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# A Complexity-Based Framework for Estimating Inspection Budgets for Transportation Infrastructure: The Case of Vietnam

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**Abstract**

Accurate and transparent estimation of inspection budgets is essential for maintaining the safety, functionality, and resilience of transportation infrastructure. In Vietnam, however, budgeting practices for bridge inspections remain constrained by outdated cost norms, inconsistent estimation methods, fragmented data systems, and limited adoption of risk-informed planning. This study develops a complexity-based framework that integrates international best practices with Vietnam's legal and institutional context to improve inspection budget estimation. Using a mixed-methods approach—including legal and document review, comparative analysis, and validation through practical cases—the study proposes three key enhancements: (i) defining cost-driving factors within inspection terms of reference, (ii) improving cost data quality through strategic cost management initiatives, and (iii) matching estimation techniques to inspection complexity classes. The resulting framework provides a structured, scalable basis for more accurate and defensible budgeting. The findings offer actionable insights for policymakers and practitioners in Vietnam and other developing countries seeking to modernize inspection budgeting systems, strengthen resource allocation, and support long-term infrastructure sustainability.

## 1. Introduction

Transportation infrastructure, including bridges, forms the backbone of economic growth, social development, and security worldwide. Roads, bridges, railways, and airports connect people and markets, underpinning national competitiveness and resilience. Globally, the maintenance and management of these assets have become increasingly challenging as infrastructure ages and traffic demands intensify. According to the American Society of Civil Engineers, cited by Infrastructure Report Card [1], the U.S. alone faces a backlog of over $125 billion in bridge repairs, with 42% of bridges at least 50 years old. In Europe [2] and Japan [3], similar concerns have led to the adoption of advanced asset management and inspection budgeting systems, integrating risk assessment, lifecycle costing, and data analytics to ensure safety and optimize expenditures .

In developing countries, the situation is often more acute. Vietnam, for example, is experiencing rapid infrastructure expansion while simultaneously grappling with the degradation of its legacy transportation assets. Many bridges and roads were built decades ago with modest technical standards and have since endured severe weather, heavy loads, and the lingering effects of war [4, 5]. According to recent government reports, a significant proportion of Vietnam's bridges are small-scale, technically simple, and have suffered extensive deterioration, threatening both safety and operational efficiency [6]. This situation is not unique to Vietnam; the World Bank (2022) highlights that inadequate inspection and maintenance are key contributors to infrastructure failures in low- and middle-income countries [7].

To carry out inspection job for facilities in general and for bridges in particular, it is necessary to have an inspection outline (or inspection plan, or terms of reference) including a budget (cost estimate) for this activity. Accurate estimation of inspection budgets is vital for effective infrastructure management. In advanced economies, agencies such as the U.S. Federal Highway Administration (FHWA) and the European Commission employ a combination of unit price, resource-based, and risk-based estimation methods, often supported by comprehensive databases and predictive analytics. These approaches enable transparent, data-driven allocation of inspection resources, prioritizing critical assets and ensuring value for money [8].

However, current practices for estimating inspection budgets in Vietnam face major challenges. Outdated cost norms, inconsistent application of estimation methods across regions, and limited use of risk-based prioritization have resulted in inefficiencies, budget mismatches, and delays in maintenance decision-making [9]. These issues are particularly problematic for bridge inspections during the operational phase, where timely and accurate budgeting is critical for sustaining infrastructure safety and longevity. Additionally, while Vietnam's regulatory framework provides detailed technical guidance for inspection procedures, it offers limited methodological instruction on how inspection budgets should be structured, adjusted for task complexity, or updated in response to technological advancements.

Despite the global literature on inspection planning, cost estimation, and asset management, a notable research gap remains: few studies propose a structured budgeting method tailored to environments where cost norms are outdated, data systems are fragmented, and infrastructure varies widely in complexity. Existing research does not address how estimation techniques should be matched to inspection-task characteristics, nor how Vietnam's legal and institutional constraints shape the budgeting process. This gap underscores the need for a context-sensitive, complexity-aware method that aligns international best practices with Vietnam's operational realities.

This research addresses these gaps by systematically analyzing the theoretical and practical aspects of inspection budget estimation in Vietnam. It compares Vietnamese practices with international methods, identifies root causes of current shortcomings, and proposes tailored improvements. The study draws on legal documents, technical standards, and empirical data from Vietnamese bridge inspections to provide actionable recommendations. The key contribution of this study is the development of an improved inspection-budgeting framework that (i) specifies cost-driving factors in inspection tasks, (ii) classifies inspection jobs by complexity, and (iii) matches appropriate estimation techniques to each complexity class. This approach enhances accuracy, transparency, and consistency, while remaining compatible with Vietnam's cost-norm–based system.

Although the research scope is limited to bridge inspection during operation, the proposed framework can serve as a foundation for future applications to other infrastructure types.

The remainder of this paper is structured as follows. Section 2 provides an overview of theoretical background and international practices related to inspection budgeting methods. Section 3 reviews the current Vietnamese regulatory framework and practices for inspection cost estimation. Section 4 introduces the proposed improved method, including its rationale, structure, and practical steps for implementation. Section 5 discusses the application of the proposed approach through case examples and synthesizes key policy recommendations. Finally, Section 6 concludes the study by summarizing the main findings, identifying limitations, and suggesting directions for future research.

## 2. Literature Review

This section reviews the existing literature on (i) transportation infrastructure and its lifecycle, (ii) the concept and role of infrastructure inspection, and (iii) global approaches and techniques for estimating inspection budgets. Together, these strands provide the conceptual foundation for developing an improved budgeting method tailored to Vietnam's context.

### 2.1.1 Transportation Infrastructure and Its Lifecycle

Transportation infrastructure—including roads, bridges, tunnels, and railways—serves as the backbone of national economies, enabling mobility, trade, and social connectivity [10-12]. The lifecycle of these assets generally comprises several key phases: planning and design, construction, operation and maintenance, inspection and rehabilitation, and decommissioning [13]. Effective management across these phases is crucial to ensure safety, serviceability, and cost-efficiency. Within this lifecycle perspective, inspection is a pivotal activity that links technical condition assessment with maintenance planning and financial decision-making.

### 2.1.2 Concept and Role of Infrastructure Inspection

Infrastructure inspection is a critical process that involves evaluating the physical condition and performance of infrastructure assets to identify defects, deterioration, and safety risks. This process typically includes visual assessments, non-destructive testing (NDT), material sampling, and structural analysis. The insights gained from inspections play a vital role in guiding decisions related to maintenance, repair, and rehabilitation, ultimately ensuring the continued safety and serviceability of infrastructure systems [14, 15].

In Vietnam, infrastructure inspection is a legally mandated activity. According to Clause 9, Article 2 of Decree No. 06/2021/ND-CP, issued by the Government of Vietnam, construction inspection is defined as "the activity of checking and evaluating the quality, causes of damage, value, service life, and other technical parameters of a construction product, component, or structure through monitoring, testing, and analytical calculations" [16]. The regulation also distinguishes between two important concepts: the “design service life,” which refers to the period a structure is expected to function safely and effectively under normal use, and the “actual service life,” which reflects the period the structure is actually in use while maintaining its intended safety and functionality [16].

Infrastructure naturally deteriorates over time due to various mechanisms—such as corrosion of reinforcement in concrete bridge decks or the scouring of abutments caused by water flow. While timely interventions can restore asset conditions, precise knowledge of deterioration patterns and intervention outcomes is rarely available in advance. Thus, inspection becomes essential for condition monitoring and informed asset management [17].

The growing age of infrastructure, combined with increasing urbanization and climate-related pressures, has elevated the importance of systematic inspections. Both traditional and advanced inspection techniques are now indispensable for enabling risk-informed infrastructure management [18, 19]. The core function of inspection is to detect early signs of structural distress or material degradation, allowing for proactive responses that prevent failures and optimize long-term performance [20].

Infrastructure inspection contributes significantly to four key outcomes:

- Safety assurance: By identifying structural vulnerabilities early, inspections help prevent catastrophic failures and ensure user safety.
- Asset longevity: Routine monitoring extends the useful life of infrastructure and reduces the need for premature reconstruction.
- Regulatory compliance: In many countries, periodic inspections are legally required—for instance, under high-consequence area (HCA) pipeline regulations or ASCE waterfront standards.
- Operational and financial stability: By avoiding unexpected failures, inspections help maintain service continuity and protect investment returns.

In the absence of inspection, several risks may arise (Fig. 1), including:

- Load-related risks: Overloading or excessive displacement can render structures unusable or cause collapse.
- Service life risks: Degradation can significantly reduce the actual lifespan compared to the design life.
- Legal risks: Failure to meet regulatory requirements can result in denied approvals or certifications.
- Business risks: Poor condition may impair facility usage, reduce revenue, or halt operations.
- Cost risks: Deferred inspections often lead to higher repair, retrofit, or reconstruction costs.


**Fig. 1** *The risks of operation construction works withouth inspection*

Inspection methodologies can vary in sophistication and application context (Fig. 2). Common approaches include:

- Traditional visual and manual inspections: Conducted by trained personnel, these assessments provide basic condition insights but are limited in their ability to detect hidden or internal damage [21].
- Non-Destructive Testing (NDT) and Remote Visual Inspection: Techniques such as ultrasonic testing, eddy current analysis, and borescopes allow for internal condition assessment without damaging the structure. These are particularly valuable in confined or hazardous environments [14].
- Robotic and automated systems: Robots and autonomous crawlers equipped with tools like ground-penetrating radar and high-resolution cameras enhance inspection precision while reducing human risk [15].
- Sensor-based and vision-laser systems: Technologies such as LiDAR, thermal imaging, embedded sensors, and AI-driven vision systems provide continuous, high-resolution monitoring, supporting digital twins and predictive maintenance.

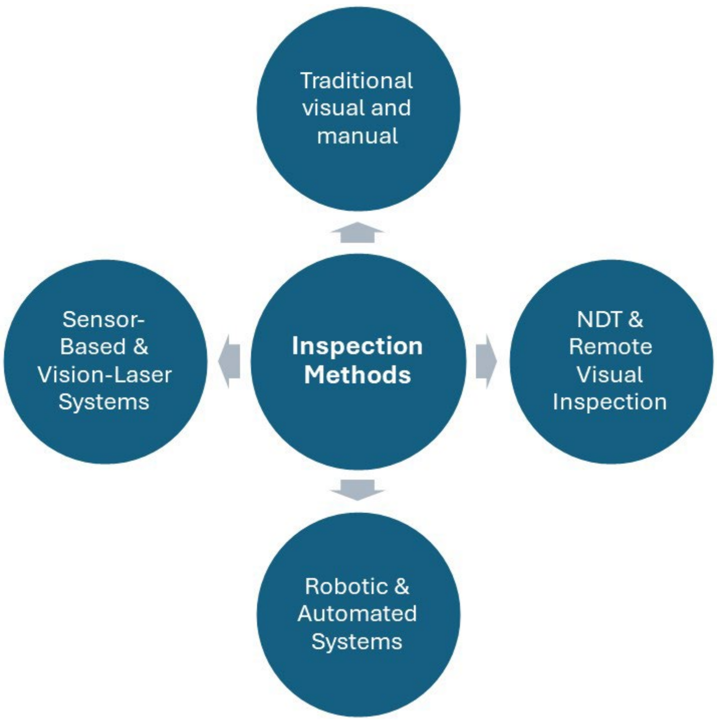


**Fig. 2** *Key inspection approaches*

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Around two decades ago, the concept of Risk-Based Inspection (RBI) emerged as a transformative approach [22]. RBI prioritizes inspections based on the likelihood and consequences of failure, optimizing inspection intervals to balance safety with cost-efficiency. Originally used in high-risk sectors like the process industry (e.g., pipelines), RBI has since influenced civil infrastructure management.

More recently, inspection data has been integrated into asset management systems, such as Bridge Management Systems (BMS) or Pavement Management Systems (PMS). These systems use inspection-generated metadata to support data-driven decision-making for maintenance prioritization and financial forecasting [23, 24].

The benefits of infrastructure inspection are multifaceted. Early detection of problems reduces downtime and the scale of necessary interventions. Health and safety are improved by limiting human exposure to hazardous conditions. Financially, the shift from reactive to predictive maintenance helps reduce long-term costs and defer capital investments in asset replacement.

Ultimately, infrastructure inspection is not just a technical procedure but a strategic tool for lifecycle planning. It provides a foundation for prioritizing investments based on asset condition, associated risks, and performance targets [25, 26]. As technologies continue to evolve, the role of inspection will remain central to enhancing infrastructure resilience, optimizing asset value, and advancing sustainable development objectives. However, while the literature clearly emphasizes the importance of inspection for asset management, it provides comparatively less guidance on how inspection activities should be budgeted in practice—particularly under normative cost systems such as those in Vietnam.

### 2.1.3 Global Methods for Estimating Inspection Budgets

Budgeting for infrastructure inspections—especially for bridges—is a fundamental component of asset management that directly impacts safety, serviceability, and fiscal responsibility. Around the world, transportation authorities use a variety of approaches to estimate inspection budgets, shaped by regulatory frameworks, data maturity, risk tolerance, and infrastructure priorities. The most prevalent global methods include condition-based, risk-based, life-cycle cost-based, and performance-based budgeting. To implement these approaches effectively, agencies rely on proven estimation techniques rooted in project management best practices. Understanding and applying these approaches appropriately is critical for efficient resource allocation and long-term infrastructure resilience [27].

**(1) Different approaches for Estimating Inspection Budgets**

** Condition-Based Budgeting [28, 29] : Reacting to Deterioration*

Condition-based budgeting is a widely adopted approach that allocates inspection resources and budgets according to the observed physical state of infrastructure assets. At its core, this method relies on periodic visual assessments, often structured through standardized frameworks such as the U.S. National Bridge Inventory (NBI) or the UK's Bridge Condition Index (BCI). By linking funding decisions directly to tangible deterioration, it offers a practical and intuitive method for managing limited inspection budgets.

The appeal of this approach lies in its straightforwardness. Engineers and decision-makers find it accessible because it translates visible deterioration into actionable priorities. In environments where resources are constrained, this method ensures that attention is focused on structures exhibiting clear signs of wear or damage, helping to mitigate immediate safety concerns.

Advantages:

- Data-Driven Prioritization: Allocates funds to assets in poor condition, reducing the risk of sudden failure.
- Transparency and Simplicity: Stakeholders can clearly trace budget decisions to inspection findings.

Limitations and Considerations:

- Reactive by Design: May encourage deferral of maintenance until defects are visible, often increasing total costs.
- Subjectivity and Inconsistency: Visual inspections vary depending on inspector training, weather, and inspection method.
- Neglect of Hidden Risks: Bridges with aging components but acceptable visual condition may be overlooked.

Despite its practicality, condition-based budgeting has inherent weaknesses when used in isolation. Its reactive nature may result in higher lifecycle costs, and the subjectivity of visual inspections can undermine consistency. Therefore, integrating this approach with risk- or performance-based budgeting can significantly improve its effectiveness. Such integration allows asset managers to address both visible deterioration and underlying vulnerabilities, promoting more proactive, data-informed decision-making that supports long-term infrastructure sustainability.

** Risk-Based Budgeting [30]: Balancing Safety and Cost*

Risk-based budgeting offers a strategic shift from traditional methods by integrating both the probability of failure and the potential consequences into funding decisions. Unlike condition-based approaches that focus solely on visible deterioration, this method takes a more comprehensive view, incorporating factors such as traffic volume, detour availability, environmental vulnerabilities, and the socioeconomic role of each asset. While structural condition remains a component, risk-based budgeting broadens the lens to assess the impact of failure on communities and infrastructure systems.

This approach enables agencies to move toward proactive asset management. By identifying and prioritizing structures with high potential for catastrophic impact, it supports more informed and forward-looking investments. It is particularly beneficial in areas prone to natural disasters—such as earthquakes or floods—or where transportation alternatives are limited and failures can result in severe disruptions.

Advantages:

- Holistic Prioritization: Structures critical to safety, mobility, or the economy are funded even if their physical condition is only moderately degraded.
- Improved Resilience: Emphasizes reducing systemic risks rather than reacting to isolated issues.

Limitations and Considerations:

- Data and Analytical Demands: Requires comprehensive and reliable datasets and may involve advanced tools such as GIS, traffic simulation, and probabilistic failure modeling.
- Equity Concerns: Socially important but low-traffic rural bridges may be overlooked if the risk framework narrowly defines significance.

Successfully adopting a risk-based budgeting approach often necessitates institutional reforms, expanded technical capacity, and collaboration across multiple sectors. While the initial investment in tools and data systems can be substantial, the long-term benefits include more effective resource allocation, reduced emergency repair needs, and enhanced network resilience. Ultimately, this approach supports a transition from reactive maintenance to a more strategic and anticipatory model of infrastructure management.

** Life-Cycle Cost Analysis (LCCA) [31]: A Long-Term Investment Perspective*

Life-Cycle Cost Analysis (LCCA) offers a comprehensive approach to budgeting by evaluating the total cost of ownership for a bridge or infrastructure asset across its entire life span. Rather than focusing solely on immediate expenditures, LCCA accounts for initial construction, ongoing inspections, routine maintenance, major rehabilitation, and eventual demolition. This shift in perspective encourages decision-makers to look beyond short-term budgets and instead aim to maximize value over the asset's lifetime.

The strength of LCCA lies in its ability to support proactive and strategic planning. By comparing the long-term financial implications of different maintenance and inspection schedules, agencies can make more informed decisions about when to invest in repairs, how often to inspect, and when to consider asset replacement. It also fosters a culture of cost-effectiveness, where early interventions are prioritized to prevent more expensive failures later.

Advantages:

- Prevention Over Cure: Enables just-in-time interventions that are more cost-effective than deferred repairs.
- Policy Alignment: Helps justify higher initial investments for long-term savings and asset preservation.

Limitations and Considerations:

- Data-Intensive: Requires deterioration models, maintenance histories, and accurate cost projections.
- Uncertainty: Future conditions, material behavior, and usage patterns may not follow predictions.

When integrated into broader asset management systems and reinforced by predictive analytics, LCCA becomes a powerful tool for optimizing infrastructure investments. Its effectiveness depends heavily on the availability and quality of data, as well as institutional capacity to interpret and act on the insights it provides. For agencies with strong data governance and long-term planning frameworks, LCCA offers significant opportunities to reduce lifecycle costs while enhancing infrastructure performance and reliability.

** Performance-Based Budgeting [32]: Funding Tied to Measurable Outcomes*

Performance-based budgeting represents a shift from input-focused spending to a results-oriented approach, where financial allocations are directly linked to achieving specific, measurable performance targets. These targets might include reducing the number of structurally deficient bridges, improving inspection intervals, or

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increasing compliance with safety standards. By aligning budget decisions with tangible outcomes, this method promotes more effective use of public funds and clearer accountability.

This approach supports the integration of budgeting processes with broader policy goals and infrastructure strategies. It enables governments and agencies to govern by results, ensuring that investments not only maintain infrastructure but also advance national objectives such as resilience, sustainability, and safety. Implementing agencies are incentivized to meet these targets, creating a culture of continuous improvement and strategic focus.

Advantages:

- Transparency and Motivation: Agencies are incentivized to meet performance targets.
- Strategic Coherence: Encourages alignment between technical efforts and broader policy priorities (e.g., Vision Zero, climate adaptation).

Limitations and Considerations:

- Metric Manipulation: Short-term fixes may be prioritized to quickly meet targets.
- Limited Flexibility: Rigid adherence to performance metrics may hinder adaptive responses.

For performance-based budgeting to succeed, the chosen metrics must be meaningful, aligned with long-term goals, and adaptable to changing conditions. Poorly designed indicators can distort priorities or encourage superficial compliance rather than genuine progress. However, when implemented with care, this budgeting approach strengthens transparency, links spending to results, and empowers infrastructure agencies to deliver higher value through improved planning, execution, and accountability.

**(2) Estimation Techniques Supporting Budgeting Approaches**

The estimation of inspection budgets, particularly in bridge and infrastructure management, requires the careful application of recognized techniques adapted from project and construction management disciplines. These techniques provide structured and justifiable means of predicting costs, each suited to different stages of project development, levels of data availability, and project complexity. While these methods differ in precision, data requirements, and use cases, they form the backbone of responsible budget planning and allow agencies to align technical needs with fiscal realities [33, 34].

One of the most widely used and flexible methods is expert judgment. Often referred to simply as expert-based estimation, this approach relies on the knowledge and experience of professionals who possess deep familiarity with similar projects, asset types, or regional contexts. It is particularly valuable in the early stages of a project or when conventional data sources are unavailable, such as in highly specialized inspections or in unique environmental conditions. The strength of this method lies in its adaptability and ability to incorporate insights that are often tacit or undocumented. Experts can draw on lessons from past projects, adjust for site-specific challenges, and anticipate risks that data alone may not reveal. However, because this approach is inherently subjective, it is susceptible to inconsistency, bias, and lack of reproducibility if not carefully documented. Despite this, expert judgment remains indispensable in conceptual planning, risk assessment, and wherever quantitative data is insufficient or incomplete [33].

Analogous estimating—also known as top-down or similar project estimating—is another commonly used technique, particularly during the feasibility and scoping phases. This method involves referencing the costs of past projects that are comparable in nature and scale to the current one, adjusting for any relevant differences in context or complexity. For example, the estimated cost for inspecting a bridge might be derived from similar inspections conducted on bridges of comparable type, size, and location. The primary appeal of analogous estimating is its simplicity and speed. It enables quick approximations and cost planning without requiring detailed technical information. However, the accuracy of this method depends heavily on how closely the current project resembles its historical reference. If contextual factors—such as regulatory changes, material prices, or technical standards—have shifted, the estimate may become unreliable. Nevertheless, this technique is highly practical for generating order-of-magnitude estimates and is often used as a starting point before transitioning to more detailed methods [33, 35].

Parametric estimating offers a more structured and data-driven approach by applying mathematical relationships between cost and measurable project parameters, such as square footage, bridge length, or inspection hours. Sometimes called model-based or statistical estimating, this method is particularly effective when supported by robust historical datasets and well-understood cost drivers. For instance, if historical data indicates that a certain type of bridge inspection typically costs $X per meter of span, that unit rate can be scaled to estimate costs for similar structures. The advantage of parametric estimating lies in its scalability and consistency. When calibrated appropriately, parametric models can produce reliable cost estimates quickly and are especially useful in comparative studies or for large-scale infrastructure programs. Still, the accuracy of parametric methods depends on the quality of the underlying data and the stability of market conditions. If data is outdated or not representative, the model's outputs can mislead decision-makers. As such, parametric estimating is most effective in mid-stage planning where sufficient data is available, but full design details are not yet finalized [33, 34].

For projects that require a high degree of accuracy, bottom-up estimating—also known as cost-based, detailed, or scratch estimating—is often the preferred technique. This method involves breaking the project down into its smallest components or work packages and calculating the cost of each in detail, before aggregating them into a total project estimate. It mirrors the approach taken by contractors when preparing formal bids, and thus produces estimates that are transparent, traceable, and defensible. Bottom-up estimating accounts for labor, materials, equipment, overhead, and profit, making it particularly suitable for final design phases or large, complex projects where accountability is paramount. While this method delivers the highest precision, it also requires significant time, effort, and expertise. Estimators must be familiar with construction techniques, local pricing, productivity rates, and scheduling constraints. Consequently, it is often used selectively—either for the most critical cost items or during later project stages when detailed technical information is available [33, 34].

To better manage uncertainty, especially in complex or novel inspection projects, many agencies turn to three-point estimating. This technique introduces probabilistic thinking into the estimation process by considering three scenarios: an optimistic estimate assuming minimal delays or cost inflation; a most likely estimate based on standard assumptions; and a pessimistic estimate reflecting worst-case conditions. The final estimate is typically calculated using a triangular or beta distribution formula, providing not only an expected value but also a clearer picture of cost variability. Three-point estimating is particularly useful in risk-sensitive environments, as it forces project teams to assess and communicate potential deviations from the norm. However, it demands careful calibration. If the three scenarios are not grounded in realistic assumptions, the results may distort budget planning rather than clarify it. This method is best applied to activities or cost items where uncertainty is high, such as inspections requiring permits, special equipment, or weather-dependent scheduling [33].

Lastly, reserve analysis plays a crucial role in determining how much contingency funding should be built into the overall inspection budget. Unlike other techniques that estimate the base cost of defined work, reserve analysis estimates the funds needed to address known and unknown risks. These reserves are often divided into two categories: contingency reserves, which cover identified uncertainties like quantity overruns or schedule slippage; and management reserves, which provide buffers for unforeseen events such as regulatory changes or natural disasters. The inclusion of reserves enhances the resilience of infrastructure programs and ensures that projects are not derailed by moderate deviations. However, the effectiveness of reserve analysis depends on the quality of the project's risk assessment. Without rigorous justification, reserve amounts may appear arbitrary—leading either to inflated budgets or inadequate protection. As a result, reserve analysis is most powerful when integrated into a comprehensive risk management process and updated regularly throughout the project lifecycle [33].

Taken together, these estimation techniques form a robust toolkit for agencies engaged in infrastructure inspection and asset management. Each method offers distinct benefits and trade-offs, and their effectiveness increases when used in combination, tailored to project stage and context. Whether applied independently or in concert, these techniques support more accurate, transparent, and defensible budgeting processes—ultimately ensuring that inspection resources are allocated efficiently, safely, and sustainably.

## 3. Inspection Budget Estimation in Vietnam: The Context

In Vietnam, the budgeting and implementation of infrastructure inspection activities are governed by a comprehensive legal framework. Key regulations include Decree No. 06/2021/ND-CP of the Government, which provides detailed provisions on quality management, construction, and maintenance of civil works. This decree, which came into effect on January 26, 2021, replaced Decree No. 46/2015/ND-CP and has since become the primary legal instrument for construction quality control and maintenance practices in the country [16, 36]. Supplementary guidance is provided through technical circulars, most notably Circular No. 10/2021/TT-BXD issued by the Ministry of Construction, which elaborates on labor safety management, construction quality and construction maintenance [37], and Circular No. 41/2024/TT-BGTVT from the Ministry of Transport, detailing the management and maintenance of road infrastructure [38].

According to Article 5, Clause 2 of Decree No. 06/2021/ND-CP [16], structural inspection activities are mandated in various scenarios. These include instances where such activities are specified in technical guidelines or contracts; when structural anomalies suggest a lack of safety or insufficient documentation for quality evaluation; upon the request of authorized agencies overseeing PPP projects; and when infrastructure has surpassed its design life but continues to be in use. Other mandatory conditions include maintenance planning needs, suspected damage or structural failure, and legal investigations into the causes of incidents.

This study focuses specifically on inspection activities conducted during the operation phase, with a particular emphasis on those supporting maintenance functions. In accordance with Clause 5, Article 33 of the same decree, inspections during operation are required in five main scenarios: (i) periodic inspection as prescribed in an approved maintenance manual; (ii) upon identification of damage or unsafe conditions in the structure; (iii) to support the creation of a maintenance plan for structures that have not yet been issued such a plan; (iv) to provide the basis for extending service life or upgrading structures whose design life has expired; and (v) when required by competent state authorities.

The scope of inspection activities is detailed in Clause 3, Article 5, which includes evaluating the quality of structural components, identifying the causes of damage or failure, and testing materials and construction elements. These inspections must be carried out based on an approved inspection outline (or inspection plan/terms of reference). As stipulated by Decree No. 10/2021/ND-CP [16], the inspection proposal must cover objectives, applicable standards, details about the personnel and laboratories involved, procedures, schedules, cost estimation, and other relevant technical specifications.

Clause 4, Article 5 of Decree No. 06/2021/ND-CP also provides guidance on how to determine inspection costs. Costs must be calculated according to current laws on construction investment cost management and based on either contractual content or approved inspection proposals [16]. Notably, if the inspection reveals defects attributable to contractors, the relevant parties are required to cover the inspection costs.

The process of preparing cost estimates is further governed by Decree No. 10/2021/ND-CP and several guiding circulars issued by the Ministry of Construction. These include Circular No. 11/2021/TT-BXD on construction investment cost management [39], Circular No. 14/2023/TT-BXD which introduces amendments to previous regulations [40], and Circular No. 01/2025/TT-BXD [41], which updates provisions from Circulars No. 11, 13, and 14. These legal instruments collectively outline the methodologies and normative bases for calculating inspection budgets. Table 1 summarizes the major groups of legal and technical documents used in preparing inspection cost estimates.

**Table 1** *Documentation as legal basis for estimating inspection budgets in Vietnam*

| Group | Documentation |
|---|---|
| 1 | Legal documents on construction cost management (Government decrees on cost control) |
| 2 | Guidelines for calculating cost components (materials, labor, equipment, etc.) |
| 3 | Documents related to applicable norms for inspection (construction, testing norms) |
| 4 | Financial regulations (circulars on tax, payment, settlement, etc.) |
| 5 | Local cost publications (prices for materials, labor rates, equipment rental, etc.) |
| 6 | Interpretive guidelines for non-standard costs (e.g., loading tests, preparation) |
| 7 | Other relevant supporting legal texts |

Source: Authors

A critical component in preparing inspection cost estimates is the use of the construction norms and unit price system, which serves as the official baseline for cost planning. Particularly relevant is the specialized testing norm system defined in Appendix V of Circular No. 12/2021/TT-BXD, which outlines norms for three key categories of construction inspections: testing of construction materials, testing of structural components and whole constructions, and laboratory testing in support of construction surveys [42].

Despite having a relatively complete legal and technical framework, challenges persist in applying these guidelines consistently across Vietnam. Cost norms are often outdated or rigid, failing to keep pace with market dynamics or evolving inspection technologies. Moreover, the decentralization of implementation and variations in local capacity can result in inconsistent and non-transparent budgeting practices. These limitations underscore the necessity for improved estimation methods that can better capture the true costs of inspection activities while accommodating both regulatory requirements and practical realities.

This paper seeks to address these challenges by proposing an improved method for estimating inspection budgets for transportation infrastructure in Vietnam. The proposed method aims to enhance accuracy, transparency, and adaptability, ultimately supporting more effective asset management and infrastructure sustainability.

## 4. Research Methodology

The research was conducted in several steps: Data Collection, Document Analysis, Comparative Analysis, Proposal of Improvement (Fig. 3).

The Data Collection gathers inspection budget documents, contracts, and legal regulations from Vietnamese consulting firms and government agencies. The next step, Document Analysis reviews legal frameworks, technical standards, and cost norms related to inspection budgeting. A Comparative Analysis was implemented to identify inconsistencies and gaps in current practices. The next step, Proposal of Improvement, will formulate improved estimation methods based on findings.

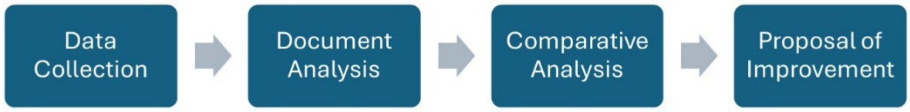


**Fig. 3** *The research flowchart*

## 5. Results and Discussion

### 5.1 The Current Issues in Transportation Infrastructure Inspection Budgeting in Vietnam

Vietnam's transportation infrastructure, particularly its bridge network, comprises a large number of small- to medium-scale structures, many of which were built decades ago under modest technical standards. These assets have since endured severe climatic conditions, steadily increasing traffic volumes, and, in some regions, residual damage from wartime, contributing to widespread structural degradation (Ministry of Transport, 2023). The growing prevalence of aging and vulnerable bridges underscores the urgent need for systematic and well-funded inspection programs.

Despite clear legal mandates and technical standards, the current process for estimating inspection budgets in Vietnam remains beset by several persistent shortcomings. Typically, cost estimates are prepared based on approved inspection outlines and standardized cost norms issued by the government. While these documents offer a procedural foundation, their application has been constrained by outdated assumptions and limited adaptation to contemporary needs.

One major issue lies in the outdated nature of cost norms. Many of the unit prices and norm-based calculations in use today are rooted in historical data that fail to account for inflation, regional variations, technological advancement, and evolving labor markets. As a result, current estimates often do not reflect actual market conditions or the modern techniques employed in inspection—such as drone surveys or non-destructive testing. In addition, there exists significant inconsistency in how consulting units and local authorities apply these estimation methods. Budget proposals may vary widely across provinces and projects, leading to inefficiencies and frequent mismatches between expected and actual costs.

Compounding these problems is the absence of risk-based prioritization in budget planning. While many advanced economies allocate inspection resources based on risk assessments—considering both the probability and consequence of asset failure—Vietnam's estimation process remains largely reactive and does not consistently incorporate asset criticality or condition data. Coordination between technical and financial units is also limited. In practice, this disconnection often results in inspection scopes that are misaligned with allocated budgets, delaying approvals and impairing project delivery.

In Vietnam, the inspection outline serves as the fundamental basis for cost estimation. Developed by the inspection contractor and approved by the project owner, this document outlines the scope, objectives, procedures, and technologies used in the inspection. From this outline, the budget is derived by assigning quantities and unit prices to each task. Key cost components typically include labor (engineers, technicians), equipment and materials, laboratory testing fees, and general overhead or contingency costs.

When inspections are implemented as part of a formal investment project—such as in cases requiring a basic design or technical-economic report—the budget must include a variety of cost items beyond direct inspection activities. The first cost item is the core inspection cost, which includes expenses for human resources, equipment, materials, field testing, laboratory analysis, and report preparation. These represent the essential tasks directly related to the physical assessment of the infrastructure. The second component is the project management cost, which covers the administrative and oversight responsibilities of the project owner. This includes managing the inspection schedule, coordinating between stakeholders, and ensuring compliance with regulations. The third major group involves construction investment consultancy costs, further broken down into two detailed items. The first sub-item is the survey cost for preparing the basic technical and economic report, which includes the preliminary assessments and data collection necessary to justify the inspection intervention. The second sub-item is the cost for preparing the technical and economic report itself, including engineering analysis, technical planning, and financial justification. These cost categories are used to prepare comprehensive budgets that support funding approval processes, particularly when inspections are embedded within broader infrastructure maintenance or rehabilitation programs. However, as discussed in the context section, such estimation practices are often applied inconsistently and may not reflect actual costs or risks without further refinement and standardization.

Nevertheless, this estimation structure remains vulnerable to bias and error due to the lack of standardized, regularly updated data. In practice, this often leads to overestimation or underestimation of actual costs, undermining both financial accountability and operational planning.

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Furthermore, reliance on manual calculations and fragmented cost data contributes to approval delays and limits transparency. The absence of dynamic inspection cost databases and advanced planning tools exacerbates inefficiencies, especially for remote or technically complex bridge projects. As a result, resources may be allocated to non-critical structures, while high-risk assets remain underfunded and under-inspected.

Vietnam's current challenges contrast sharply with international practices. Agencies such as the U.S. Federal Highway Administration (FHWA), the European Commission, and the Japan Road Association have embraced data-driven, risk-sensitive approaches. These include the integration of asset management systems, life-cycle cost analysis, and the use of historical cost databases to improve estimation accuracy and guide resource allocation [43-46]. In Vietnam, however, cost estimation for inspection continues to follow a more prescriptive and less adaptive approach.

In response to these issues, there is a growing need for Vietnam to develop improved estimation methods that combine regulatory compliance with international best practices. Such a method should incorporate contextual factors—such as topography, asset complexity, and technological requirements—while allowing for flexibility, traceability, and regular updates. By doing so, inspection budgeting in Vietnam can become more transparent, consistent, and aligned with long-term infrastructure sustainability goals.

This paper aims to fill that gap by proposing an improved method for estimating inspection budgets of transportation infrastructure during the operational phase, grounded in both global practices and Vietnam's specific regulatory and institutional landscape.

## 5.2 Complexity-Based Framework for Inspection Budget Estimation

The research findings indicate that inappropriate budgeting for infrastructure inspection activities mainly stems from: (i) inadequate task terms of reference (in the inspection plan or inspection outline), (ii) incomplete or low-quality cost data, and (iii) mismatched cost estimation approaches that fail to reflect the diverse nature of inspection tasks. Below are the proposed solutions for addressing each of the issues (as summarised in Fig. 4), therefore the budgeting methods can be improved for bridges inspection in the condition of Vietnam.

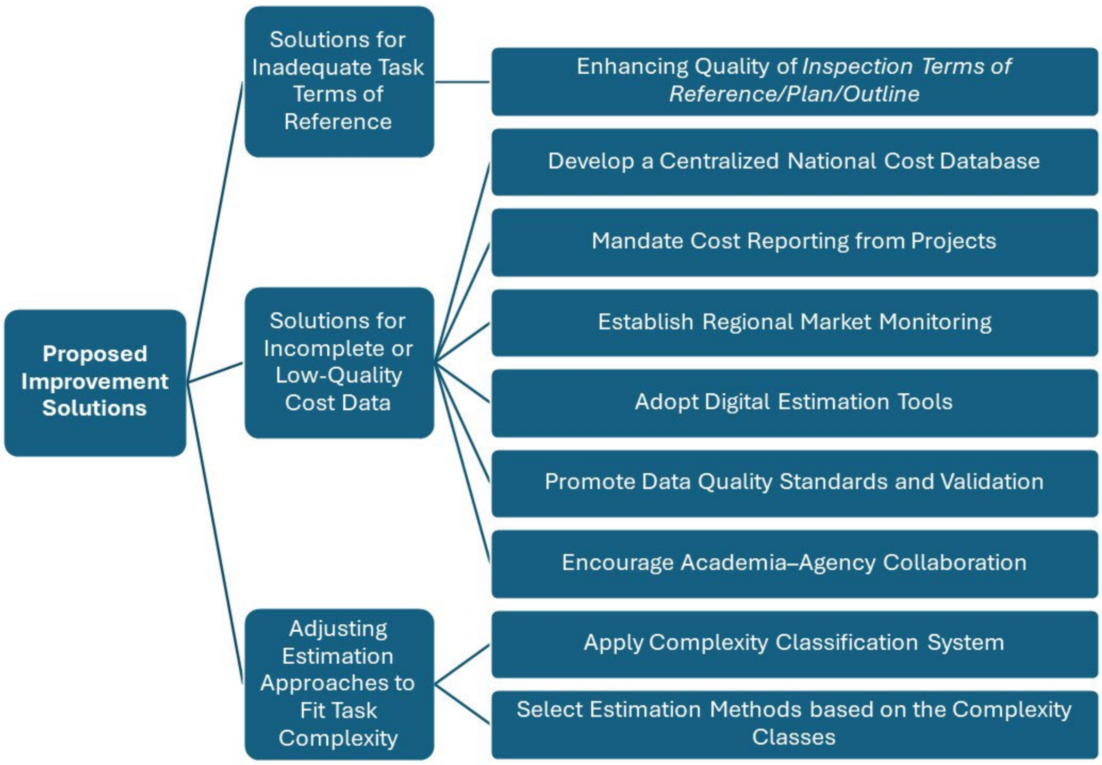


**Fig. 4** *The proposed solutions for improving budgeting method*

### 5.2.1 Defining Cost-Driving Factors in Inspection Terms of Reference

High-quality task outlines (inspection plans/tems of reference) help guide cost estimation effectively and minimize deviations, especially by correctly identifying cost-driving factors. These factors, detailed in Table 2 below, should be clearly defined in the inspection terms of reference.

**Table 2** *Key cost drivers to be specified in the inspection terms of reference/plan/outline*

| Factor | Cost Drivers |
|---|---|
| Inspection Methods & Techniques | Equipment, frequency, accuracy, and traffic disruption |
| Access & Safety Measures | Specialized vehicles, drones, divers, safety protocols |
| Structural and Foundation Complexity | Specialized vehicles, drones, divers, safety protocols |
| Environmental & Location Context | Size, materials, design, underwater elements |
| Frequency & Planning Approach | Remoteness, lighting, weather, terrain |
| Regulatory Requirements | Fixed intervals vs. lifecycle-based risk models |
| Administrative & Data Systems | Minimum inspection standards, certifications, environmental provisions |

Each factor is further elaborated as follows:

- **Inspection Methods & Techniques**: Basic visual inspections using under-bridge vehicles or bucket trucks are relatively inexpensive but may miss hidden defects. Advanced nondestructive evaluation (NDE) methods—such as Ground Penetrating Radar, Infrared Thermography, and drones—are costlier per inspection but enhance detection accuracy and reduce long-term costs. Traffic management measures (e.g., lane closures) can add substantial costs.
- **Access Methods & Safety**: Specialized access methods (e.g., snooper cranes, scaffolding, boats, or divers) significantly increase costs. Drones can reduce costs and safety risks by minimizing the need for heavy equipment.
- **Bridge Characteristics**: Larger or complex bridges (arched, truss, multi-span) require more inspection time and specialized techniques. Underwater or deep foundations necessitate divers or remote sensing technologies.
- **Location & Environmental Context**: Remote or challenging locations raise mobilization and logistics costs. Harsh climates may require more frequent inspections and specialized testing.
- **Inspection Frequency & Planning Models**: While some regions use fixed inspection intervals, risk-based scheduling (informed by deterioration models) can reduce lifecycle costs. Probabilistic models using Bayesian updating allow dynamic planning based on uncertainty.
- **Regulations & Standards**: National standards may mandate specific inspection types and frequencies (e.g., underwater inspections every 5 years per NBIS in the U.S.).
- **Administrative and Data Systems**: Investment in Bridge Management Systems (BMS) and inspection software improves efficiency but involves upfront costs. Training and staffing also affect cost and quality.

These factors should be integrated into the task outline to serve as the foundation for accurate cost estimation.

### 5.2.2 Enhancing Cost Data and Strategic Cost Management

There are several solutions for addressing this problem, as summarized in Table 3.

**Table 3** *Solutions for addressing incomplete or low-quality cost data*

| Solutions | Contents | Benefits |
|---|---|---|
| Develop a Centralized National Cost Database | Host by the Ministry of Transport or Construction.<br>Include regularly updated unit costs by region, bridge type, and complexity. | Standardization, benchmarking, and improved transparency |
| Mandate Cost Reporting from Projects | Require detailed post-project cost breakdowns (e.g., labor, equipment, access, traffic management, and methods used) | Builds a historical cost database for future estimates and enhances transparency |
| Establish Regional Market Monitoring | Regular surveys to update regional prices (e.g., cranes, scaffolding, traffic management) | Reflects actual market conditions and reduces reliance on outdated assumptions |

| Solutions | Contents | Benefits |
|---|---|---|
| Adopt Digital Estimation Tools | Use Excel or web-based tools integrated with the national cost database and inflation indexes. | Greater accuracy and institutional knowledge retention |
| Promote Data Quality Standards and Validation | Set standards for how data is reported and verified (e.g., minimum required fields, validation before entry into the national system) | Increases data reliability and trust in estimates |
| Encourage Academia–Agency Collaboration | Engage universities to develop cost models using machine learning or statistical methods. | Transforms data into actionable intelligence |

The solutions can be implemented with a strategic cost management Initiatives as in Fig. 4.


**Fig. 5** *The proposed timeline for strategic cost management initiatives*

### 5.2.3 Matching Estimation Methods to Inspection Complexity Classes

To address inappropriate estimation perspectives, inspection jobs should be classified by complexity and then matched with suitable estimation methods. Table 4, 5, 6, 7 illustrate the criteria for the job classification, using the dimensions of Structural Complexity, Access and Equipment Needs, Environmental and Location Context, and Inspection Method Requirements.

**Table 4** *Criteria for the dimension of structural complexity*

| Criteria | Description | Complexity Weight |
|---|---|---|
| Span length | Short (<30 m), Medium (30‑100 m), Long (>100 m) | ↑ Longer = more equipment and effort |
| Bridge type | Slab, girder, box girder, arch, cable-stayed, suspension | ↑ Non-standard = higher complexity |
| Material type | Concrete, steel, composite, masonry | ↑ Composite/steel = specialized NDE |

**Table 5** *Criteria for the dimension of access and equipment needs*

| Criteria | Description | Complexity Weight |
|---|---|---|
| Access difficulty | Easy ground access vs. need for cranes, scaffolding, or boats | ↑ Hard-to-access = higher cost |
| Overwater or underwater elements | Requires divers, sonar, or floating platforms | ↑ Underwater = specialist inspection |
| Traffic condition | Urban/highway vs. rural/local road | ↑ High-traffic = additional safety cost |

**Table 6** *Criteria for the dimension of environmental and location context*

| Criteria | Description | Complexity Weight |
|---|---|---|
| Terrain | Mountainous, delta, coastal, or flat | ↑ Complex terrain = logistics cost |
| Weather exposure | Subject to flooding, typhoons, corrosion (marine or industrial zones) | ↑ Harsh = higher frequency and scope |
| Remote location | Far from service centers or urban logistics | ↑ Remote = higher mobilization cost |

**Table 7** *Criteria for the dimension of inspection method requirements*

| Criteria | Description | Complexity Weight |
|---|---|---|
| Method type | Visual only, or includes NDE (ultrasound, GPR, thermography, etc.) | ↑ NDE = more labor and tech cost |
| Drone or robotic support | Requires drone, crawler, or AI-assisted scanning | ↑ Tech-enabled = upfront cost, but may reduce time |

This classification can be used by scoring the bridge to be inspected using a weighted checklist (e.g., 0–3 points per criterion). Total scores will determine the class:

Class I: Low Complexity
Class II: Moderate Complexity
Class III: High Complexity
Class IV: Very High Complexity

The class of the bridge inspection is used to determine the estimation method to be used for budgeting the bridge inspection. Table 8 shows the suggested methods for each of the classes.

**Table 8** *Matching estimation methods to complexity classes*

| Class | Complexity Level | Estimation Method(s) |
|---|---|---|
| I | Low | Parametric Estimation (e.g., cost per meter or bridge, adjusted for inflation) |
| II | Moderate | Unit Price Estimation (with quantity takeoffs, site adjustments) |
| III | High | Resource-Based Estimation + Risk Adjustment (includes labor, equipment, contingency) |
| IV | Very High | Bottom-Up Estimation + Scenario-Based and Lifecycle Costing |

To ensure that budgeting approaches are appropriate to the nature and scale of each bridge inspection project, estimation methods should be selected based on the complexity of the task. Table 8 outlines recommended approaches for four distinct complexity classes, ranging from simple rural inspections to highly specialized evaluations of critical infrastructure.

*Class I – Low Complexity*

Inspections in this category typically involve small structures such as concrete slabs or culverts located in rural areas. These projects generally require only visual assessments and do not involve traffic control or special access arrangements. For such low-risk and repetitive tasks, parametric estimation is the most suitable method. This approach relies on average cost indicators, such as the cost per linear meter or per bridge, with adjustments made for inflation. Estimators can use simplified tools like Excel-based templates or standardized cost worksheets built on historical data. The method is straightforward, quick to apply, and provides sufficient accuracy for routine jobs.

*Class II – Moderate Complexity*

Moderate complexity inspections are often conducted on medium-span bridges with relatively straightforward ground access, although they may involve traffic control and some basic nondestructive evaluation (NDE) techniques—such as hammer tapping or rebound hammer testing. For these cases, unit price estimation is recommended. This method involves breaking down the work into individual components—such as labor hours, equipment usage, and travel costs—then applying standardized unit costs. It also allows for site-specific adjustments based on environmental conditions, traffic, or location. This approach offers greater precision than parametric methods while remaining manageable for typical mid-level projects.

*Class III – High Complexity*

High-complexity inspections are required for longer-span bridges, often located in urban or highway environments, and may include overwater sections. These jobs typically demand a more advanced suite of inspection techniques, such as NDE tools, drone or UAV support, and the use of snooper trucks, alongside detailed

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traffic management plans. Resource-based estimation is best suited here. This approach entails a comprehensive itemization of required human resources—including specialized NDE-certified personnel—as well as daily rental rates for equipment, transportation, and lodging. Given the uncertainty inherent in these projects, it is prudent to include a contingency factor of around 10–15% to account for delays or complications such as inclement weather or traffic issues. Optionally, cost modeling software like Primavera P6 or @Risk can further support estimation accuracy. This method is ideal for projects where scope, risk, and asset criticality demand a higher level of detail.

*Class IV – Very High Complexity*

The most complex inspections pertain to major infrastructure such as cable-stayed or suspension bridges, often situated in geographically challenging or critical locations. These inspections typically involve a combination of advanced methods—ranging from visual and NDE techniques to artificial intelligence-supported tools, underwater evaluations, and even international expertise. In these cases, bottom-up estimation provides the highest level of accuracy. Every task and resource is detailed and calculated individually, with careful consideration of logistical challenges, such as the need to mobilize teams or equipment from distant regions or abroad.

This estimation strategy also incorporates scenario-based costing, which involves preparing multiple cost scenarios depending on the specific access conditions (e.g., routine versus barge-based access). Where appropriate, advanced modeling techniques such as Monte Carlo simulations or Bayesian cost forecasting may be employed. Additionally, lifecycle cost modeling can help weigh inspection costs against long-term maintenance needs. This comprehensive method is essential when even small errors in estimation could lead to serious safety, financial, or reputational consequences.

*Optional Enhancements for All Classes*

Regardless of the complexity class, several enhancements can be applied across all estimation processes. Digital integration—such as linking cost estimation systems with Building Information Modeling (BIM) or Bridge Management Systems (BMS)—can streamline workflows and improve data accuracy [47, 48]. Incorporating risk matrix tools allows planners to factor in asset criticality and condition when determining inspection frequency and cost ranges. Finally, applying inflation indices and technology adjustment factors helps ensure that estimates remain current and reflect real market conditions.

## 5.3 Recommendations

Drawing from the analysis of Vietnamese practices and global inspection budgeting standards, several actionable recommendations are proposed to enhance the accuracy, transparency, and effectiveness of inspection budget estimation for transportation infrastructure in Vietnam:

### 5.3.1 Regularly Update and Calibrate Cost Norms and Unit Prices

To address the misalignment between prescribed norms and actual market conditions, it is essential to establish a mechanism for regularly updating unit prices and technical norms. These updates should incorporate:

- Inflation adjustments, regional price differences, and new technologies (e.g., drones, NDE tools);
- Integration of technological adjustment coefficients into current cost norm systems;
- Benchmarking against international standards such as FHWA (USA) and BASt (Germany) to improve reliability and consistency.

### 5.3.2 Institutionalize Risk-Based Prioritization in Cost Estimation

Budgeting should move beyond reactive, condition-based approaches to incorporate risk and asset criticality. This can be achieved by:

- Embedding risk-based planning into estimation models using factors like bridge condition rating, exposure to hazards, traffic volume, and structural importance;
- Developing scenario-based estimation tools to account for emergency inspections or event-driven needs;
- Linking budgeting practices to asset management systems (e.g., BMS) to ensure that inspection resources are allocated where they are most needed.

### 5.3.3 Enhance Coordination Between Technical and Financial Stakeholders

Bridging the gap between technical inspection scope and financial estimation is critical. The following measures are recommended:

- Form interdisciplinary budgeting teams comprising engineers, economists, and project managers from the earliest planning phases;
- Utilize integrated project management and digital cost estimation platforms (e.g., BIM-enabled or Primavera) to ensure real-time alignment between scope and budget;
- Implement joint training and capacity-building initiatives to harmonize understanding across disciplines.

### 5.3.4 Develop a Centralized National Inspection Cost Database

A national database would allow for consistent benchmarking, promote transparency, and support dynamic pricing. Key components include:

- Historical inspection cost records (labor, equipment, access methods, and test types) from completed projects;
- Regular updates by region and infrastructure type;
- Mandated cost reporting and data submission by all inspection service providers;
- Data quality standards and validation protocols.

### 5.3.5 Promote Digital Tools and Strategic Cost Management Frameworks

Modern digital solutions can greatly enhance estimation accuracy and institutional efficiency:

- Adopt digital estimation tools linked to centralized databases and inflation indices;
- Encourage academia–government collaboration to develop cost models using statistical or AI-based approaches;
- Embed estimation practices within strategic cost management frameworks that consider both technical complexity and long-term sustainability.

### 5.3.6 Build Institutional Capacity and Foster Cross-Sectoral Collaboration

Sustaining these improvements requires long-term investment in institutional and human resource capacity:

- Provide regular training for local consultants and public sector staff on modern estimation techniques and digital tools;
- Establish policy mandates for inter-agency coordination and shared responsibility in inspection planning and budgeting;
- Encourage pilot projects and phased implementation of new methods to allow for feedback and adjustment.

By implementing these recommendations, Vietnam can transition from fragmented, outdated estimation practices to a more strategic, transparent, and data-driven approach aligned with international best practices and national infrastructure safety goals.

## 6. Conclusion

This study examined the challenges inherent in estimating inspection budgets for transportation infrastructure in Vietnam and developed a context-sensitive, complexity-based framework to improve current practices. The analysis revealed several critical limitations in the Vietnamese system, including outdated and rigid cost norms, inconsistent application of estimation techniques, insufficient cost data, and limited integration of risk-based decision-making. By synthesizing international standards, legal requirements, and empirical insights from actual inspection practices, the study proposed a structured framework comprising three components: (i) defining cost-driving factors within inspection terms of reference, (ii) strengthening cost data quality through strategic cost management initiatives, and (iii) aligning estimation methods with clearly defined inspection complexity classes.

The proposed framework enhances transparency, accuracy, and defensibility in inspection budgeting while remaining compatible with Vietnam's normative cost control system. Its contributions extend beyond bridges, offering a methodological foundation applicable to other infrastructure sectors in Vietnam and similar developing countries. Furthermore, the framework supports longer-term objectives of infrastructure resilience by encouraging the adoption of modern inspection techniques, digital tools, and risk-informed planning.

Despite these contributions, the study has limitations. Its validation relies primarily on available Vietnamese regulations and illustrative cases, which may not fully reflect regional variations or the full diversity of bridge types nationwide. In addition, successful implementation of the proposed method will require institutional commitment, updates to cost norms, investments in data systems, and capacity-building for both technical and financial personnel.

Future research should explore the integration of advanced digital technologies—such as BIM-enabled workflows, artificial intelligence, and digital twins—to automate data capture and enhance estimation precision. Applying the framework to other infrastructure categories (such as tunnels, maritime structures, or railway assets) would further test its scalability and refine its practical relevance. Overall, the study provides a practical roadmap for transitioning Vietnam's inspection budgeting practices toward a more transparent, data-driven, and resilient system aligned with international best practices.

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## Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

## Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** TXMD, HMD; **data collection:** MLV, TBP; **analysis and interpretation of results:** TXMD, HMD, MLV, TBP; **draft manuscript preparation:** TXMD, MLV, TBP. All authors reviewed the results and approved the final version of the manuscript.*

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