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Implementation of Risk-Based Quality Management (RBQM) in Controlling Quality and Cost Risks in the Widening Work of Hang Tuah Street, Airport Intersection-Batu Besar Intersection Section In Batam City

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A B S T R A C T

A disproportionate quality cost structure was created as a result of the systematic failure to use RBQM, where failure costs far outweighed the initial expenditures in prevention. The entire recorded quality charges came to Rp2,527,699,700.32, which is 3.70% of the Rp68,284,483,721.22 final contract value. The real project failure costs are projected to be significantly higher than the stated value since Prevention Costs and Internal Failure Costs were not recorded as distinct categories. The external failure costs of Rp980,049,700.32 were equal to more than half of the entire supervision investment made, as shown by the ratio of external failure costs to appraisal expenses reaching 63.3%. Rp726,113,833.42, or 74.1%, of this sum. According to the relationship pattern discovered, risks that are not identified until the project is finished result in External Failure Costs (EFC), whereas risks that are fixed during implementation still result in Internal Failure Costs (IFC), which are absorbed in project overhead and are not explicitly documented. In the case of road infrastructure projects, the two aforementioned results show that the RISK → QUALITY → COST chain is a tangible and quantifiable causal mechanism rather than just a theoretical framework. Inadequate RBQM implementation immediately leads to quality failures that go unnoticed, which eventually results in expenses that are significantly higher than those that might have been avoided in the first place

INTRODUCTION

Road infrastructure development is a strategic program that plays a crucial role in supporting public mobility, facilitating the distribution of goods, and driving economic growth in a region. In the context of Batam City as a national strategic area, the availability of adequate road infrastructure is an increasingly crucial need, particularly in supporting connectivity between international airports, industrial areas, and ports. One section that plays a vital role in this network is Jalan Hang Tuah, between the Airport Intersection and Batu Besar Intersection, which serves as the main route for the movement of people and goods along this corridor.

The high traffic volume on this section has resulted in the current road capacity being insufficient to provide optimal service. Therefore, road widening work is being undertaken to improve the capacity and overall network performance. The widening work, which will take place from September 27, 2023, to August 25, 2024, requires not only increased capacity but also effective quality control to ensure high-quality work and manage costs.

In reality, road construction is inherently fraught with uncertainties that can potentially pose risks. Risks in construction projects are known to have a direct impact on project performance, particularly on quality and cost, making their management a crucial part of the project decision-making process. Risks that are not identified and controlled early on tend to develop into quality deviations, such as specification discrepancies, rework, and resource inefficiencies, which in turn lead to project cost overruns.

The main problems in construction projects are often related to ineffective risk management, which impacts project costs. On the other hand, the implementation of effective risk management not only contributes to improved work quality but also plays a role in controlling project costs more efficiently. Thus, there is a strong causal relationship between risk, quality, and cost in construction projects, where risk acts as a driving factor, quality as a connecting variable, and cost as a consequence (Alsaadi & Norhayatizakuan, 2021; Tinambunan, 2024).

Although this relationship is understood theoretically, in practice, risk management and quality control in construction projects tend to be carried out separately and not systematically integrated. Quality control is often reactive, that is, implemented after deviations occur, so that the costs incurred are no longer costs for prevention, but rather costs resulting from quality failures.

Numerous empirical studies support this argument. Cost overruns in construction projects in Indonesia are generally influenced by project complexity, limited resources, and unpredictable external factors, with weak cost control in the field being a dominant factor. Studies on building construction projects in Banda Aceh City also identified a number of factors causing cost overruns and time overruns, with material quality and weak quality control as the most influential factors in increasing project costs (Sebastian & Oei Fuk Jin, 2025; Soviana et al., 2024).

These findings confirm that failure to maintain work quality and weak implementation controls in the field have a direct impact on project cost increases, and indicate that the current reactive approach has not been able to optimally prevent these deviations.

This situation is particularly relevant to the characteristics of the Jalan Hang Tuah widening project, which involves a high level of complexity due to persistent traffic conditions during implementation, limited work space, and the involvement of multiple parties in construction coordination. This complexity increases the potential for various risks that could impact the quality of the work and impact project costs. Given that this work is funded through a contractually established budget, costs are the most critical performance indicator, being locked in and difficult to control Compensation is essential, so any quality failures that occur will directly impact project cost performance.

Based on this gap between theoretical approaches and field practice, an approach is needed that systematically and proactively integrates risk management with quality control, allowing quality deviations to be prevented early and their implications for project costs minimized. Risk-Based Quality Management (RBQM) presents a relevant approach to address this need, as it positions risk analysis and control as the foundation for all quality assurance and control activities, from the planning stage to project implementation.

With this framework, RBQM shifts the orientation of quality control from reactive to predictive and preventive, better aligning it with the needs of construction projects with high levels of complexity and uncertainty, such as the widening of Hang Tuah Road. Therefore, this research focuses on analyzing the relationship between risk, quality, and cost in construction projects, using a case study of the widening of Hang Tuah Road between the Airport Intersection and Batu Besar Intersection in Batam City. It also develops a contextual RBQM model to improve the effectiveness of quality control and project cost efficiency. Without an integrated management approach like RBQM, the same problems have the potential to recur on similar projects, hindering optimal project performance.

The majority of previous research in the context of road construction projects has used a purely quantitative approach with analytical techniques such as Failure Mode and Effects Analysis (FMEA) or Analytical Hierarchy Process (AHP), which produce risk rankings in the form of Risk Priority Numbers (RPN) or priority weights. These approaches are not fully capable of describing the causal mechanisms between risk, quality, and cost in depth within a specific project context, as they are limited to numerical results without exploring the institutional context, construction actors' behavior, and underlying field dynamics.

This research fills this gap through a qualitative approach with a case study design, reinforced by limited quantitative elements: FMEA for risk prioritization and Cost of Quality (CoQ) for calculating the implications of quality on cost. In this context, FMEA and CoQ are not used as stand-alone primary instruments, but rather as analytical tools bridged by qualitative narratives based on the experiences, perceptions, and actual practices of construction actors in the field, resulting in a contextual and applicable RBQM model.

Thus, this research is expected to contribute both theoretically and practically. From a theoretical perspective, this research strengthens understanding of the RISK → QUALITY → COST relationship, with risk as a driving factor, quality as a mediating variable, and cost as a consequence in road construction projects, while also enriching the body of knowledge on the application of RBQM in the context of road widening projects in Indonesia.

From a practical perspective, this research produces two main outputs that complement each other, namely the Contextual RBQM Model as a theoretical contribution and the RBQM Implementation Guidelines as a practical contribution, which can be utilized by construction actors, namely implementing contractors, supervisory consultants, and the Batam Free Trade Zone and Free Port Authority (BP Batam) as the work owner in improving project performance effectively, efficiently, and sustainably, especially for work that has similar characteristics to the Hang Tuah Road widening project for the Simpang Bandara-Simpang Batu Besar section in Batam City.

The widening of Hang Tuah Road between the Airport Intersection and Batu Besar Intersection in Batam City is a highly complex road infrastructure project, encompassing demanding technical implementation, active traffic conditions, and intensive multi-party involvement. This complexity places the project in a risk-prone environment, where risks that are not effectively managed have the potential to develop into quality deviations and ultimately burden project costs.

The fundamental problem that arises is that risk management and quality control in road construction projects are generally still carried out separately. Quality control is more reactive to deviations that have already occurred rather than preventive measures against risks that have not yet been realized.

An integrated approach such as RBQM, which places risk as the basis of quality control, offers a more systematic perspective. However, its implementation in the field faces various contextual constraints, ranging from organizational and human resource aspects to inter-stakeholder coordination and the availability of technical data.

Based on the description, the problem formulation in this research is:

What are the implications of construction work quality on project costs in the context of implementing Risk-Based Quality Management (RBQM), considering risk as a factor influencing work quality.

THEORETICAL REVIEW

Various previous studies have discussed construction project management, particularly regarding risk, quality, and cost, using diverse approaches and perspectives. These studies provide a conceptual and empirical basis for the urgency of integrating risk management with quality control to improve project performance.

Sebastian & Oei Fuk Jin (2025) in their research revealed that cost increases in construction projects are caused by project complexity, resource constraints, and external factors. The study also highlighted that effective risk management can be achieved through the integration of risk management, the use of technologies such as Building Information Modeling, and probabilistic estimation techniques based on Monte Carlo and Artificial Neural Networks. The results indicate the crucial role of risk in project cost performance.

Furthermore, Sulistiyowati et al. (2025) in a study on the integration of quality and risk management found that combining the two can increase the effectiveness of project quality improvement. This reinforces the notion that quality control without incorporating risk will be less than optimal in achieving desired project performance.

Willar et al. (2022) applied the Delphi method to assess quality management in road construction projects. The findings indicate that quality performance is influenced by human resource capabilities and effective inter-stakeholder coordination, with the primary obstacle being the implementation of quality management systems in the field. This underscores the role of managerial factors in determining the quality of construction outcomes.

METHODOLOGY

Risk Concept in Construction Projects

Risk is a fundamental concept in project management, particularly in construction projects characterized by high levels of complexity and uncertainty. According to ISO (2018), risk is understood as the impact of uncertainty on the desired objectives. This definition emphasizes that risk relates to the possibility of deviations from plans, whether negative consequences or opportunities, which can impact overall project performance.

In project management practice, the Project Management Institute (2021) emphasizes that risk needs to be managed systematically through the stages of identification, analysis, evaluation, and control. This approach aims to reduce the impact of risk on key project aspects, particularly quality, time, and cost. Therefore, risk management is not merely reactive to problems that have already occurred but also proactive in anticipating potential failures from the outset of project implementation.

According to Hillson (2002), project risk analysis needs to consider two main dimensions: impact and likelihood. This approach allows for risk prioritization, allowing attention and resources to be focused on the most significant risks. In this context, risks with a high impact and a high probability of occurrence become the top priority for control.

In construction projects, risks have unique characteristics: they are dynamic, interconnected, and can have a cascading effect. Risks that emerge at one stage of implementation have the potential to trigger other risks at subsequent stages, cumulatively increasing their impact on the overall project quality and cost. Therefore, risk management requires a comprehensive approach, considering the interrelationships between factors and the potential long-term impacts.

In general, risks in construction projects can be grouped into three main categories based on their source (Smith et al., 2006):

1. Technical risks, which relate to technical aspects of the work, such as material quality, implementation methods, and conformity to specifications. These risks directly impact the quality of the work.

2. Managerial risks, which relate to project management, including planning, supervision, coordination, and control. These risks can lead to inefficiencies and non-conformities in work execution.
3. External risks, which originate from factors beyond the project's control, such as environmental conditions, weather, and policies. These risks tend to be difficult to control but have a significant impact on project implementation.

Quality Concept in Construction Projects

Quality is one of the primary objectives in construction project implementation, alongside cost and time, as recognized in the triple constraint concept (Project Management Institute, 2021). In general, quality relates to the extent to which work results meet the needs and requirements established during the planning stage.

In the quality management literature, Juran & Godfrey (1999) view quality as fitness for use, namely the ability of a product or work product to be used for its intended purpose. Meanwhile, Crosby (1979) defines quality as conformance to requirements. Both perspectives essentially emphasize that quality is not solely measured by the final result, but also by the degree of conformity to predetermined standards.

A more comprehensive approach was proposed by Feigenbaum (1991) through the concept of Total Quality Control, which places quality as the responsibility of all elements within the project organization. In this view, quality does not depend solely on final inspection activities but is the result of the entire integrated project implementation process from beginning to end.

Similarly, ISO (2015) defines quality as the degree to which characteristics meet requirements. This standard emphasizes the importance of a process-based approach and the principle of risk-based thinking, which links quality management with risk identification and control. This principle serves as the conceptual basis for the RBQM approach used in this study.

In the context of road construction, quality is measured based on the conformity of work results to the technical specifications established by the Ministry of Public Works and Public Housing, Directorate General of Highways (2018). These quality indicators include layer density, pavement thickness, surface evenness, structural strength, and the quality of the materials used. These indicators serve as the primary reference for assessing whether the work meets applicable technical standards.

Risk-Based Quality Management (RBQM) as an Integrative Approach

Risk-Based Quality Management (RBQM) is an approach that combines risk management and quality control within a single, integrated framework to improve project performance. This approach is based on the understanding that optimal quality cannot be achieved without sound risk management, and that project costs ultimately reflect the quality of the work produced.

Within the RBQM framework, risk is viewed as a driving variable that influences quality, while quality becomes a factor that determines the implications for costs. With this perspective, quality control is no longer carried out reactively through final inspections, but rather proactively through risk identification and control from the early stages of project implementation. This approach aligns with the risk-based thinking principle in ISO (2015), which emphasizes the importance of considering risk in every process to maintain consistent quality.

Conceptually, RBQM establishes an interconnected relationship between risk, quality, and cost, where risk affects quality, quality affects cost, and cost is a reflection of the effectiveness of overall risk and quality management. Thus, this approach places process management as the key to achieving quality, rather than relying solely on inspection results.

Research Location and Time

The location and time of the research are two operational components that determine the scope of the research. The location defines the geographic boundaries of the phenomenon being studied, while the time of the research regulates the scheduled implementation stages. The research was conducted retrospectively on completed projects, so data collection was not aimed at observing ongoing construction, but rather at exploring in-depth references, documents, and the experiences of project participants that were still accessible.

RESULTS AND DISCUSSION

Implementation of RBQM between Formal Procedures and Field Reality

The implementation of RBQM on the Hang Tuah Road widening project was incidental and unstructured. Quality control activities were ongoing, but not based on an explicit and documented risk analysis from the planning phase.
Research findings indicate that the implementation of RBQM on the project was not systematic and was still dominated by conventional quality control approaches.

1. Risk Identification

No formal risk register or Quality Control Plan was found before work commenced. Quality risks were identified primarily through the experience of field personnel and informal communication between project parties, rather than through a systematic, documented identification process (Transcripts 2.1; 3.1).

2. Risk Prioritization

The project lacked a risk assessment mechanism that measurably considered the level of impact, likelihood of occurrence, and detectability. As a result, quality control priorities were not focused on tasks with the highest risk levels.

3. Establishment of Quality Control Points

Laboratory testing and field inspections were still conducted, but control points were not established based on a previously prioritized risk profile. Supervision still followed general procedures and was not based on the level of job risk.

4. Risk Response

Corrective actions are generally only taken after quality deviations are discovered through testing results or field findings. This situation indicates that risk responses are still reactive and not directed towards preventative measures from the start of the work.

5. Monitoring and Evaluation

The existing control system still produces pass/fail decisions without an early warning mechanism for potential quality deviations (Transcript 1.2; 2.2).

Although field findings are regularly documented, these evaluation results are not fully utilized as a basis for learning from risk control in subsequent work.

The gap identified is not a lack of resources or technical capacity, but rather the absence of a framework that integrates all control activities into a coherent, risk-based logic.

Costs as a Consequence of Quality Failure

The CoQ analysis was performed on the four components identified in Appendix D, referring to Formula 2.4. Prevention Cost and Internal Failure Cost could not be measured because they were not documented as separate budget items in the project financial report. Therefore, the calculation only included components with documented measurable values. Total Measured CoQ = AC + EFC

= Rp1,547,650,000.00 + Rp980,049,700.32

= Rp2,527,699,700.32

The EFC value of Rp980,049,700.32, or 1.44% of the contract value, consists of non-conformities in the quality of K-350 rigid pavement worth Rp726,113,833.42, or 74.1% of the total EFC, and a shortage of work volume worth Rp253,935,866.90, or 25.9% of the total EFC (DOC-MUT-029). The EFC to AC ratio reached 63.3%, meaning that the documented external failure costs were close to two-thirds of the total supervision costs incurred. This figure does not reflect the IFC that logically occurred but was not measured, so the total actual failure costs of the project far exceeded the recorded value. The causal mapping between each risk and its resulting cost components shows the following pattern:

1. R-02 (K-350 concrete quality failure) was the primary source of EFC, contributing Rp726,113,833.42 or 74.1% of the total BPK findings (DOC-MUT-029).
2. R-03 (work volume deficiencies) contributed Rp253,935,866.90 or 25.9% of the total BPK findings (DOC-MUT-029; FIN-KON-01 to 06).
3. R-01 (AC-WC thickness deficiencies) did not generate measurable EFC because corrective actions were taken before handover, but all remedial costs were absorbed into undocumented IFC (Transcripts 2.1, 2.3).

This pattern demonstrates that failure costs do not arise immediately, but rather accumulate as quality deviations pass through each stage of supervision undetected.

Based on the Second Work Handover Report dated February 27, 2025 (DOC-ST-004), no premature failures, user claims, or repairs were found during the 180-day maintenance period. Therefore, the EFC of Rp980,049,700.32 identified in this study stems entirely from payment deductions based on the Audit Board's findings, not from warranty or early maintenance costs.

The second research question, concerning the implications of construction work quality on project costs, is addressed through a key quantitative finding in Subsection 4.2.3. The ratio of external failure costs to supervision costs of 63.3% provides empirical evidence that is difficult to achieve through qualitative narrative alone. This figure is not simply an indicator of technical inefficiency. When nearly two-thirds of all supervision investments are ultimately offset by the costs of preventable failures, this finding confirms that control systems that are not oriented toward risk prevention will bear disproportionate financial consequences. In the context of road projects in Indonesia, empirical documentation of such cost patterns is still scarce, so the findings in Subsection 4.2.3 provide a contribution that goes beyond the scope of a single case study.

Practically, both findings point to the same conclusion. The risk register and risk-based Quality Control Plan are not.

supplemental documents, but rather prerequisites that determine the direction of the entire quality control system. The limitations of this study lie in the scope of a single project and the lack of data on Prevention Costs and Internal Failure Costs as separate items. Therefore, the resulting CoQ figure represents a lower limit of the actual quality costs incurred.

Pattern Matching Analysis and Causal Chain of Risk, Quality, and Cost

A comparison of field conditions and the five key elements of RBQM yields a consistent and concerning pattern. No formal risk register or Quality Control Plan was found in the project documents, risks were identified informally based on field intuition, quality control points were not designed based on risk profiles, mitigation actions were only implemented after failures were confirmed, and the evaluation system only produced pass/fail decisions without adequate early warning mechanisms. These five gaps are not isolated but rather reinforce each other, forming a systemic condition that undermines the overall effectiveness of quality control.

These conditions paved the way for the AC-WC and K-350 failures to slip undetected during construction, only to be identified during the BPK audit after the project was completed. This delay in detection had measurable and significant financial consequences. The supervision contract value of Rp1,547,650,000.00, which should have been a preventative measure, was unable to prevent the emergence of external failures worth Rp980,049,700.32, equivalent to 63.3% of the total supervision costs incurred. This proportion reflects that expenditure on appraisal functions is not offset by the system's capacity to detect and prevent failures before they exceed the point of financial irrecoverability.

RBQM Implementation Guidelines

This guideline is based on empirical findings from the Hang Tuah Road project as a practical guide for managers of road infrastructure projects with similar characteristics.

1. Risk Register Development

This is prepared based on contract documents before physical work begins. It should at a minimum include identification of potential failures for each critical work item, complete with an initial assessment of the S (Severity), O (Occurrence), and D (Detection) components as the basis for calculating the RPN. Without this document, all subsequent steps are flawed.

2. FMEA Analysis with Dual Severity

This is conducted immediately after the risk register is developed. The RPN-Quality and RPN-Cost are calculated separately so that control decisions consider both consequences simultaneously. All risks with an RPN-Quality above 300 are included in a special control priority list.

3. Quality Control Plan Development

This refers directly to the FMEA results. Each high-priority risk is assigned a separate inspection point and early warning threshold before final testing is conducted. These control points are an additional layer beyond routine testing, not a substitute for it.

4. Proactive Risk Response

The contractor, supervising consultant, and the PPK agreed on a clear escalation mechanism if monitoring indicates a trend of deviations, well before the work was declared complete.

5. Continuous and Evaluative Monitoring

Monitoring reports provide a periodic analysis of deviation developments, not simply a pass/fail record. This report serves as the basis for evaluating the effectiveness of controls and adjusting the risk register if field conditions change during implementation.

Consistent implementation of these five steps on the Hang Tuah Road project has the potential to detect AC-WC and K-350 failures well before the BPK audit is conducted, significantly minimizing external failure costs of Rp980,049,700.32.

CONCLUSION AND RECOMMENDATION

Quality Implications on Project Costs

The systemic failure to implement RBQM resulted in a disproportionate quality cost structure, where failure costs far exceeded the prevention investments that should have been made from the outset. The detailed findings are as follows:

1. The total documented quality costs reached Rp2,527,699,700.32, or 3.70% of the final contract value of Rp68,284,483,721.22. This figure is partial because Prevention Costs and Internal Failure Costs were not documented as separate items, so the actual project failure costs are estimated to far exceed the recorded figure.
2. The ratio of External Failure Costs to Appraisal Costs reached 63.3%, meaning that external failure costs of Rp980,049,700.32 were equivalent to more than half of the total supervision investment incurred. Of this amount, Rp726,113,833.42, or 74.1%, stemmed from quality nonconformities that went undetected during construction.
3. The relationship patterns found indicate that risks not detected until completion generate External Failure Costs (EFC), while risks corrected during implementation continue to generate Internal Failure Costs (IFC), which are absorbed into project overhead and not specifically recorded.

These two conclusions demonstrate that the RISK → QUALITY → COST chain is not merely a conceptual framework, but rather a real and measurable causal mechanism in the context of road infrastructure projects. Weak implementation of RBQM directly opens the door to undetected quality failures, ultimately borne as costs far exceeding the costs of prevention that should have been incurred in the first place.

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