across China have entered maintenance phases. Notably, highways constructed during the 1980s and 1990s are gradually aging, prompting a shift from traditional minor repairs to comprehensive maintenance strategies. M. Hagood proposed that (2014)

Compared with preventive maintenance, rehabilitation, and major maintenance, routine maintenance is characterized by periodicity, repetitiveness, and timeliness (Li, 2021). Prolonged operational lifespans, natural erosion, human-caused accidents, and surging traffic volumes have exacerbated damage to highway infrastructure, significantly raising maintenance challenges. The entrenched "construction over maintenance" mindset has led to neglected repairs or inadequate maintenance practices, resulting in substantially higher long-term maintenance costs. Given that proper maintenance directly impacts highway longevity, travel service quality, and safety performance, maintenance efforts have become increasingly critical. With the continuous improvement of national road networks and growing vehicle populations, the demand for highway maintenance services continues to rise.

To meet growing maintenance demands, the government has introduced multiple policies to guide the highway maintenance industry toward market-oriented, standardized, and intelligent development. Additionally, maintenance investment accounts for an increasing proportion of total highway investments, reflecting the market's urgent need for high-quality, in-depth maintenance services. MOTC (2006) conducted Taiwan has a total roadway lane length over 20,000 km, of which approximately 350 million square meters annually needs to be maintained and repaired for road surface and subgrade base. Kumar (2021) proposed that enterprises can effectively address pavement defect risks during maintenance operations through rational workforce allocation, efficient machinery deployment, and reliable material supply, thereby minimizing road asset losses and achieving optimal cost control. Scholar Bao (2021) conducted focused research on Pavement Condition Index (PCI) analysis. Liu (2022) conducted in-depth studies on optimizing maintenance budget utilization throughout highway operation cycles. Li Bin (2021) highlighted critical issues in highway project cost control such as lack of standardization, inaccurate cost estimation, incomplete supply chain management, unclear strategic positioning, insufficient cost analysis, and weak internal control mechanisms, with detailed elaboration on cost control standardization. Liu Fang (2021) found that most engineering bidding processes commonly suffer from issues such as inadequate management systems, particularly in non-public bidding categories. He proposed a comprehensive cost control accounting method for maintenance costs to achieve full-process cost management from planning, bidding, implementation, to maintenance, thereby realizing the goal of overall cost control. Scholar Yang Long (2021) combined the current operational realities of China's highways to conduct an in-depth analysis of the shortcomings in highway maintenance cost management and proposed several practical maintenance cost management methods. Lü Xinjian (2022), through case studies of highway maintenance across multiple provinces, argued that adopting the concept and methodology of full-process cost control and accounting for maintenance construction could effectively address issues such as inconsistencies between planned and actual progress, accelerated growth trends in maintenance costs, slow measurement and payment progress due to delayed acceptance, loopholes in safety production management, and high risks associated with maintenance funding.

Against this backdrop, this study takes the A Expressway project as a research case study. By analyzing maintenance cost data and management practices from 2019 to 2023, it identifies pain points and challenges in cost control across key stages. Targeted optimization strategies are developed for four critical areas: maintenance design, material procurement, construction implementation, and inventory management. The research aims to expand the scope and depth of cost control measures, transform traditional management models, maximize maintenance fund utilization efficiency, enhance the market competitiveness and operational sustainability of the A Expressway project, while providing theoretical insights and practical references for cost management in other domestic expressway projects.

2. Current Status of Maintenance Cost Control for Highway A Project

The A Expressway features a mainline spanning 200 kilometers and three connecting routes totaling 39.8 kilometers, with six lanes in each direction and a design speed of 120 km/h. As a key component of the Ministry of Transport's "Five Vertical and Seven Horizontal" national trunk road network, the A Expressway forms an interconnected transportation system that connects eastern and western regions while ensuring comprehensive connectivity. This study systematically analyzes maintenance cost control characteristics through five dimensions—overall costs, construction implementation costs, procurement costs, design costs, and period expenses—by examining maintenance cost data from 2019 to 2023.

2.1 Current Status of Maintenance Cost Control for Highway Project A

From 2019 to 2023, the total maintenance costs for the A Expressway Project increased from 909.9249 million yuan to 1,096.3992 million yuan, maintaining an annual growth trend. The primary maintenance costs rose from 415.5627 million yuan to 550.7213 million yuan, accounting for 50.23% of total costs compared to 45.67% previously, becoming the core cost component. Although total operating revenue grew from 1,554.1078 million yuan to 1,786.2889 million yuan, the significant increase in maintenance costs has exerted pressure on operational efficiency, highlighting the urgency of cost control. Table 1 presents the relevant maintenance cost data for the A Expressway Project during the 2019-2023 period.

Table 1. Maintenance-related costs for the A Expressway project Unit: 10,000 yuan

project	2019	2020	2021	2022	2023
Main maintenance costs	41,556.27	44,060.31	45,603.21	47,885.43	55,072.13
Other costs	1,237.72	1,270.35	1,259.66	1,345.72	1,296.83
total cost	90,992.49	95,409.94	105,270.57	105,544.29	109,639.92
Proportion of main maintenance costs to total costs	45.67%	46.18%	43.32%	45.37%	50.23%
Total operating revenue	155,410.78	161,381.91	168,457.11	173,763.51	178,628.89

As a transportation service industry, highway maintenance involves production costs that constitute a significant proportion of total maintenance expenses. These primarily include direct materials, labor costs, machinery expenses, and raw material procurement costs, as detailed below:

Construction process costs. The implementation of maintenance construction is a critical component of cost control for the A Expressway. The costs incurred during maintenance construction on the A Expressway are influenced by various factors, such as labor costs, material costs, and machinery expenses.

Table 2. Implementation Cost Table for Maintenance Construction of Highway Project A Unit: Ten Thousand Yuan

project	2019	2020	2021	2022	2023
direct labor	6,536.23	7,643.88	9,816.27	10,627.41	12,129.34
direct material	31,638.23	33,927.16	34,562.73	34,686.23	36,783.77
Direct machinery	2,473.16	2,538.96	9,837.16	1,782.52	1,227.38

As shown in the table above, labor costs for maintenance operations on Highway A exhibit a consistent annual upward trend. This is primarily attributed to the prolonged operation period of the highway, deteriorating road conditions, and inadequate preventive maintenance measures. Compared to previous years, the required workforce for repairing equivalent engineering volumes has increased significantly. Additionally, the highway's internal maintenance capacity remains insufficient, necessitating substantial external labor recruitment while wages continue to rise annually. Concurrently, regulatory oversight from highway police and road administration departments has become increasingly stringent. Construction or repair crews often receive immediate evacuation orders from traffic authorities or highway police before completing tasks due to heightened security requirements or heavy traffic volumes. This results in repeated repair operations requiring additional personnel. When construction is eventually permitted again, maintenance teams are forced to deploy large-scale manpower for emergency repairs. Although this approach fulfills dispatch requirements, it substantially increases labor costs.

Raw material procurement costs. The maintenance raw material procurement costs for the A Expressway project primarily include raw material procurement costs and employee compensation for the procurement department. The cost composition of the procurement phase for the A Expressway project maintenance from 2019 to 2023 is shown in Table 3.

Table 3. Composition of Maintenance Procurement Costs for Highway Project A Unit: 10,000 yuan

	2019	2020	2021	2022	2023
raw material procurement cost	31,234.73	32,089.12	33,983.25	34,267.91	36,326.79
employee compensation	139.21	143.66	145.08	150.17	152.63

The table above reveals that raw material procurement costs constituted the largest share of maintenance procurement expenses for the an Expressway Project between 2019 and 2023. The inherent nature of the transportation industry ensures sustained demand for raw materials throughout service operations. Procurement costs significantly influence maintenance expenditures. Key materials for A Expressway maintenance include routine maintenance supplies such as expansion joints, asphalt, barbed wire mesh, and guardrail panels; miscellaneous materials like pesticides for landscaping; bulk de-icing agents for snow removal and traffic flow maintenance; along with specialized maintenance materials used in various engineering applications. Currently, all raw materials for A Expressway maintenance are sourced externally, making procurement costs highly susceptible to fluctuations in material prices.

Maintenance design serves as the foundation and prerequisite for the entire maintenance process, with all subsequent operations conducted based on this blueprint. The rationality of maintenance design directly determines the quality, efficiency, and effectiveness of post-maintenance tasks, thereby influencing overall cost control. Moreover, the quality of maintenance design significantly impacts the travel experience of drivers and passengers, which in turn exerts a decisive influence on the operational revenue of Highway A. Consequently, maintenance design constitutes a critical foundational task. The leadership of Highway A places high priority on maintenance design, allocating substantial resources for design expenditures as detailed in Table 4.

Table 4. Cost Composition of Maintenance Design Expenses for Highway Project A Unit: Ten Thousand Yuan

	2019	2020	2021	2022	2023
salary	3,737.92	3,805.81	5,437.13	5,506.68	5,614.56
travel expense	1,010.25	1,016.34	1,520.72	1,526.19	1,535.12
Outsourced design fee	5,291.80	5,339.81	8,415.98	8,586.19	8,701.56
other	386.26	453.19	661.98	633.1	653.04

The data in the table above reveals that wages and outsourced design fees accounted for the largest proportion of maintenance design costs in the A Expressway project from 2019 to 2023, collectively exceeding 80% of total design expenses. This proportion has shown a significant upward trend since 2021. The primary reason lies in the fact that after 2021, many outsourcing agencies shifted industries due to macroeconomic impacts, while the remaining few capitalized on the situation to continuously raise design fees. Additionally, the A Expressway project lacked effective internal exploration of maintenance design potential, coupled with insufficient employee awareness and capability in independent design, forcing reliance on external contractors. If this trend persists, maintenance design costs will become a substantial burden, while employee salaries continue to rise, adversely affecting overall cost control. This issue demands urgent attention.

Table 5. A: Cost Statistics During Maintenance Period of Expressway Projects Unit: Ten Thousand Yuan

project	2019	2020	2021	2022	2023
general expenses	61736.35	79324.81	81829.26	89826.11	98378.02
cost of financing	85205.11	82912.34	73178.29	65934.56	53126.72
inventory carrying cost	36723.72	38123.61	40731.85	43149.26	45932.71

The maintenance costs of Highway Project A primarily consist of administrative expenses, financial expenditures, and inventory management costs. As shown in Table 5, the administrative costs for highway maintenance during 2019-2023 exhibited a consistent annual increase, reflecting the Group Company's commitment to self-driven development strategies. Conversely, financial maintenance costs demonstrated a steady decline throughout this period, with a 37.65% reduction in 2023 compared to 2019. This improvement stems from the post-enterprise restructuring reforms, which enabled Highway Project A to adopt an independent operation model with self-accountability for profits and losses. Through systematic optimization of maintenance cost management systems, expenses such as service fees, late payment penalties, and interest charges have been progressively reduced. Meanwhile, inventory costs saw a gradual rise from 2019 to 2023, driven by rapid traffic volume growth that intensified maintenance demands and increased procurement of materials. Consequently, associated costs including inter-section transportation fees, storage charges, and warehouse rental expenses have also risen accordingly.

2.2 Maintenance Cost Control Measures for Highway Project A

Prior to initiating highway maintenance projects, conduct cost budgeting by gathering foundational data including road conditions, facility status, and traffic volume. Analyze maintenance requirements and cost drivers by integrating historical maintenance records with future planning strategies. Break down costs into categories such as routine maintenance, engineering works, and equipment procurement to estimate labor, material, and equipment expenses. Compile the maintenance cost budget and allocate funds rationally, specifying cost targets for individual projects, materials, and labor costs. This ensures budget accuracy and operational feasibility of maintenance cost planning.

During maintenance operations, we strictly adhere to budgetary guidelines by conducting comprehensive cost accounting. All incurred expenses—including material costs, labor expenses, and equipment machinery costs—are accurately recorded and documented. We systematically collect and verify original vouchers, maintain accounting records, and regularly summarize and analyze maintenance cost ledger data to assess actual expenditure patterns while ensuring data authenticity and integrity. Additionally, we continuously monitor variance between actual costs and budget allocations, making timely adjustments to maintenance strategies to achieve effective cost control.

After maintenance operations are completed, conduct an in-depth analysis of the cost formation process and influencing factors to identify reasons for cost overruns or savings, thereby exploring cost reduction strategies. Simultaneously, evaluate cost control effectiveness to ensure accurate assessment of cost forecasting, decision-making, planning, control, and analysis processes, providing references for future maintenance cost management. Based on cost analysis and evaluation results, implement corresponding cost control measures such as optimizing maintenance workflows, reducing material consumption rates, and improving equipment utilization rates to minimize maintenance costs.

3. Issues in Maintenance Cost Control for the A Expressway Project

Through analyzing the current maintenance cost status and data of the an Expressway Project, combined with its actual operation and management processes, it was found that cost control issues primarily concentrate in four key areas: maintenance design, material procurement, construction implementation, and inventory management.

3.1 Unreasonable Maintenance Design

From conceptual design to final implementation, the entire process was independently managed by the Business Development Department, with minimal participation from related departments including Financial Management Department, Cost Accounting and Control Center, Maintenance Management Department, and Material & Equipment Management Center. When developing maintenance plans, the Business Development Department relied solely on historical experience and maintenance data analysis results. The final plans were formulated from the perspective of individual business units, focusing solely on analyzing maintenance requirements, priorities, and key areas while failing to comprehensively consider factors from other departments. This resulted in maintenance content, methods, timelines, and budgets that did not fully align with actual operational needs.

Furthermore, maintenance staff at the an Expressway Project were influenced by the “guaranteed income regardless of performance” mentality prevalent in public institutions before their corporate restructuring. This led to widespread low work motivation, with some employees adopting complacent attitudes and even exhibiting passive resignation behaviors. Despite consecutive annual salary increases, many workers perceived their current living standards as secure without additional effort, settling for status quo conditions and lacking ambition or competitive drive. Within this “guaranteed income” environment, employees showed insufficient attention to corporate maintenance and operational costs, subconsciously believing personal earnings were unrelated to cost control measures or business performance. The absence of cost-consciousness awareness among staff often resulted in severe resource wastage and reduced work efficiency.

3.2 Significant Procurement Risks for Materials

The procurement strategy for highway maintenance projects typically involves sporadic and decentralized purchases based on raw material requirements. This approach not only incurs time costs due to excessive procurement frequency but also risks mismatching supply quantities with actual demands. Lacking procurement autonomy, contractors often passively endure issues like suppliers’ sudden price hikes and delivery delays. Such disruptions can adversely affect construction schedules, exacerbate structural deterioration, compromise traffic safety, and escalate repair costs, ultimately leading to a sharp increase in overall expenses.

For maintenance operations of Highway A, materials with high daily demand and relatively low costs—including barbed wire mesh, isolation fences, guardrails, anti-glare nets, asphalt, cement, and sand/gravel—alongside technically demanding and expensive components like expansion joints, directly impact overall maintenance cost control. Fragmented procurement practices, characterized by small order quantities and extended cycles, remain vulnerable to market price fluctuations, hindering cost management. Currently, Highway A primarily employs quotation and price comparison methods to control procurement costs, often selecting the lowest bid. However, purchasing departments frequently prioritize price over critical factors such as technical specifications, after-sales service, and contract fulfillment capabilities, resulting in costly overinvestment where premium materials are inadequately procured. Additionally, repetitive procurement approval processes consume excessive time, significantly compromising maintenance efficiency.

The maintenance department of Highway Project A has yet to establish strategic partnerships with suppliers in procurement. Currently, the procurement process primarily involves posting tender notices on the official website, allowing any supplier to submit bids. Coupled with the procurement department's reliance on methods such as price inquiries, this results in varying winning bidders each time, leading to discrepancies in the quality and specifications of supplied materials and equipment. Additionally, the lack of comprehensive process control often results in only post-event monitoring, creating numerous uncertainties throughout procurement and maintenance operations. Furthermore, frequent supplier changes and short collaboration cycles hinder effective communication between Highway Project A and suppliers, eroding trust foundations. Any temporary adjustments to procurement quantities or product categories require renegotiation and new contract signings, significantly extending procurement cycles and compromising cost control during subsequent maintenance phases.

3.3 Coarse Cost Control in Construction Implementation

During the construction of Highway A, the construction plan has proven insufficient in constraining cost control during implementation. The plan merely specifies requirements for machinery types and quantities, labor quotas, and maintenance cycles without addressing practical maintenance cost control needs through detailed operational plans for each construction phase. This has resulted in inadequate resource conservation awareness and low efficiency among frontline maintenance personnel. Maintenance sub-centers and teams mechanically follow work orders, as shown in Table 6 which outlines preventive maintenance data from recent years. Due to insufficient emphasis on preventive maintenance, minor defects often go untreated, escalating into major issues that require additional manpower, materials, and equipment for repairs. Consequently, cost control during actual maintenance operations remains challenging.

Table 6. A: Statistical Table of Preventive Maintenance Proportion for Highway Projects Unit: Number, Percentage

	Maintenance Task Order	Maintenance Task Order	Proportion of preventive maintenance
2019	23875	2141	8.97
2020	27967	2518	9.01
2021	33826	3689	10.91
2022	38641	3935	10.18
2023	40982	4683	11.43

The A Expressway exhibits deficiencies in safety production management during maintenance operations. From 2019 to 2023, substantial safety compensation expenditures were incurred, with detailed figures presented in Table 7. Consecutive workplace accidents in 2022 and 2023 not only resulted in disciplinary actions against responsible parties but also forced the expressway to bear significant post-incident remediation costs, with compensation amounts far exceeding market pricing benchmarks. The failure to utilize insurance reimbursement mechanisms exacerbated project cost overruns. In June 2022, improper placement of reflective cones in construction transition zones led to penalties from highway traffic police, causing seven-day work stoppages across the entire route, direct economic losses, and extended maintenance timelines. Additionally, maintenance crews—particularly subcontracted workers—demonstrated complacency and inadequate safety awareness. Daily operations frequently involved violations such as improper helmet usage, compromised safety protocols, failure to conduct mandatory three-minute pre-job briefings and safety training, and non-compliant operational procedures, resulting in workplace injuries, machinery damage, and other incidents. These systemic issues have created substantial challenges for cost control in A Expressway construction projects.

Table 7. A: Statistical Table of Maintenance Safety Compensation Fees for Expressway Projects Unit: Ten Thousand Yuan

project	2019	2020	2021	2022	2023
security indemnity	372.93	581.13	943.88	1,393.71	1,811.85

3.4 Inadequate Inventory Management Measures

Currently, warehouses at grassroots units such as the Maintenance Sub-center and maintenance teams of Highway A project remain inadequately stocked, resulting in daily maintenance materials not being stored according to regulations. Raw materials required for maintenance operations are stored independently by grassroots units. Analysis from Table 8 shows that raw material inventories at Highway A increased annually from 2021 to 2023 with significant growth rates. The average raw material expenditure reached 111.4482 million yuan, while inventory write-offs also showed an upward trend. On one hand, inventory management for Highway A's maintenance operations primarily relies on grassroots units, where warehouse managers handle stock entry and exit procedures. However, challenges including numerous grassroots units, aging warehouse managers, and low educational backgrounds have slowed the implementation of standardized inventory management systems. Insufficient warehouse facilities at most grassroots units have led to suboptimal maintenance environments, disorganized material storage, and even instances of raw materials being mixed with scrap materials. On the other hand, chaotic inventory management practices—including excessive stockpiles without proper sorting and scattered storage locations—have not only increased company inventory verification costs but also caused time wastage, disrupted construction schedules, and indirectly elevated maintenance expenses.

Table 8. Statistical Table of Maintenance Inventory for Highway Project A Unit: Ten Thousand Yuan

	2019	2020	2021	2022	2023
Raw material inventory	9,630.19	9,912.76	10,616.29	10,983.27	11,834.91
inventory balance	19,837.45	20,351.16	22,853.82	23,926.17	24,947.15
amortization amount	212.13	267.14	327.86	361.93	398.52

4. Optimization Scheme for Highway Cost Control

To address cost control challenges in A Expressway maintenance projects, this study proposes targeted optimization strategies covering four critical phases: maintenance design, material procurement, construction execution, and inventory management. These solutions aim to drive comprehensive management upgrades across all operational stages.

4.1 Optimization Scheme for Maintenance Design Cost Control

An expressway should break down overarching objectives into specific tasks and targets for each department, ensuring clear understanding of their roles and contributions to corporate goals. For instance, when designing maintenance plans, departments such as Financial Management, Maintenance Management, Cost Accounting & Control Center, and Materials & Equipment Management Center should collaborate to fulfill their respective responsibilities, avoiding the Development Department taking on sole responsibility. Maintenance Management Departments, Sub-centers, and Work Teams must actively provide raw data to support subsequent maintenance design. Simultaneously, an information communication mechanism should be established through regular or ad-hoc multi-department meetings to facilitate joint problem-solving, information sharing, and resource integration. Leveraging internal networks and platforms like DingTalk management systems, we should develop efficient information-sharing platforms to ensure seamless communication channels. Critical progress updates and dynamic data should be readily accessible, enabling timely aggregation of key information for decision-makers and management to make informed decisions. Additionally, regular workflow optimization should be implemented to ensure smooth inter-departmental coordination. Clear collaboration guidelines and systems must be established to provide operational direction. Through team-building activities and training programs, employees' teamwork spirit should be strengthened, helping staff truly understand that unity and cooperation are essential for achieving mutual growth between individuals and the organization.

Enterprises should regularly organize cost awareness education programs, utilizing training sessions and seminars to educate employees on the importance and fundamental methods of cost control, thereby enhancing staff cost consciousness. Concurrently, establish a performance evaluation mechanism linked to cost performance, integrating cost control metrics into employee assessment systems and correlating compensation, promotions, and other incentives with cost control outcomes to motivate active participation. Implement comprehensive budget management by incorporating maintenance expenditures for Highway A into budgetary frameworks, strictly controlling waste during execution to ensure effective cost containment. Develop a cost control accountability system that leverages internal staff potential, boosts motivation, strengthens cost awareness, and fulfills assigned tasks while reducing outsourcing expenses. Clearly define responsibilities and obligations across departments and positions to foster a culture of collective cost control participation. Establish robust cost control protocols, rewarding departments demonstrating exceptional performance while holding underperforming units accountable. This incentive-driven approach enhances employee engagement and ensures effective implementation of cost control measures. Cultivate an organizational culture emphasizing cost management practices, enabling all staff to naturally adopt cost-conscious operational philosophies in daily operations.

4.2 Optimization Plan for Material Procurement Cost Control

Highway authorities should proactively implement cross-departmental coordination mechanisms to enhance procurement process flexibility. By conducting in-depth analysis of operational conditions across units and forecasting future procurement demands, they can utilize data analytics tools such as historical purchase records and market trends to improve prediction accuracy. Establishing a supplier evaluation and selection system will ensure the recruitment of high-quality, reliable partners. Implementing quality control procedures guarantees that procured materials meet established standards. Real-time procurement progress monitoring provides critical data for subsequent maintenance planning. Regular training programs should be organized to equip procurement staff with up-to-date knowledge, skills, and regulatory compliance training. Inviting industry experts to share practical insights will continuously elevate professionals' expertise. Encouraging open communication channels between procurement teams and other departments enables timely understanding of grassroots-level procurement needs. By systematically analyzing procurement patterns at the operational level, procurement personnel can strengthen collaboration capabilities while gaining comprehensive insights into authentic requirements across departments and frontline units.

The Maintenance Management Department of Highway Project A should comprehensively integrate procurement requirements for labor, materials, and equipment through centralized bidding processes to establish bulk purchase orders. This approach significantly enhances bargaining power with suppliers while reducing fragmented procurement approvals, cutting processing time, and markedly improving procurement efficiency. Departments may organize joint meetings for strategic planning, conduct quantity verification against annual maintenance construction blueprints, and accurately calculate procurement demands for labor, materials, machinery, and equipment. This enables targeted division of construction sections. By referencing Highway A's historical operational data, annual bidding plans should be formulated with proactive procurement strategies. Consolidating similar procurement items and expanding centralized procurement scale will strengthen scientific rigor, timeliness, foresight, and accuracy in procurement operations, ultimately achieving comprehensive efficiency improvements.

The Maintenance Management Department of Highway Project A should maintain close communication with suppliers through regular meetings, phone calls, and emails. This ensures timely sharing of critical factors affecting maintenance efficiency, including material/equipment requirements, quality standards, and delivery locations, thereby guaranteeing seamless information flow. Relevant highway departments must conduct periodic comprehensive evaluations of suppliers' performance across quality metrics, delivery compliance, cost-effectiveness, and service support capabilities. When maintenance budgets permit, proactive measures should be taken to provide essential training and technical assistance to enhance suppliers' management expertise and technical proficiency. Both parties should jointly develop contingency plans to facilitate prompt problem-solving through coordinated communication, minimizing time losses caused by interdepartmental coordination delays.

4.3 Optimization Plan for Construction Implementation Cost Control

Based on differences in service scope and content, operation centers are categorized into three types: material operation centers, mechanical equipment operation centers, and labor personnel operation centers. For detailed information, refer to Table 9 below.

Table 9. Analysis of Operation Centers and Driving Factors for Maintenance Installation Panel Projects in Highway A Expressway Project

Work Center	school assignment	Activity driver
Material Operations Center	Guardrail panel	Guardrail panel tonnage
	lean concrete	Concrete volume
	tiling	Number of square bricks per ton
	upright column	Number of column roots
Mechanical Leasing Operations Center	Crane Rental	Number of cranes
	Excavator rental	Excavator count
	Pile Driver Rental	Number of pile drivers
	Early Warning Vehicle Rental	Number of warning vehicles
	sporadic machinery leasing	Number of scattered machinery
Labor Service Center	Guardrail panel team operation	Guardrail panel installation
	Bricklayer team operation	Concrete and Masonry Construction
	Closing team operations	Work area cleaning

Through in-depth analysis and meticulous consideration of resource drivers at each activity center, the types and quantities of resources utilized by each activity center are clarified. The specific analysis results of resource drivers for each activity center are presented in Table 10.

Table 10. A Analysis of Operation Centers and Resource Drivers for Guardrail Installation Maintenance Project at the A Highway Project

Work Center	school assignment	Activity driver
Material Operations Center	Guardrail panel	Labor Day
	lean concrete	Labor Day
	tiling	Labor Day
	upright column	Labor Day
Mechanical Leasing Operations Center	Crane Rental	Labor Day
	Excavator rental	Labor Day
	Pile Driver Rental	Labor Day
	Early Warning Vehicle Rental	Labor Day
	sporadic machinery leasing	Labor Day
Labor Service Center	Guardrail panel team operation	Labor Day
	Bricklayer team operation	Labor Day
	Closing team operations	Labor Day

Through in-depth analysis of operational activities and related resource drivers, we consolidated resource costs generated across all activity centers to establish the project activity library cost structure, while systematically summarizing cost profiles for each center. Material costs, machinery equipment rental expenses, and labor costs associated with this project are detailed in Table 11, Table 12, and Table 13 respectively.

Table 11. Material Costs for Guardrail Installation Maintenance Project of Highway A

construction stage	material	unit	quantities	unit-price	Total price (RMB)
Main construction	Guardrail panel	t	1035	1578	1633230
	lean concrete	m³	560	380	212800
	tiling	m³	165	95	15675
	cast-in-place shoulder stone	m³	81	105	8505
Installation and Construction	upright column	root	2070	367	759690
	Anti-glare facilities	Xiang	1	158432	158432
	Contour material	m^2	500	249	124535
	Traffic sign material	m^2	368	162	58960
	Other materials	Xiang	1	8950	8950
amount to					2980777

Table 12. A: Machinery and Equipment Rental Costs for Guardrail Installation Maintenance Project of Highway Expressway

construction machinery	unit	quantity	Lease unit price (RMB/month)	Lease term (months)	Lease cost (RMB)
backhoe	tower	6	8000	2	96000
crane	tower	3	5500	2	33000
monkey engine	tower	6	5000	2	60000
Early warning vehicle	moon	6	3000	2	36000
Other machinery	Xiang	1	10000	2	20000
amount to					245000

Table 13. Labor Costs for Guardrail Installation Maintenance Project of Highway A

Assignment Project	primary coverage	Total price (RMB)
traditional cure	Excavation and backfilling	180000
Guardrail panel	Transportation, installation, and calibration	550000
concrete bed	Cast-in-place, curing, installation	98300
Signboard production	install	86000
pouring	Transportation, pouring, and curing	60760
road	Construction of Road shoulders and curbs	30000
Other assignments	Other construction	36000
amount to		1041060

Table 14. Labor Costs for Guardrail Installation Maintenance Project of Highway A

Fee Name	the cost of the project	Cost (RMB)
Salary for team leaders	Salary + Performance Bonus	83200
car fare	Travel expenses + meal allowance	13000
Other transaction costs	Office expenses + Labor insurance premium	3670
amount to		99870

The maintenance and installation of guardrail panels for the A Highway project involves numerous costs during the transaction process, including project information fees and business management fees, among others. These expenses are challenging to control and estimate. However, by employing statistical analysis methods to examine these transaction costs, stakeholders can achieve more precise cost management and control. As demonstrated in Table 15.

Table 15. Transaction Costs for Highway Maintenance Project: Guardrail Panel Installation

Project Information Fee	Business management fee	amount to
8000	90000	98000

Regarding the maintenance and installation of guardrail panels for the A Expressway project, Table 16 details other direct costs, Table 17 outlines indirect costs, and Table 18 shows the breakdown of period expenses for the enterprise.

Table 16. Other Direct Costs for Highway Maintenance and Guardrail Installation Project on Highway A

Cost item	the cost of the project	charge against revenue
Garbage disposal fee	$650m^2$ × 34 yuan/sqm	22100
Security Measures Fee	2% of the contract amount	300000
Construction water and electricity charges	Water and electricity charges	8000
Large machinery entry and exit fees	Entry and Exit Fees for Large Machinery Equipment	62000
amount to		392100

Table 17. Indirect Costs of Guardrail Installation Maintenance Project for Highway A

Cost item	the cost of the project	charge against revenue
Project staff salaries	Project staff salaries	831000
travel expense	Transportation costs + subsidies	22170
charges	Pollution discharge fee + social security fee, etc.	16820
Other indirect costs	Business entertainment expenses, etc.	54000
amount to		923990

Table 18. Periodic Cost of Enterprise for Highway Project Maintenance Installation of Guardrail Panels on Highway A

Cost item	the cost of the project	charge against revenue
performance bond processing fee	Amount of performance bond × 0.125%	18750
insurance	All Risks Insurance, Safety Liability Insurance, Work Injury Insurance	45000
general and administrative expenses	Corporate management fee payable	113220
Safety Production Expense	Safety design, facility layout	84830
expenses of taxation	engineering tax	1050000
amount to		1311800

According to the cost statistics of the A Expressway Project maintenance and installation of guardrail panels, the transaction costs incurred during the transaction period, including project personnel salaries and transportation expenses, amounted to 99,870 yuan.

Labor Service Center Cost Driver Allocation Rate:

1041060/（1041060+245000+2980777）=24.40%

Material Activity Center cost driver allocation rate:

2980777/（1041060+245000+2980777）=69.86%

Cost driver allocation rate for equipment leasing operations center:

245000/（1041060+245000+2980777）=5.74%

The transaction cost of the labor supply operation center is:

99870 × 24.40% = 24,368.28 yuan

The transaction cost of the material processing center is:

99870 × 69.86% = 69,769.18 yuan

The transaction cost of the equipment leasing operation center is:

The total cost for the guardrail installation maintenance project of Highway A (99870 × 5.74% = 5732.54 yuan) is detailed in Table 19.

Table 19. Total Cost of Guardrail Installation Maintenance Project for Highway A

Cost item	the cost of the project	charge against revenue
material cost	Civil construction, installation, and auxiliary materials	2980777
Equipment leasing cost	Mechanical equipment and small tools	245000
cost of service rendered	labor employment	1041060
Other direct costs		392100
project indirect cost		923990
interperiod cost		1311800
customer transaction cost		99870
amount to		6994597

Using guardrail panel installation as a case study, this paper demonstrates how Activity-Based Costing (ABC) is applied in corporate cost management accounting. Other operations can reference this analytical approach to obtain precise cost estimates for various activities.

(1) The calculation steps for guardrail panel labor costs are as follows:

In the guardrail installation project for Highway A maintenance, the labor contract signed with the main structural construction team explicitly stipulated centralized procurement for guardrail panels. Accordingly, the labor team's responsibilities were limited to panel cutting and installation. After comprehensive evaluation of all relevant factors, the transaction cost between the project and the labor supplier was determined to be 24,368.28 yuan.

The operational transaction cost for guardrail panel engineering is:

550,000 ÷ 104,1060 × 24,368.28 = 12,873.95 yuan

The total actual installation cost for guardrail panels is:

The total cost of 550,000 yuan plus 12,873.95 yuan equals 562,873.95 yuan. As shown in Table 11 (Material Cost Table), the total weight of installed guardrail panels is 1,035 tons, indicating the labor cost for installation as follows:

562,873.95 yuan per 1,035 tons = 543.84 yuan per ton

(2) The calculation steps for mechanical costs of installing guardrail panels are as follows:

In the installation project of guardrail panels, the mechanical equipment used is not directly related to the specifications and materials of the guardrail panels. Based on this, when calculating machinery costs, installation expenses can be determined according to different models of guardrail panels.

Table 20. A: Machinery Rental Costs for Highway Maintenance and Guardrail Installation Project

Cost item	unit	quantity	Usage time (months)	Rent (RMB)	Total cost (RMB)
cutting machine	tower	6	2	2000	24000
arc welder	tower	6	2	2000	24000
Other miscellaneous machinery	Xiang	1	2	1200	2400
amount to					50400

The calculation above shows that the transaction cost between the project and the machinery leasing supplier amounts to 5,732.54 yuan.

The transaction cost for installing guardrail panels and operating machinery rental is:

50400/245000 × 5732.54 = 1179.26 yuan

The actual cost for installing guardrail panels through mechanical leasing is:

50,400 + 1,179.26 = 51,579.26 yuan

As shown in Table 11 Material Cost Table, the total weight of installed guardrail panels is 1,035 tons, resulting in a per-ton installation machinery cost of:

51579.26 ÷ 1035 = 49.83 yuan per ton

(3) The material cost calculation steps for centralized procurement of guardrail panels are as follows:

By integrating project and material supplier transaction cost allocation mechanisms, the cost driver allocation rate for guardrail panel installation projects at material operation centers is as follows:

1633230/2980777=54.79%

The transaction cost for guardrail panel material procurement is:

69,769.18 × 54.79% = 38,226.53 yuan

The actual procurement cost of guardrail panels during installation is as follows:

1633230 + 38226.53 = 1,671,456.53 yuan

As shown in Table 11 Material Cost Table, the total installation volume of guardrail panels is 1,035 tons, resulting in a centralized procurement cost of [amount] per ton.

1671456.53 ÷ 1035 = 1614.93 yuan per ton

(4) The calculation steps for other direct costs associated with guardrail panel installation are as follows:

Other direct costs associated with guardrail panel installation include inspection and testing fees, primarily assessing structural integrity, surface quality, dimensions, raw materials, anti-corrosion coatings, and toughness. The standard fee is 80 yuan per set. Based on the actual on-site testing costs (including sample submission fees) of 8,850 yuan, the actual additional direct costs incurred per ton of guardrail panels are calculated as follows:

8850/1035 = 8.6 yuan per ton

(5) The cost accounting steps for guardrail panel installation are as follows:

The above calculations indicate that the direct cost for the guardrail installation maintenance project of Highway A is as follows:

550,000 + 50,400 + 1,633,230 + 885 = 2,242,480 yuan

The total direct costs incurred during construction are as follows:

1633230 + 245000 + 2980777 + 392100 = 5251107 yuan

Therefore, the operational motivation rate for the guardrail installation maintenance work under the A Expressway Project is as follows:

2242480/5251107=42.70%

The total of project indirect costs, administrative overheads, and transaction costs between the project and clients amounts to:

923990 + 1311800 + 98000 = 2,333,790 yuan

Therefore, the indirect costs incurred in the A Expressway project's guardrail installation maintenance work are as follows:

2333790 × 42.70% = 996528.33 yuan

The indirect cost per ton of guardrail panel installation is calculated as: 996,528.33 ÷ 1,035 = 962.83 yuan per ton.

In summary, the actual cost per ton for guardrail panel installation works is:

543.84 + 49.83 + 1614.93 + 8.6 + 962.83 = 3180.03 yuan

4.4 Optimization Plan for Inventory Management Cost Control

The construction of facilities such as warehouses not only reduces material and equipment loss rates but also enhances maintenance construction efficiency. Conduct comprehensive inspections of existing warehouses and implement customized upgrade strategies for each facility to ensure rational and orderly material storage. Firstly, warehouse construction enables materials to be preserved according to maintenance management requirements, mitigating adverse effects caused by natural factors. Secondly, it facilitates inventory management through regular stocktaking and clearance processes, allowing timely identification and resolution of inventory management issues, reducing stockpiling, and improving inventory turnover rates. Thirdly, categorizing materials by type, properties, and quantity enables quick location retrieval during daily maintenance operations, saving time while ensuring accuracy in material classification and quantities to support construction activities. Fourthly, coordinated equipment scheduling revitalizes idle assets, expands equipment leasing services, and creates new profit growth opportunities.

Based on the locations of maintenance sub-centers and teams, strategically establish regional emergency material central warehouses. Collaborate with functional departments including Maintenance Management Department, Business Development Department, and Cost Accounting & Control Center to conduct rational procurement of materials and equipment according to historical demand patterns and current maintenance plans. These materials are then allocated to designated emergency material warehouses, enabling centralized procurement, tiered management, and unified distribution to effectively reduce material costs. When maintenance sub-centers or teams require replenishment or face stock shortages, resources can be promptly allocated from nearby emergency material warehouses, significantly shortening delivery times and lowering inventory management costs. Concurrently, enhance warehouse administrator training programs to improve professional skills and ethical standards. Select responsible and meticulous staff members for warehouse management positions, while implementing robust incentive mechanisms to boost employee motivation.

5. Conclusion

This study conducts an analysis and research on maintenance cost control for the A Expressway project, expanding the scope of cost management to achieve greater comprehensiveness. The objective is to provide innovative approaches for maintenance cost control in A Expressway projects. The research yields the following conclusions:

The A Expressway project should promptly transition from its current traditional maintenance cost control approach to expand both the scope and depth of cost management strategies. Traditional cost control methods primarily focus on internal factors during highway maintenance operations, overlooking external influences such as supplier relationships and client interactions. While these approaches may yield noticeable short-term results, they often fail to meet long-term cost control objectives. Therefore, adopting modern cost management models becomes imperative. Based on the current maintenance status of the A Expressway project, we have identified key challenges through research and implementation adjustments. By addressing critical aspects including maintenance design, material procurement, construction execution, and inventory management, we have systematically developed optimized cost control solutions.

Against the backdrop of continuously growing highway maintenance demands and escalating cost pressures nationwide, highway operators must abandon the outdated approach of prioritizing construction over maintenance and single-point control. By identifying cost management pain points based on operational realities, they should establish comprehensive, precision-driven maintenance cost control systems to drive industry transformation toward marketization, standardization, intelligentization, and cost efficiency. Future strategies should integrate smart technologies—including big data analytics, IoT solutions, and AI systems—across all maintenance processes. This integration will enable accurate demand forecasting, automated material procurement, real-time construction monitoring, and dynamic inventory management, ultimately achieving intelligent cost optimization and enhanced operational efficiency in highway maintenance.

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