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Research Paper

Construction Risk Management Using PCA and AS/NZS 4360:2004: Evidence from an Educational Building Project in Tulungagung, Indonesia

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ABSTRACT: *Construction projects executed within active educational facilities face a distinctive combination of logistics, safety, technical, and stakeholder risks. This study identifies, groups, prioritizes, and proposes responses to risks in Phase 1 of the cafeteria and classroom construction project at SMK Sore Tulungagung, East Java, Indonesia. A descriptive-analytical case-study design was applied. Thirty-one risk variables covering preparatory works, earthworks, foundations, and reinforced-concrete works were assessed by ten members of the contractor's project management and implementation team using five-point likelihood and consequence scales. Instrument items were screened using Pearson item-total correlation and Cronbach's alpha. Principal Component Analysis with varimax rotation and an eigenvalue threshold of 1.0 was then used to reduce the risk set, followed by semi-quantitative assessment using the AS/NZS 4360:2004 likelihood–consequence framework. Seven likelihood components explained 96.208% of the variance, while six consequence components explained 93.209%. The most critical risks were difficult mobilization of materials and equipment to the site (risk score 25), material delay (20), and workers being struck by materials (20), all categorized as extreme risks. Other high risks included a shortage of skilled workers (16), injuries caused by work tools (16), nonconforming foundation depth (15), inadequate concrete curing (12), reinforcement cutting and bending errors (12), and nonconforming stirrup spacing (12). The priority responses are coordinated delivery windows, early procurement and buffer stock for critical materials, site-specific logistics planning, stronger occupational safety controls, daily briefings, independent inspections, worker training, and tighter quality supervision. The study demonstrates that combining component reduction with a standardized risk matrix can produce a practical priority list for a constrained building site, while the small single-project sample limits statistical generalization.*

KEYWORDS: *AS/NZS 4360:2004, construction risk, educational building, principal componenet analysis, risk response.*

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I. INTRODUCTION

Construction projects are temporary organizations in which technical activities, resources, contractual obligations, safety requirements, and environmental conditions interact under uncertainty. Risk therefore affects not only the probability of financial loss but also project time, quality, occupational safety, and the continuity of stakeholder activities. In building projects, uncertainty may arise from design decisions, labor capability, equipment availability, procurement, site access, weather, community relations, and unsafe work practices. Systematic risk management is required to identify these conditions before they develop into disruptions or accidents [1–6].

The need for structured risk management becomes more pronounced when construction is undertaken inside an operating educational complex. Project logistics must coexist with teaching schedules, student movement, parking, and limited access. Heavy vehicles may have restricted delivery windows, work zones may be narrow, and construction personnel must protect users who are not part of the project organization. These constraints can intensify ordinary risks such as material delay, equipment mobilization, interference with surrounding communities, and exposure to falling materials.

The Phase 1 cafeteria and classroom construction project at SMK Sore Tulungagung illustrates this condition. The project is located within an active vocational-school campus in Boyolangu, Tulungagung, East

Java. Field observations reported that the main access had a vertical clearance of approximately 3.2 m, the route crossed an area used for student parking, and material deliveries could be conducted more safely after learning activities. The site also presented geotechnical, weather, equipment, labor, and occupational-safety concerns. These conditions required a risk-management approach that could distinguish the most important threats from a relatively large initial list.

Previous construction-risk studies have applied qualitative matrices, AS/NZS 4360:2004, literature-based screening, and other prioritization techniques to identify dominant technical, operational, and safety risks [5,11–14]. However, a long list of correlated risk variables can reduce decision clarity. Principal Component Analysis (PCA) offers a way to condense related variables into a smaller number of components while preserving a substantial proportion of the observed variance [7]. A standardized likelihood–consequence matrix can then translate the selected risk aspects into priority categories that are directly usable by project managers [1,3].

This study integrates PCA and the AS/NZS 4360:2004 semi-quantitative framework in a single case-study workflow. The objectives are to: (1) identify risk variables affecting the project; (2) determine the dominant likelihood and consequence components; (3) classify priority risks using risk scores; and (4) formulate practical response measures for project implementation. The contribution lies in connecting statistical screening with field-specific mitigation for a constrained educational building site.

II. LITERATURE REVIEW

2.1. Construction Risk and Project Objectives

Risk is commonly understood as the possibility that an uncertain event will affect an objective. In construction, the effect may be negative or positive, but project-control practice primarily focuses on events that threaten schedule, cost, quality, safety, or operational performance. Flanagan and Norman explain that risk can be recognized through its source, event, and effect, while Thompson and Perry emphasize the importance of linking risk identification to project decisions [2,3].

Construction risk management is a continuous process consisting of context establishment, identification, analysis, evaluation, treatment, communication, and monitoring. The process does not eliminate uncertainty; instead, it improves preparedness and directs limited resources toward the most important exposures. For contractors, effective risk management can reduce surprise events, improve planning, protect assets and personnel, strengthen stakeholder communication, and support more consistent decision-making [1,4,5].

2.2. Principal Component Analysis for Risk Screening

PCA transforms a set of correlated observed variables into a smaller set of uncorrelated linear combinations. Components are ordered according to the amount of variance they explain, and an eigenvalue threshold is often used to determine the number retained. Varimax rotation can improve interpretability by increasing the contrast between high and low loadings [7,8]. In risk studies, PCA is useful as an exploratory screening method when multiple risk statements represent related underlying conditions.

The quality of PCA results depends on the measurement instrument and the available data. Item validity and reliability are therefore evaluated before extraction. Pearson item-total correlation is used to examine whether an item is aligned with the total scale, while Cronbach's alpha indicates internal consistency [8–10]. In the present case study, PCA is interpreted as a project-specific reduction tool rather than a basis for broad population inference because the respondent group is small.

2.3. Semi-Quantitative Assessment using AS/NZS 4360:2004

The AS/NZS 4360:2004 framework supports qualitative, semi-quantitative, and quantitative assessment. In a semi-quantitative matrix, the likelihood of an event and the severity of its consequence are assigned ordinal scores. The product of the two scores provides a risk value that can be mapped into priority categories. The method is straightforward, transparent, and suitable for communication among project participants [1,11].

A risk matrix should not be treated as an automatic decision. Field conditions, existing controls, technical feasibility, and stakeholder constraints must also be considered. A high score identifies the need for management attention, whereas the chosen response may include avoidance, reduction, transfer, retention, or a combination of preventive and corrective controls. Monitoring is required because risks and project conditions change during execution [1–6].

III. RESEARCH METHOD

3.1. Research Design and Study Site

The research used a descriptive-analytical case-study design. The unit of analysis was the Phase 1 construction of cafeteria and classroom facilities at SMK Sore Tulungagung, Jalan Mastrip No. 100, Serut Village, Boyolangu District, Tulungagung Regency, East Java, Indonesia. The project was implemented within an operating school environment, creating direct interaction between construction logistics and educational activities.

Primary data were obtained through questionnaires, structured interviews, and field observation. Secondary data included project drawings and literature related to construction risk management. The respondent population consisted of ten members of the contractor's project-management and implementation team, and total sampling was used. The questionnaire employed a five-point scale for both likelihood and consequence.

3.2. Risk Variables and Instrument Assessment

Thirty-one risk variables were compiled from previous studies and field conditions. They were grouped into preparatory works, earthworks, foundation works, and reinforced-concrete works. The variables included difficult mobilization, security disturbances, extreme weather, community rejection, shallow groundwater, narrow site conditions, excavation collapse, dust exposure, material delay, equipment damage, design change, nonconforming foundation depth, shortages of skilled labor, inadequate personal protective equipment, workers being struck by materials, reinforcement errors, formwork leakage, inadequate concrete curing, ready-mix delay, and wet-cement exposure.

Validity was assessed using Pearson item-total correlation at a 95% confidence level. With ten respondents, the study used an r-table value of 0.632. The thesis reported that all likelihood and consequence items had item-total correlations greater than 0.632. Reliability was evaluated using Cronbach's alpha, and all variables were reported to have alpha values above 0.60; consequently, the instrument was accepted for further analysis.

3.3. PCA and Risk-Priority Procedure

PCA was conducted separately for likelihood and consequence data using SPSS. Components with eigenvalues equal to or greater than 1.0 were retained, and varimax rotation was applied to support interpretation. The variables with the strongest representation in the retained components were then treated as dominant risk aspects.

The risk score was calculated as $R = L \times C$, where L is the likelihood score and C is the consequence score. The study applied four categories: extreme risk for scores of 17–25, high risk for scores of 10–16, medium risk for scores of 5–9, and low risk for scores of 1–4. Field observations and interviews were used to interpret why the selected risks were relevant and to formulate response strategies.

Table 1. Research framework and analytical outputs

Element	Application in the Study	Main Output
Risk identification	Literature review, questionnaire, interviews, and field observation; 31 variables in four work groups	Project risk register
Instrument screening	Pearson item-total correlation and Cronbach's alpha	Valid and reliable items
Component reduction	PCA, varimax rotation, eigenvalue ≥ 1.0	Dominant likelihood and consequence components
Risk assessment	Likelihood × consequence using AS/NZS 4360:2004-based categories	Extreme, high, medium, and low priorities
Risk response	Interpretation of field relevance and existing controls	Recommended preventive and corrective measures

IV. RESULT AND DISCUSSION

4.1. Instrument Performance and Component Extraction

The questionnaire results confirmed that all 31 likelihood items and all 31 consequence items passed the validity criterion used in the study. The reported Cronbach's alpha values were also above 0.60. These results indicate acceptable consistency for the project-specific analysis, although the small number of respondents requires cautious interpretation.

PCA of the likelihood data retained seven components with eigenvalues of at least 1.0. Together, the components explained 96.208% of the total variance. The dominant likelihood aspects were shallow groundwater, material delay, inadequate concrete curing, extreme weather, equipment damage, shortage of skilled labor, and nonconforming stirrup spacing. PCA of the consequence data retained six components explaining 93.209% of total variance. The dominant consequence aspects were reinforcement cutting and bending errors, nonconforming foundation depth, workers being struck by materials, difficult mobilization of materials and equipment, workers being injured by work tools, and material delay.

Material delay appeared in both analyses, indicating that respondents considered it both likely and capable of producing serious project effects. This convergence strengthens its position as a management priority. Other variables, such as difficult mobilization and workers being struck by materials, were particularly dominant in the consequence dimension, reflecting the project's access restrictions and safety exposure.

Table 2. PCA component summary

Assessment Dimension	Retained Components	Cumulative Variance	Dominant Aspects
Likelihood	7	96.208%	Shallow groundwater; material delay; inadequate concrete curing; extreme weather; equipment damage; shortage of skilled labor; nonconforming stirrup spacing
Consequence	6	93.209%	Reinforcement cutting/bending errors; nonconforming foundation depth; workers struck by materials; difficult mobilization; injuries from work tools; material delay

4.2. Risk-Priority Results

The highest risk score was 25 for difficult mobilization of materials and equipment, followed by material delay and workers being struck by materials, each with a score of 20. These three risks were classified as extreme. Their scores show that the main threats were not confined to one project objective: mobilization and delay threaten schedule and productivity, while struck-by hazards directly threaten worker safety and can also trigger stoppages, investigation, and reputational damage.

High risks included shortage of skilled labor and injuries from work tools, both with scores of 16; nonconforming foundation depth with a score of 15; and several technical or quality risks with scores of 12. Extreme weather and equipment damage were classified as medium risks with scores of 9 and 6. No selected dominant aspect was categorized as low risk.

Table 3. Prioritized dominant risks

Risk Aspect	Likelihood	Consequence	Score	Category
Difficult mobilization of materials and equipment	5	5	25	Extreme
Material delay	4	5	20	Extreme
Workers struck by materials	4	5	20	Extreme
Shortage of skilled labor	4	4	16	High
Workers injured by work tools	4	4	16	High
Foundation depth not conforming to design	3	5	15	High
Shallow groundwater	4	3	12	High
Inadequate concrete curing	3	4	12	High
Nonconforming stirrup spacing	3	4	12	High
Reinforcement cutting and bending errors	3	4	12	High
Extreme weather	3	3	9	Medium
Equipment damage	3	2	6	Medium

4.3. Field Interpretation of the Highest Risks

Difficult mobilization obtained the maximum score because the project's physical access did not accommodate ordinary heavy-vehicle movement. The main entrance had a clearance of approximately 3.2 m, the lobby route included a textured stone floor, and part of the underlying ground consisted of relatively recent fill. These conditions limited access for high vehicles and heavily loaded trucks. Deliveries also crossed an area used for student parking, making afternoon or evening delivery windows more feasible after learning activities ended.

The same access conditions contributed to material delay. The risk was therefore operationally linked to mobilization rather than being solely a supplier issue. Without a synchronized procurement and delivery plan, materials could arrive outside the permitted window, wait off-site, or fail to reach the work front when needed. The result could be idle labor, disrupted concrete or reinforcement sequences, and schedule slippage.

The risk of workers being struck by materials reflected insufficient occupational-safety supervision. Reinforced-concrete construction involves lifting, stacking, cutting, moving, and installing heavy or sharp materials within a confined space. Weak exclusion zones, inconsistent use of personal protective equipment, or inadequate communication can increase both the likelihood and severity of struck-by events.

The foundation-depth risk was associated with field strata. At several points, a sand layer was encountered at approximately 6.0 m, while the design depth was 6.5 m. Drilling was reportedly stopped at approximately 6.0 m at those points. This condition illustrates why design conformity must be evaluated through documented engineering decisions rather than informal field adjustment. Likewise, reinforcement geometry, stirrup spacing, concrete curing, and workmanship require hold-point inspections before subsequent work proceeds.

The medium risks remain relevant. Construction occurred during the rainy season, and some project equipment was old enough to experience breakdowns during execution. Although their matrix scores were below the high-risk range, either condition could interact with the extreme logistics risks and worsen schedule disruption. Risk treatment should therefore address combinations of events rather than viewing each score in isolation.

4.4. Risk-Response Priorities

The response strategy should first reduce the probability of logistics failure. A detailed delivery plan should identify vehicle dimensions, permitted routes, delivery windows, unloading locations, temporary storage, responsible coordinators, and contingency arrangements. Critical materials should be procured early and protected through an appropriate buffer stock, while just-in-time delivery should be reserved for large or space-consuming materials that cannot be stored safely on site.

Safety controls should combine engineering, administrative, and personal-protection measures. The project should establish exclusion zones, safe material-stacking limits, designated lifting paths, daily toolbox meetings, trained signal persons, and documented inspection of lifting and hand tools. Safety helmets, safety footwear, gloves, and other task-specific personal protective equipment must be consistently used. Supervisors should have authority to stop unsafe work.

Technical and quality risks require inspection points before work is concealed. Foundation depth should be verified by the contractor, surveyor, supervising personnel, and designer when unexpected soil conditions are encountered. Reinforcement cutting, bending, spacing, and cover should be inspected before concrete placement. Concrete curing must maintain moisture for the specified period, and equipment should be subject to preventive maintenance and operator checks.

The proposed treatments are summarized in Table 4. They preserve the mitigation measures identified in the thesis while organizing them according to the risk source and the project objective being protected.

Table 4. Recommended response plan for priority risks

Priority Risk	Main Response Measures	Primary Objective Protected
Difficult mobilization	Survey access dimensions and bearing condition; define delivery windows; assign traffic marshals; prepare unloading and alternative-route plans; include schedule buffer	Time, safety, site operations
Material delay	Early procurement; supplier coordination; approved delivery calendar; buffer stock for critical materials; monitor lead times daily	Time and productivity
Workers struck by materials	Exclusion zones; safe stacking; lifting plan; trained signal persons; PPE; toolbox meetings; direct supervision	Occupational safety
Shortage of skilled labor	Competency screening; targeted training; clear work instructions; daily briefings; closer supervision	Quality, time, safety
Injury from work tools	Tool inspection; SOPs; operator training; guards and PPE; immediate correction of unsafe behavior	Occupational safety

Priority Risk	Main Response Measures	Primary Objective Protected
Nonconforming foundation depth	Joint inspection by foreman, surveyor, supervisor, and designer; document soil condition; obtain technical approval before changing depth	Structural quality
Concrete and reinforcement quality risks	Pre-pour inspection; verify bar cutting, bending, stirrup spacing, and cover; maintain proper curing; record inspections	Quality and rework prevention
Weather and equipment damage	Weather contingency plan; protect materials and work areas; preventive maintenance; standby repair arrangement	Time and continuity

4.5. Managerial Implications and Limitations

The integrated procedure offers a practical sequence for contractors: begin with a broad risk register, screen the instrument, condense correlated risks, apply a transparent scoring matrix, verify the results against field conditions, and assign specific controls. This sequence prevents management attention from being distributed equally across all 31 risks. It also shows that project risks are interconnected. In this case, access constraints increased the probability of material delay, while constrained work areas increased the importance of safety and supervision.

The findings are specific to one contractor team and one educational-building project. The sample consisted of only ten respondents, which is substantially smaller than normally preferred for stable multivariate inference. Consequently, the reported PCA output should be treated as exploratory and project-specific. Future studies should involve larger and more diverse respondent groups, including workers, consultants, designers, owners, and school representatives. Comparative application of FMEA, House of Risk, AHP, or quantitative simulation could also test the robustness of the priority order.

V. CONCLUSION

The study identified 31 risks affecting preparatory works, earthworks, foundations, and reinforced-concrete works in the Phase 1 cafeteria and classroom construction project at SMK Sore Tulungagung. All questionnaire items were reported as valid and reliable under the criteria used. PCA retained seven likelihood components explaining 96.208% of variance and six consequence components explaining 93.209%.

The most urgent risks were difficult mobilization of materials and equipment, with a score of 25, followed by material delay and workers being struck by materials, each with a score of 20. Shortage of skilled labor, injuries from work tools, and nonconforming foundation depth were also high priorities. The recommended response combines controlled delivery windows, early procurement and buffer stock, project-specific logistics planning, strengthened occupational-safety supervision, worker training, pre-work and pre-pour inspections, proper concrete curing, and equipment maintenance.

The combination of PCA and the AS/NZS 4360:2004 matrix produced a focused, field-relevant risk priority list. Its main value is managerial rather than broadly statistical: it helps the project team connect observed constraints with explicit preventive and corrective actions. Broader validation is required before the findings can be generalized to other projects.

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