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PROJECT MONITORING AND CONTROL: A COST-BENEFIT ANALYSIS OF TRADITIONAL AND SMART TECHNOLOGY PRACTICES

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A B S T R A C T

Construction firms in developing regions such as the Philippines continue to rely on labor-intensive, paper-based project monitoring and control (PMC) methods, resulting in cost overruns, scheduling inaccuracies, and delayed decision-making. This study evaluates the economic feasibility of transitioning from Traditional PMC (T-PMC) to Smart Technology PMC (S-PMC) in the province of Bataan, Philippines, a context for which localized empirical evidence remains scarce. Using a quantitative design with purposive sampling, survey data were collected from 30 construction professionals to establish a T-PMC cost baseline. A Cost-Benefit Analysis (CBA) framework was then applied, incorporating internationally validated S-PMC reduction factors and locally sourced vendor cost data. Key financial metrics — Net Present Value (NPV), Benefit-Cost Ratio (BCR), and Return on Investment (ROI) — were computed over a five-year horizon using a 10% Social Discount Rate (SDR), anchored to a representative Php 150 million infrastructure project. Results indicate that S-PMC yields an NPV of Php 23,934,420, a BCR of 4.40, and an ROI of 340%, driven primarily by a 60% reduction in daily operational costs and significant savings from reduced rework and material waste. Sensitivity analysis confirmed financial viability even under conservative assumptions, yielding a minimum ROI of 115.1%. Survey findings further revealed a significant readiness gap: local professionals reported only slight awareness of advanced monitoring tools, and technology awareness was found to differ significantly across PMC adoption groups ($\chi^2(2) = 6.80$, $p = .033$). These findings confirm that, despite higher initial capital expenditure, investing in S-PMC delivers substantial long-term financial returns. The study recommends phased adoption beginning with BIM and digital project management software, supported by targeted training and government-backed digital infrastructure programs.

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1. INTRODUCTION

The global construction industry is undergoing rapid digital transformation, driven by mounting pressures to reduce cost overruns, minimize delays, and enhance transparency in project delivery. Despite this trend, developing regions such as the Philippines remain predominantly reliant on manual, paper-based monitoring methods. According to Layno and Famadico (2024), only approximately 25% of Philippine construction firms have adopted digital tools, with adoption constrained by skills gaps and the widespread perception that smart technologies represent a luxury expense rather than an operational necessity (Takyi-Annan & Zhang, 2023).

Smart construction technologies — including Building Information Modeling (BIM), Internet of Things (IoT) sensors, and drone-based aerial intelligence — offer data-driven solutions that enhance transparency, safety, and productivity. However, the financial justification for their adoption in provincial and developing-region contexts remains insufficiently documented. Existing cost-benefit evidence is drawn largely from India, England, and the United States (Das et al., 2025; Qadir et al., 2025), raising concerns about direct transferability to lower-resource provincial environments such as Bataan, Philippines.

Bataan is a province in Central Luzon characterized by an industry-based economy in which construction activity plays a substantial role, particularly in infrastructure development. Despite this economic significance, construction firms in the province continue to rely on traditional, manual PMC systems characterized by daily progress reports, manual Gantt charts, and paper-based workflows. These practices have been associated with persistent cost overruns and scheduling delays attributable to slow communication, untimely data collection, and reactive management approaches (Sami Ur Rehman et al., 2023).

This study addresses this gap by conducting a quantitative, comparative Cost-Benefit Analysis (CBA) of T-PMC and S-PMC during the project execution phase in Bataan. The specific objectives are: (1) to establish a baseline profile of current PMC practices among Bataan construction professionals; (2) to assess industry awareness of, and perceived challenges associated with, smart monitoring technologies; (3) to quantify the costs and monetized benefits of both PMC approaches; and (4) to compute and compare NPV, BCR, and ROI under baseline and sensitivity scenarios.

The findings are intended to provide construction firms with a rigorous economic rationale for technology investment, inform local government units on efficient public fund utilization, support academic curriculum development, and furnish technology providers with localized market intelligence. The study is limited to Bataan-based firms, applies internationally validated S-PMC reduction factors given the absence of comprehensive local adoption data, and excludes qualitative stakeholder perception factors outside the survey instrument.

2. METHODOLOGY

2.1 Conceptual Framework

The study follows an Input-Process-Output (IPO) framework. Inputs comprise current PMC practice profiles, available S-PMC technology parameters, and associated cost and benefit data. The process applies a CBA framework involving monetization of tangible and intangible costs and benefits, application of the Social Discount Rate (SDR), and computation of NPV, BCR, and ROI. Outputs include a quantitative comparison of T-PMC and S-PMC approaches and determination of the more economically viable system. The framework provides an evidence-based foundation for recommending the most effective PMC approach for Bataan's construction sector.

2.2 Research Design and Sampling

A quantitative research design was employed. Data were collected from 30 construction professionals operating in Bataan through purposive sampling, targeting individuals with direct involvement in project monitoring and control activities. Survey instruments were validated by subject-matter experts and pilot-tested prior to full deployment. Internal consistency was confirmed using Cronbach's Alpha, yielding coefficients ranging from $\alpha = .773$ to $\alpha = .959$ across subscales, indicating acceptable to excellent reliability (Nunnally, 1978). Participants occupied roles including Project Manager (23.3%), Project Engineer (20.0%), Site Engineer (20.0%), Cost Engineer (10.0%), and other related roles (26.7%).

The authors acknowledge that a sample of 30 represents an exploratory baseline rather than a statistically representative census of the Bataan construction industry. Accordingly, all generalizations are bounded to the surveyed firms and the study is positioned as a foundational pilot warranting future validation with larger, probability-based samples.

2.3 Cost-Benefit Analysis Framework

The CBA modeled a five-year lifecycle anchored to a representative infrastructure project valued at Php 150 million, consistent with the modal project cost tier reported by the survey respondents (36.7% indicated projects exceeding Php 100 million). The Social Discount Rate of 10% was selected in alignment with Philippine government economic analysis guidelines (Zhuang et al., 2007). This rate reflects the opportunity cost of capital in the Philippine public infrastructure context.

Traditional PMC costs were derived directly from survey respondents using mode category midpoints, with open-ended upper categories estimated at 1.5× the stated lower bound. S-PMC costs were sourced from local vendor quotations current as of March 2026 (MakerLab, Henry's Camera, Taradigm, Autodesk, CAAP, Microcadd Institute, NobleProg Philippines) and from 2026 labor

market benchmarks (JobStreet, SalaryExpert). S-PMC benefit reduction factors were drawn from peer-reviewed international literature.
NPV was computed as the present value of total benefits minus the present value of total costs. BCR was computed as the ratio of total discounted benefits to total discounted costs. ROI was computed as net benefit divided by total investment cost, expressed as a percentage:

ROI (%) = [(Total PV of Benefits − Total PV of Costs) / Total PV of Costs] × 100

A three-scenario sensitivity analysis was conducted: (a) Conservative — benefit reductions halved (e.g., rework at 10% instead of 20%; daily operational savings at 30% instead of 60%) with costs increased 10–20%; (b) Base Case — published reduction factors applied at face value; and (c) Optimistic — upper-bound reduction rates applied (e.g., contractual penalty savings at 50%; time savings at 15%) with costs reduced 10–20%.

2.4 Statistical Analysis

Descriptive statistics (frequency distributions, percentages, weighted means) were computed to characterize respondent profiles and PMC practice baselines. Perceived effectiveness and awareness were measured on four-point Likert-type scales. A Kruskal-Wallis H test was performed to assess whether perceived effectiveness, smart technology awareness, and perceived challenges differed significantly across three PMC adoption groups (Predominantly Traditional, Mixed, and Predominantly Smart Technology). Effect sizes were reported using epsilon-squared (ε^2).

3. RESULTS AND DISCUSSION

3.1 Respondent Profile and Current PMC Practices

Table 1 presents the demographic and professional profile of the 30 respondents. The sample reflects a mix of experience levels; notably, 46.7% reported fewer than five years of experience, while 36.7% had over a decade. Infrastructure projects constituted the dominant project type (53.3%), and 36.7% of respondents were involved in projects exceeding Php 100 million in estimated cost — informing the Php 150 million CBA anchor. Private-sector firms comprised 50.0% of respondents.
Regarding PMC approach, 46.7% reported predominantly traditional methods, 46.7% used a mixed approach, and only 6.7% had predominantly transitioned to smart technology. Traditional practices were dominated by Daily Progress Reports (DPR), used by 90% of respondents, and Manual Gantt Charts (50%). Among smart technology options, 60% of respondents indicated these tools were 'Not Applicable' to their current workflows — a finding that underscores the low baseline adoption rate in the province.

Table 1. Demographic and Professional Profile of Respondents (N = 30)

Characteristic	f	%
Current Role		
Project Manager	7	23.3
Project Engineer	6	20.0
Site Engineer	6	20.0
Cost Engineer	3	10.0
Others	8	26.7
Years of Experience		
< 5 years	14	46.7
5–10 years	5	16.7
> 10 years	11	36.7
Primary Project Type		
Residential	11	36.7
Commercial	1	3.3
Industrial	2	6.7
Infrastructure	16	53.3
PMC Approach		
Predominantly Traditional	14	46.7
Mixed	14	46.7
Predominantly Smart Technology	2	6.7

3.2 Perceived Effectiveness of Current PMC Practices

Table 2 presents perceived effectiveness scores across project monitoring and project control dimensions.

Table 2. Perceived Effectiveness of Current PMC Practices (N = 30)

Item	M	SD	Interpretation
Project Monitoring			
Data Reliability	3.10	0.48	Effective
Reporting Speed	3.23	0.57	Effective
Real-Time Site Visibility	3.03	0.41	Effective
Resource Productivity	3.10	0.48	Effective
Composite	**3.12**	**0.39**	**Effective**
Project Control			
Schedule Adherence	3.03	0.49	Effective
Rework Prevention	3.00	0.59	Effective
Risk Mitigation	3.03	0.49	Effective
Issue Resolution	3.00	0.53	Effective
Resource Allocation	3.03	0.56	Effective
Composite	**3.02**	**0.44**	**Effective**

Note. 4-point scale: 1.00–1.75 = Very Ineffective; 1.76–2.50 = Ineffective; 2.51–3.25 = Effective; 3.26–4.00 = Very Effective.

All items fell within the 'Effective' range (M = 3.00 to 3.23 on a four-point scale), with no item approaching the 'Very Effective' threshold (≥ 3.26). Reporting Speed received the highest individual rating (M = 3.23, SD = 0.57), while Rework Prevention and Issue Resolution tied for the lowest (M = 3.00). These findings suggest that while traditional methods satisfy baseline functional requirements, they do not deliver the proactive, real-time management capabilities increasingly required for complex infrastructure projects.

The consistently moderate effectiveness ratings, combined with the high prevalence of DPR-based reporting (90%), reinforce the characterization of Bataan's construction industry as operating in a reactive rather than predictive monitoring posture — a condition that smart technologies are specifically designed to address.

3.3 Awareness of Smart Technology Practices

Table 3 presents awareness scores across five smart technology categories. The overall composite score of 2.40 (SD = 0.67) corresponds to 'Slightly Aware,' confirming that technology awareness represents a structural barrier to adoption. Familiarity was highest for intermediate digital tools — Digital PM Software (M = 2.90, 'Moderately Aware') and Drones/Aerial Intelligence (M = 2.83) — while advanced technologies including Digital Twins (M = 2.10), Blockchain (M = 2.13), and IoT Structural Health Monitoring (M = 2.17) registered the lowest awareness scores.

Table 3. Level of Awareness on Smart Technology Practices (N = 30)

Technology	M	SD	Interpretation
Intermediate Digital Tools			
Digital PM Software	2.90	0.88	Moderately Aware
BIM Visualization	2.53	0.97	Slightly Aware
Real-time Field Data Integration	2.37	0.96	Slightly Aware
IoT and Sensors			
RTLS Tracking	2.57	1.04	Slightly Aware
IoT Structural Health Monitoring	2.17	0.91	Slightly Aware
Biometric Wearables / Sensors	2.17	1.05	Slightly Aware
Drones and Reality Capture			
Drones / Aerial Intelligence	2.83	1.05	Moderately Aware
3D Laser Scanning	2.40	0.93	Slightly Aware
Advanced Analytics			
AI/ML Monitoring	2.33	0.96	Slightly Aware
Digital Twins	2.10	0.71	Slightly Aware
Cloud Collaboration	2.40	0.97	Slightly Aware
Emerging Smart Tools			
Blockchain	2.13	0.73	Slightly Aware
Smart Construction Objects	2.27	0.83	Slightly Aware
Overall Composite	**2.40**	**0.67**	**Slightly Aware**

Note. 4-point scale: 1.00–1.75 = Not Aware; 1.76–2.50 = Slightly Aware; 2.51–3.25 = Moderately Aware; 3.26–4.00 = Very Aware.

Zero respondents reported active adoption of IoT sensors. This technology awareness gap aligns with findings from Takyi-Annan and Zhan (2023) and is consistent with broader patterns of digital construction adoption in developing Southeast Asian economies.

3.4 Perceived Challenges and Benefits of Current PMC Practices

Table 4 presents composite scores for perceived benefits and challenges across cost, time, and quality dimensions, alongside an organizational readiness assessment. Cost benefits received the highest composite rating (M = 3.32, SD = 0.36), indicating that respondents perceive their current systems as providing measurable cost management value. However, time-related benefits registered the lowest composite score (M = 2.95), reflecting consensus that traditional methods are only marginally effective at managing schedules — a limitation consistent with the broader literature on paper-based construction monitoring (Sami Ur Rehman et al., 2023).

Table 4. Composite Scores for Perceived Benefits and Challenges (N = 30)

Dimension	M	SD	Interpretation
Cost — Benefits	3.32	0.36	Agree
Cost — Challenges	2.79	0.39	Agree
Time — Benefits	2.95	0.25	Agree
Time — Challenges	2.96	0.35	Agree
Quality — Benefits	3.15	0.28	Agree
Quality — Challenges	3.06	0.37	Agree
Organizational Readiness (IT Infrastructure)	2.87	0.51	Agree

Note. 4-point scale: 1.00–1.75 = Strongly Disagree; 1.76–2.50 = Disagree; 2.51–3.25 = Agree; 3.26–4.00 = Strongly Agree.

Organizational readiness for digital transformation scored 2.87 (SD = 0.51), indicating that basic IT infrastructure exists but comprehensive preparedness remains limited. This finding positions Bataan firms at a transitional juncture: foundational infrastructure is present, but targeted investment in skills and systems is required to enable full S-PMC implementation.

3.5 Comparative Analysis: PMC Approach Groups

Table 5 presents Kruskal-Wallis H test results comparing the three PMC adoption groups. Of nine subscales tested, only Smart Technology Awareness yielded a statistically significant difference ($\chi^2(2) = 6.80$, $p = .033$, $\varepsilon^2 = .234$, large effect). This finding carries important implications: it suggests that prior exposure to smart technologies is the primary differentiator between adoption groups, not perceived effectiveness or satisfaction with current methods. In practical terms, firms currently using traditional or mixed methods do not rate their PMC practices as significantly less effective — they simply remain unaware of the alternatives. This positions awareness campaigns and experiential training as the most strategically impactful interventions for driving industry-wide adoption.

The non-significant results across effectiveness, benefits, and challenges subscales (p > .05) should not be dismissed as null findings. Rather, they reveal that across all three adoption groups, respondents perceive similar cost, time, and quality performance from their respective PMC approaches — indicating that the financial case for S-PMC must be made on objective economic grounds (as demonstrated by the CBA) rather than relying on self-reported dissatisfaction with traditional methods.

Table 5. Kruskal-Wallis Test Results: PMC Approach Group Comparisons

Subscale	χ^2	df	p	ε^2
Effectiveness in Monitoring	2.751	2	0.253	0.095
Effectiveness in Control	1.438	2	0.487	0.050
Smart Technology Awareness	6.799	2	0.033*	0.234
Perceived Benefits – Cost	0.013	2	0.994	< 0.001
Perceived Challenges – Cost	0.310	2	0.857	0.011
Perceived Benefits – Time	5.058	2	0.080	0.174
Perceived Challenges – Time	1.367	2	0.505	0.047
Perceived Benefits – Quality	0.387	2	0.824	0.013
Perceived Challenges – Quality	2.360	2	0.307	0.081

Note. *$p < .05$. ε^2 = epsilon-squared effect size: 0.01 = small; 0.06 = medium; 0.14 = large. The Predominantly Smart Technology group (n = 2) was retained for completeness; its small size limits statistical power.

3.6 S-PMC Technology Cost Parameters

Table 6 summarizes S-PMC cost parameters and the reduction factors applied in the CBA. All cost data were sourced from Philippine vendors or validated local market benchmarks current as of March–April 2026. Reduction factors were derived from peer-reviewed international case studies; given the absence of localized S-PMC adoption data in Bataan, these factors represent conservative proxies. The sensitivity analysis (Section 3.8) directly addresses this limitation by testing scenarios in which reduction benefits are halved.

Table 6. S-PMC Technology Cost Parameters and Benefit Reduction Factors

Parameter	Value / Reduction Factor	Source
Hardware: 3D Laser Scanner	Php 59,499–83,899 / unit	MakerLab Philippines (2026)
Hardware: Drone	Php 14,290–140,890 / unit	Henry's Camera Philippines (2026)
Software: Revit (Autodesk)	Php 55,000 / user / year	Autodesk (2026)
Software: Primavera (initial)	Php 211,200–231,000 / user	Taradigm Philippines (2026)
Software: Primavera (annual)	Php 46,440–52,440 / year	Taradigm Philippines (2026)
Training: RPA Drone Certificate	Php 3,500	CAAP Philippines (2025)
Training: 3D BIM Level III	Php 18,000–19,000	Microcadd Institute (2026)
Training: IoT Data Management	Php 72,000–180,000	NobleProg Philippines (2026)
Labor: BIM Coordinator	Php 53,000–63,000 / month	JobStreet & SalaryExpert (2026)
Labor: Drone Operator	Php 33,000–40,000 / month	JobStreet & SalaryExpert (2026)
Labor: Data Analyst	Php 33,000–43,000 / month	JobStreet & SalaryExpert (2026)
Man-Hours (Reporting)	50% time reduction	Qadir et al. (2025) — BIM-based inspection
Safety Incident Costs	40% reduction	Khan et al. (2024) — IoT wearables, Pakistan
Contractual Penalties	14.5–50% reduction	Alnaser et al. (2023); Das et al. (2025) — BIM, India/Saudi Arabia
Daily Operational Costs	60% reduction	Das et al. (2025) — BIM adoption, India
Rework Percentage	20% reduction	Das et al. (2025) — BIM adoption, India
Material Waste Percentage	20% reduction	Qadir et al. (2025) — BIM+IoT, England
Project Completion Time	10–15% reduction	Ariono et al. (2022); Qadir et al. (2025) — England

Note. All cost data sourced from Philippines-based vendors; reduction factors sourced from peer-reviewed international literature. Cost figures represent midpoints of quoted ranges used in the base case scenario.

3.7 Traditional and Smart PMC Cost Baselines

Table 7 presents the Traditional PMC annual cost baseline derived from survey responses. The most significant cost drivers are daily operational costs (Php 9,750,000, computed as Php 37,500/day × 260 working days, derived from the survey mode midpoint for daily site overhead) and material waste (Php 3,750,000, representing 2.5% of the Php 150M project value). These two items alone account for Php 13,500,000 of the annual cost burden. By contrast, initial hardware investment is minimal (Php 100,000), with no software or training expenditure — reflecting the 'low entry, high loss' profile characteristic of reactive, manual-based management.

The daily operational cost figure of Php 37,500 per day was derived as the weighted modal midpoint from survey responses pertaining to total daily site overhead, including supervision personnel, reporting labor, and indirect coordination costs. While this figure represents a conservative estimate for a Php 150M infrastructure project, it was deliberately tested at half its value in the conservative sensitivity scenario.

Table 7. Traditional PMC Annual Cost Baseline (Php 150M Reference Project)

Cost Parameter	Amount (Php)
Initial Investment (Year 0)	
Hardware	100,000
Software / Training	0
Annual Operating Costs	
Equipment Maintenance	45,000
PMC Personnel Salary (Php 32,500/mo × 12)	390,000
Reporting Labor (8 hrs/wk × 52 wks × Php 203.13/hr)	84,500
Annual Losses / Inefficiencies	
Safety Incident Costs	25,000
Contractual Penalties	0
Daily Operational Costs (260 days × Php 37,500/day)	9,750,000
Rework (1.0% of Php 150M)	1,500,000
Material Waste (2.5% of Php 150M)	3,750,000

Note. Daily operational costs computed as survey-derived modal midpoint for site overhead (Php 37,500/day) × 260 working days. Salary computed as monthly modal midpoint (Php 32,500) × 12 months. Reporting labor computed as 8 hrs/wk × 52 wks × Php 203.13/hr.

Table 8 presents the S-PMC cost profile. The total Year 0 CAPEX of Php 573,389 is dominated by software licensing (Revit + Primavera: Php 276,100) and specialized training (IoT: Php 126,000). Annual OPEX of Php 1,705,902 is heavily labor-driven, with the three specialized roles (BIM Coordinator, Drone Operator, Data Analyst) representing 93.2% of recurring costs at Php 1,590,000 per year. This labor intensity underscores a key implementation prerequisite: the S-PMC framework delivers value through human expertise, necessitating investment in both hiring and skills development.

Table 8. Smart Technology PMC Cost Profile (Php 150M Reference Project)

Cost Parameter	Amount (Php)
Initial Investment — Year 0 CAPEX	
3D Laser Scanner (1 unit, midpoint)	71,699
Drone (1 unit, midpoint)	77,590
Revit License (1 user, annual)	55,000
Primavera Installation (1 user, midpoint)	221,100
RPA Controller Certificate	3,500
3D BIM Level III Certification (midpoint)	18,500
IoT Data Management Training (midpoint)	126,000
Total Year 0 CAPEX	**573,389**
Annual Operating Costs — OPEX (Years 1–5)	
Revit Annual Subscription	55,000
Primavera Annual Subscription (midpoint)	49,440
Scanner Maintenance (3% of unit cost)	2,151
Drone Maintenance (12% of unit cost)	9,311
BIM Coordinator Salary (Php 58,000/mo × 12)	696,000
Drone Operator Salary (Php 36,500/mo × 12)	438,000
Data Analyst Salary (Php 38,000/mo × 12)	456,000
Total Annual OPEX	**1,705,902**

Note. All figures represent midpoints of vendor-quoted ranges. Salary figures represent midpoints of 2026 market benchmarks from JobStreet Philippines and SalaryExpert.

3.8 Cost-Benefit Analysis: NPV, BCR, and ROI

Table 9 presents the CBA decision metrics for the S-PMC transition under the base case scenario. The analysis yields a strongly positive NPV of Php 23,934,420, a BCR of 4.40, and an ROI of 340.0%, computed over a five-year horizon at a 10% SDR. The BCR of 4.40 indicates that for every peso invested in S-PMC systems and operations, the firm recovers Php 4.40 in monetized benefits — a return driven primarily by the 60% reduction in daily operational costs, which contributes the largest single benefit stream.

Table 9. Summary of CBA Decision Metrics — Base Case Scenario

Metric	Value (Php)	Decision Indicator
Total PV of Benefits	30,974,519	—
Total PV of Costs	7,040,099	—
Net Present Value (NPV)	**23,934,420**	NPV > 0: Viable
Benefit-Cost Ratio (BCR)	**4.40**	BCR > 1: Beneficial
Return on Investment (ROI)	**340.0%**	Positive return

Note. SDR = 10%; five-year lifecycle; anchored to Php 150M infrastructure project. ROI = [(Total PV of Benefits − Total PV of Costs) / Total PV of Costs] × 100. All values in Philippine Pesos.

The annual benefit calculation applies the internationally validated reduction factors (Table 1) to the T-PMC baseline costs to derive monetized annual savings. Total discounted benefits of Php 30,974,519 substantially exceed total discounted costs of Php 7,040,099, confirming the economic superiority of S-PMC under base case conditions.

Table 10 presents results across all three sensitivity scenarios. Critically, even the conservative scenario — which halves all benefit reduction rates and increases costs by 10–20% — yields a strongly positive result: NPV of Php 9,027,882, BCR of 2.15, and ROI of 115.1%. This robustness finding directly addresses the limitation of applying international reduction factors to a Philippine provincial context: even if actual local benefits materialize at only half the internationally reported rates, the investment remains financially viable with a return exceeding 100%. The optimistic scenario yields an ROI of 406.2%, illustrating the upside potential if Philippine conditions approximate international benchmarks.

Table 10. Sensitivity Analysis Results Across Three Scenarios

Metric	Conservative	Base Case	Optimistic
Annual Benefits (Php)	4,451,125	8,171,000	8,414,750
Year 0 CAPEX (Php)	688,067	573,389	486,321
Annual OPEX (Php)	1,888,082	1,705,902	1,534,165
NPV (Php)	**9,027,882**	**23,934,420**	**25,596,508**
BCR	**2.15**	**4.40**	**5.06**
ROI	**115.1%**	**340.0%**	**406.2%**

Note. Conservative: benefit reductions halved (e.g., rework at 10%, daily ops at 30%), costs +10–20%. Optimistic: upper-bound reductions (e.g., penalties at 50%, time savings at 15%), costs −10–20%. SDR = 10%, five-year horizon.

These findings collectively suggest that the perceived adequacy of traditional methods, as reflected in survey effectiveness scores, masks substantial hidden costs that smart technologies are specifically equipped to address. The 'low entry, high loss' profile of T-PMC — minimal upfront investment offset by millions in operational inefficiencies — represents a financially suboptimal equilibrium maintained primarily by low technology awareness and inertia rather than rational economic calculation.

4. CONCLUSION AND RECOMMENDATIONS

This study provides the first quantitative, CBA-based economic evaluation of smart project monitoring and control technologies in the province of Bataan, Philippines. The evidence supports three primary conclusions.

First, Bataan's construction industry operates with a significant technology awareness gap. The overall composite awareness score of 2.40 ('Slightly Aware') and zero reported adoption of IoT sensors confirm that advanced smart monitoring tools remain largely unknown to local practitioners. This gap is not attributable to dissatisfaction with current methods — perceived effectiveness scores across all PMC dimensions were rated 'Effective' — but rather to limited exposure, a finding confirmed by the Kruskal-Wallis analysis in which awareness was the sole significant differentiator across adoption groups ($p = .033$).

Second, traditional PMC practices in Bataan follow a 'low entry, high loss' cost structure in which nominal savings from avoiding technology investment are outweighed by systemic operational inefficiencies. For a representative Php 150 million infrastructure project, annual traditional PMC costs are dominated by daily operational overhead and material waste, amounting to losses that far exceed the cost of smart technology deployment.

Third, S-PMC is economically superior to T-PMC under all tested scenarios. The base case CBA yields an NPV of Php 23,934,420, a BCR of 4.40, and an ROI of 340%. Even under the conservative scenario, which deliberately discounts international reduction factors by 50% to account for potential Philippine-context gaps, all metrics remain strongly positive (NPV: Php 9,027,882; BCR: 2.15; ROI: 115.1%). This robustness to pessimistic assumptions provides a compelling, risk-adjusted financial rationale for S-PMC adoption.

Based on these findings, the following recommendations are offered. Construction firms should initiate phased S-PMC adoption beginning with the most familiar and accessible tools — BIM software and digital PM platforms — before progressing to drone-based monitoring and IoT systems. Industry associations and academic institutions, including those in Bataan, should conduct targeted awareness campaigns that reposition smart technologies as economic necessities rather than optional enhancements. Government agencies responsible for public infrastructure procurement should consider incorporating S-PMC requirements into contractor evaluation criteria, thereby accelerating industry-wide transformation. Future research should expand this study's sample to a probability-based framework, validate the applied international reduction factors against Philippine-specific implementation data, and model CBA outcomes across multiple project cost tiers to capture the scale-dependency of technology returns.

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