

The object of this study is completed road construction projects in East Kalimantan that experienced negative schedule deviations during the 2022–2024 period. The problem addressed in this study is the persistence of construction delays that remain unresolved despite the frequent application of time extensions, indicating systemic weaknesses in planning, control, and governance. The results show that the most significant delay factors from RCA (root cause analysis) are weak project control and operational planning, unreliable material and procurement supply chains, unstable productivity in critical on-site activities, and unanticipated external constraints. The fuzzy analytics hierarchy process (FAHP) results indicate that the adoption of digital-based project management and scheduling systems is the most effective mitigation strategy, achieving the highest synthesis score of 0.599 compared to other alternatives. This result is further supported by sensitivity analysis, confirming the stability of the ranking. From the relative importance index (RII) analysis, weather-related factors emerge as the most significant contributors to delays, with a factor-level score of 0.729, followed by time factors (0.662) and equipment factors (0.643). At the indicator level, delays in material delivery show the highest individual impact, with an RII value of 0.779. Overall, five out of six major delay factor groups fall within the "high importance" category, highlighting the dominant role of systemic and operational issues rather than isolated technical problems. These results are explained by deficiencies in preventive planning and integrated control mechanisms, which lead to delayed decision-making and reactive project management practices. The distinctive feature of the proposed results lies in the integration of causal identification, priority weighting, and policy-oriented decision support, enabling delays to be addressed systematically rather than administratively. The results can be applied by public infrastructure agencies using digital scheduling systems, performance-based evaluations, and stronger accountability mechanisms, especially in regions with fast infrastructure development

Keywords: construction delay, FAHP, project management, RCA, RII, road construction

PRIORITIZING CONSTRUCTION DELAY TYPES AND MITIGATION STRATEGIES USING AN INTEGRATED RCA-FAHP-RII FRAMEWORK

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1. Introduction

Currently, nationwide infrastructure development is a priority in Indonesia, particularly following the designation of East Kalimantan Province as the site of the new national capital (IKN). The implementation of development projects in the region is expected to enhance national connectivity, economic growth, and the development of surrounding areas. However, with the increasing number of construction projects for the IKN plan, delays frequently occur repeatedly, indicating that the implementation of the IKN project requires management tailored to the project's conditions and the recurring factors causing delays. These delays not only reduce efficiency but also incur unnecessary costs, lead to contract disputes, and threaten public trust in infrastructure providers [1].

Given the frequent recurrence of delays, there is an urgent need to investigate the causes of construction delays and to

implement regulations that indirectly alleviate the burden on projects experiencing delays. East Kalimantan Governor Regulation No. 6 of 2024 grants contractors additional time beyond the project completion deadline in the event of a delay [2]. Indonesian Ministry of Finance Regulation No. 109 of 2023 also provides for time extensions beyond the project completion deadline in the event of a delay. These policies seem to offer a lifeline to contractors in the event of delays, leading contractors to view delays as a common occurrence [3]. Without a systematic approach to identifying and prioritizing delay factors and available solutions, delays will continue to recur and result in financial losses for the state.

Numerous studies have addressed delays in road construction projects, but one aspect that has not yet been emphasized is the systematic prioritization of delay factors [4]. Previous studies have focused on identifying causes such as scheduling issues, resource constraints, and unfavorable conditions [5, 6].

Recent studies have also shown progress by integrating analytical methods such as failure mode and effects analysis (FMEA), matrix of cross-impact multiplications applied to a classification (MICMAC), and fuzzy analytical hierarchy process (FAHP) to effectively prioritize delay factors [7]. The integrated approach in those studies serves as a reference for the application of method integration in this study.

By prioritizing the factors causing delays, stakeholders can allocate resources more efficiently and implement effective mitigation strategies [7]. This is particularly important in highway construction projects, where delays are very common and often result in cost overruns and reduced efficiency [5]. Therefore, studies discussing the identification and prioritization of factors affecting construction project delays are relevant to this study because they can support the findings of this study and enhance understanding of the factors causing delays, as well as appropriate solutions to reduce delays in highway construction projects in East Kalimantan.

2. Literature review and problem statement

Paper [8] explains that project success should be evaluated using a multidimensional approach, rather than relying solely on time and cost indicators. It has been demonstrated that aspects such as quality, safety, and stakeholder satisfaction also play a crucial role in optimizing overall project performance. However, recurring delays continue to occur and cannot be resolved simply by identifying and prioritizing delays in road construction projects that occur repeatedly. This occurs because previous studies focused on general performance measurement rather than identifying the operational and contextual factors that directly cause delays [9].

To address the issues identified in previous studies, this study employs a more focused and factor-oriented approach to identifying and analyzing causes. This approach was applied in papers [2, 3], which emphasize an empirical approach to operational problems in road construction projects. The study indicates that delays frequently occur due to land acquisition issues, sudden design changes, poor contractor performance, poor coordination, financial issues, material shortages, low labor productivity, and unfavorable weather conditions. Unlike the broader performance frameworks discussed previously, this study enables more accurate prioritization and more technical solutions based on the conditions of previously completed road construction projects.

This approach is supported by [10], which measures the performance of supervising consultants on road construction projects. The study found that consultant effectiveness, occupational safety and health (OSH) controls, and worker attendance contribute positively to the mitigation of delays. Paper [11] also presents study on workforce stability as an indicator of sustainability performance in project scheduling, supported by findings showing that workforce allocation plays a crucial role in maintaining schedule consistency. Further development is explored in paper [12], which integrates cost and time considerations into a workforce scheduling model. From these papers, there remain unresolved issues regarding the causes of delays identified directly from road construction project reports.

There is a reason behind this issue: rather than focusing on empirical data, most studies focus on theoretical optimization and variable selection [13]. To address this issue, it is necessary to integrate theoretical scheduling perspectives with field observations to identify the causes of recurring delays. One empirical

study has shown that procurement issues contribute to project delays [14]. Another study also indicates that weak field control and external constraints disrupt construction schedules [15]. These studies indicate the need for a systematic approach to identify and prioritize the actual causes of delays in road construction projects using an empirical methodology, as well as the integration of delay factors with the prioritization of addressing specific delay types and solutions for the prioritized factors.

Based on several previous studies discussed earlier, it is known that delays in road construction projects are caused by complex interactions between technical, managerial, and external factors. Although many studies have successfully identified various causes of delays, these studies still focus on specific aspects such as performance measurement, scheduling optimization, or individual operational factors, resulting in unresolved core issues, such as the absence of an integrated analytical framework capable of systematically linking root causes, prioritizing issues based on severity, and implementing mitigation strategies for key factors based on systematic findings from the framework to inform sound decision-making. A comprehensive approach is needed to establish a hierarchy of influences and translate it into mitigation strategies that can be applied to any road construction project scenario.

3. The aim and objectives of the study

The objective of this study is to develop an integrated RCA-FAHP-RII framework to identify and prioritize factors affecting delays in road construction projects. This framework enables more accurate decision-making in managing project scheduling. To achieve this objective, the following are the specific goals the researcher must accomplish:

- identify the primary causes of delays in completed road construction projects with negative schedule deviations in East Kalimantan through Root Cause Analysis (RCA);
- identify factors that should be prioritized for addressing in road construction projects in East Kalimantan using the Relative Importance Index (RII);
- determine mitigation strategies to minimize delays in road construction projects using the Fuzzy Analytic Hierarchy Process (FAHP).

4. Materials and methods

The subject of this study is a road construction project in East Kalimantan that has been completed but experienced negative deviations during the 2022–2024 period. The findings of this study are intended to inform the implementation of road project management practices aimed at improving the quality of planning and control, the reliability of procurement, and the effectiveness of risk mitigation in road projects, with the expectation that this will reduce project delays in the future.

The study is based on the hypothesis that delays in road construction projects in East Kalimantan are predominantly caused by systemic and recurring factors rather than by isolated technical incidents. These factors are assumed to include weak project control and operational planning, unreliable material and equipment supply chains, unstable productivity in critical on-site activities, and external constraints that were not anticipated at the outset. It is further hypothesized that an integrated RCA-FAHP-RII framework can effectively identify these dominant delay causes, prioritize their relative importance, and

determine the most appropriate mitigation strategy. The following are the assumptions made in this study:

- the completed road construction projects with negative schedule deviations observed during 2022–2024 are assumed to provide representative evidence of the dominant delay patterns in East Kalimantan Road infrastructure projects. The data was collected in Microsoft Excel format and filtered for projects with negative deviations;

- the problems identified from project observations and completed project records are assumed to reflect the actual operational constraints that occurred during project execution and can therefore serve as valid inputs for root cause analysis (RCA). Various issues related to the project were identified from project reports, including progress reports, documentation of delays, and field records of completed road construction projects during the 2022–2024 period. RCA was selected because, during a road construction project in East Kalimantan, numerous issues arose that caused work stoppages which significantly disrupted the schedule; identifying the root causes is essential to minimize such stoppages in the future;

- the judgments provided by the Ministry of Public Works and Housing (PUPR) core team and representatives of the Physical Commitment Making Office (PPK)/Public Works unit are assumed to be sufficiently competent and relevant for evaluating mitigation alternatives in the FAHP stage. This analysis collected at Microsoft Excel and processed using the SuperDecision application. The fuzzy analytical hierarchy process (FAHP) was selected in this study due to its superior capability in handling uncertainty and subjectivity inherent in expert-based decision-making processes. Unlike the classical analytical hierarchy process (AHP), which relies on precise numerical judgments, FAHP integrates fuzzy set theory to accommodate the ambiguity and vagueness of human perception in pairwise comparisons;

- the variables and indicators used in the RII analysis from interviews with the contractor, the supervising consultant, and the project owner that are total of 32 respondents are assumed to adequately represent the main dimensions influencing project delays, including management and administration, materials and procurement, workforce and technical performance, external and environmental factors, and logistics. This analysis uses Microsoft Excel to calculate the RII score. RII was selected because the objective of this study is not only to identify the main issues and solutions but also to determine which issues should be prioritized for resolution in the project.

Simplifications adopted in the study are:

- the study was limited to road construction projects in East Kalimantan and did not include other infrastructure sectors, which reduced contextual variability and allowed the analysis to focus specifically on public road project delays;

- only completed projects with negative schedule deviations (progress < 100%) in the 2022–2024 observation period was included, so the analysis was simplified to cases that were directly relevant to delay investigation;

- the numerous issues identified in the field were consolidated into four main root-cause categories, namely weak project control and operational planning, unreliable supply chains for materials and equipment, unstable productivity in critical tasks, and unanticipated external obstacles;

- in the FAHP stage, the decision-making process was simplified into a limited number of criteria, sub-criteria, and alternatives so that the most appropriate mitigation option could be ranked in a structured and comparable manner.

- in the RII stage, the analysis was focused on ranking the relative importance of indicators rather than on developing

probabilistic or predictive delay models, thereby simplifying the interpretation toward priority-based managerial action.

5. Results of integrated RCA-FAHP-RII framework development

5.1. Identify root cause of delays in road construction projects in East Kalimantan

During the preliminary stage of this study, delay factors in road construction projects in East Kalimantan were examined using root cause analysis (RCA). The analysis commenced with the identification of problems encountered throughout project execution that contributed to schedule delays. The root cause analysis (RCA) method in this study was conducted through a structured sequence starting from data acquisition to causal identification. Raw data were collected from project reports, including progress reports, documentation of delays, and field records of completed road construction projects during the 2022–2024 period. These data were then systematically coded and classified into predefined delay categories. Subsequently, each delay event was analyzed using a cause-and-effect approach to identify its underlying root causes, applying iterative reasoning to trace problems beyond their surface-level symptoms. The identified causes were then grouped into major categories, allowing the construction of a comprehensive causal structure that reflects the interrelationships among delay factors. This step-by-step procedure ensures that the RCA results are derived directly from empirical data and can systematically explain the origins of construction delays.

As part of the root cause analysis (RCA), the study first documented the main operational problems encountered in completed road construction projects with negative schedule performance in East Kalimantan. The identified issues were grouped into five broad categories: project management and administration; materials and procurement; field technicians; equipment, labor, and logistics; and external, regulatory, and environmental factors. The aim was to identify recurring patterns that cause delays in various projects. The issues identified from road construction projects in East Kalimantan are presented at Table 1.

Delays in road construction projects during the three-year observation period were caused by a combination of internal and external factors with varying frequencies of occurrence. Issues related to project management and administration were consistently identified as the primary contributors, including delays in advance payment disbursement, late mobilization, inadequate implementation of quality management and occupational safety and health, and the project's continued reliance on manual action plans. These conditions led to delayed project start-ups, weak coordination, and ineffective control of work progress from the early stages of project implementation.

Issues related to materials and procurement were also encountered throughout the entire study period, primarily due to delays in the delivery of critical materials and reliance on supplies from outside Kalimantan. These constraints caused delays in both major construction work and finishing work, as essential materials were not available at the project site when needed. In addition, technical problems in the field were also prominent in two of the three years of observation, characterized by poor workmanship and repeated rework on critical activities such as excavation, backfilling, paving, drainage, and structural work. These shortcomings led to decreased productivity and disrupted the project's critical path, ultimately contributing to schedule delays.

Table 1

Issues with road construction projects in East Kalimantan

Category	Problem list	Impact	Indicative frequency
Project management & administration	Waiting for advance payment, delayed mobilization, suboptimal quality/safety management, inadequate traffic management, and action plans that are still manual	The project started late, coordination was slow, progress monitoring was weak, and early deviations were difficult to address	3 out of 3 years
Materials & procurement	Materials arrived late, purchase orders were delayed, supplies were sourced from outside East Kalimantan and Java, and granite tiles, curbs, bollards, steel, and concrete were not available on time	The main work and finishing touches have been delayed because key items are not yet ready on-site	3 out of 3 years
Field technician	Inadequate execution, repeated rework, and missing key technical components (excavation, backfill, paving, drainage, structures, bridges)	Low productivity, physical output falling short of targets, and critical tasks falling behind schedule	2 out of the next 3 years, supported by a breakdown of reasons (2023 and 2024)
Equipment, labor & logistics	Equipment malfunctions, untimely equipment mobilization, shortage of skilled labor, remote locations far from concrete or asphalt sources, and unreliable logistics	Work efficiency has declined, idle time has increased, and daily targets have not been met	1 out of 3 years + supported by a resume (2024)
External, regulatory & environmental	Land disputes, utility relocation permits, awaiting quality test results/ Job Mix Design (JMD), weather conditions/rainy season, open traffic	There are delays beyond the site's control that are disrupting the project's workflow	1 out of 3 years + supported by a resume (2024)

Factors related to equipment, labor, and logistics emerged as relatively minor but still significant challenges during the final year of observation. These issues primarily relate to equipment breakdowns, delays in equipment mobilization, insufficient availability of skilled labor, and logistical constraints, which collectively increase idle time and hinder the achievement of planned daily work volumes. In addition, external, regulatory, and environmental factors were also identified during the same period, including land acquisition disputes, utility relocation permitting processes, delays in obtaining quality test results, unfavorable weather conditions, and the obligation to maintain open traffic. These factors caused work stoppages beyond the contractor's control and disrupted the overall project workflow.

Based on the identified conditions, four principal delay categories were established, along with their corresponding root causes:

1. Weak project control and operational planning.

This is evident from the late mobilization, manual scheduling, manual action plans, suboptimal quality and occupational safety and health management, and delays in initial administrative procedures.

2. The supply chain for materials and equipment is not yet reliable.

This is evident from delays in material delivery, slow processing of purchase orders, materials sourced from outside the region, delays in the delivery of granite tiles, concrete, steel, curbs, and bollards, as well as damaged or insufficient equipment.

3. On-site productivity has not yet stabilized for critical tasks.

This is evident from the predominance of negative values in excavation, backfill, concrete paving, drainage, structures, and bridge components, as well as the occurrence of repeated rework.

4. External obstacles were not anticipated from the outset.

These include weather conditions, land disputes, existing utilities, open traffic, and awaiting test results.

After identifying the main issues in the project, solutions were determined for each of these issues based on a review of the relevant literature. After identifying the major root causes of delay through the RCA stage, the next step was to formulate corrective actions that directly correspond to each problem category. The proposed solutions were derived from the relevant

literature and aligned with the specific operational weaknesses observed in delayed road construction projects in East Kalimantan. Thus, each recommendation was designed not only to address the visible symptoms of delay, but also to reduce the recurrence of the underlying causes. The Table 2 are the solutions derived from the literature review that address these issues.

Table 2

Solutions to every major problem

Category	Solution
Weak project control and operational planning	Require a digital baseline schedule (Microsoft Project/ Primavera or equivalent) from the outset, including the S-curve, critical path, and weekly recovery plan
The supply chain for materials and equipment is not yet reliable	Create a procurement plan based on actual lead times for primary materials and finishing materials, including backup vendors and buffer stock
On-site productivity has not yet stabilized for critical tasks	– establish a project control dashboard that integrates physical progress, equipment requirements, materials, labor, and administrative status; – conduct weekly audits of critical items: mobilization, earthwork, paving, structures, drainage, and finishing work
External obstacles were not anticipated from the outset	– prepare a project risk register that includes weather, utilities, land disputes, and open traffic, along with clear mitigation plans and designated points of contact; – strengthen quality control during construction to reduce repetitive rework and daily volume deviations

Based on Table 2, it is evident that in the category of weak project control and operational planning, the recommended solution emphasizes the mandatory implementation of a digital baseline schedule from the early stages of the project. These findings indicate that the root of the problem primarily stems from inadequate planning quality and the absence of standardized time management practices. In the category of unreliable

material and equipment supply chains, the proposed solutions focus on developing procurement strategies that account for actual lead times, supported by alternative suppliers and the provision of buffer stock. This suggests that project delays are largely driven by a lack of anticipation regarding the supply chain, rather than solely by on-site execution issues.

For productivity categories that remain unstable in critical field activities, the recommended solution emphasizes operational strengthening through the use of an integrated project control dashboard and routine weekly audits of critical work items. This reflects the need for strict monitoring and daily production control to reduce recurring performance deviations. Meanwhile, for external challenges not anticipated from the outset, the recommended approach prioritizes the development of a comprehensive project risk register as well as enhanced quality control measures during project execution. These findings indicate that the impact of factors beyond the direct control of the field can still be mitigated through stronger risk management and better-quality planning.

5. 2. Determining optimal solutions to root causes of delays using the FAHP

Based on the issues and solutions identified through the RCA method, the FAHP was conducted to determine the optimal policy solution from among the options presented, using criteria derived from the issues identified in the RCA. The fuzzy analytical hierarchy process (FAHP) was applied to prioritize mitigation strategies through a multi-stage computational procedure. First, a hierarchical structure was developed based on the results of RCA, consisting of goals, criteria, sub-criteria, and alternative strategies. Expert judgment data were collected through pairwise comparison questionnaires, where experts assessed the relative importance of each element using linguistic scales. These qualitative judgments were then transformed into triangular fuzzy numbers to capture uncertainty in expert perceptions. The fuzzy pairwise comparison matrices were processed to obtain fuzzy synthetic extent values, followed by the calculation of the degree of possibility between criteria. These results were then defuzzified to generate crisp priority weights, which were further normalized to determine the final ranking of mitigation strategies. This sequential computation ensures consistency between expert input and decision outcomes while accounting for uncertainty in the evaluation process.

The optimal solution was determined based on the opinions of one respondent from the PUPR core team and three respondents from the Physical PPK unit of the Public Works Department. As an initial step in the FAHP analysis, the study determined the weighting of the main respondent criteria to identify the dominant basis for evaluating mitigation alternatives. The comparison focused on schedule delay and support from the operations manager across all respondent groups involved in the assessment. The priority scores for each respondent are shown in Fig. 1.

The "respondent criteria weights" figure illustrates a comparison between two assessment criteria, schedule delays and project manager support, across five respondent groups: core team, PUPR agency 1, PUPR agency 2, PUPR agency 3, and the aggregated (combined) group. Within the core team group, project manager support is assigned a strongly dominant priority, accounting for approximately 75% of the total weight, while schedule delays represent only about 25%. In contrast, all three PUPR agency groups exhibit an opposing pattern, with schedule delays receiving substantially higher weights ranging from

80% to 85%, compared to project manager support at approximately 15–20%. This trend indicates that the PUPR Agencies consistently regard schedule delay as the most critical consideration in evaluating project performance or risk. The combined results present a more balanced weighting; however, schedule delays remain predominant at around 70%, while project manager support contributes roughly 30% of the overall weight.

As the next step in the FAHP procedure, the study evaluated the relative importance of the sub-criteria under the schedule delay criterion. The assessment compared planning, coordination, and clarity of scope across all respondent groups to identify the most influential factor contributing to project delay risk. The priority scores obtained from this comparison are shown in Fig. 2.

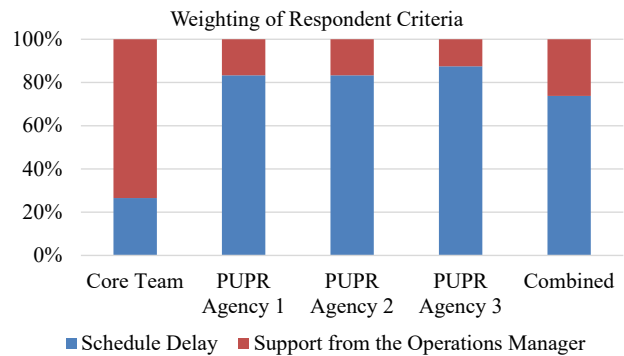


Fig. 1. Priority scores for criteria by respondent

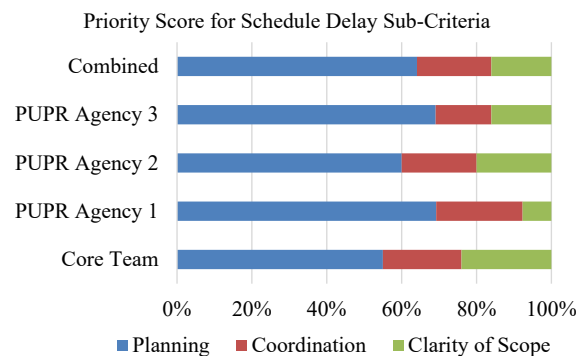


Fig. 2. Priority scores for sub-criteria of the schedule delay criteria

Based on the priority scores of the sub-criteria within the schedule delay criterion, all respondent groups consistently assigned the highest weight to the Planning sub-criterion, with values ranging between approximately 60% and 70%. This finding confirms that planning quality is perceived as the most influential factor affecting the risk of project delays. The coordination sub-criterion received a moderate level of importance and exhibited noticeable variation among respondent groups; for instance, the core team and PUPR agency 1 placed greater emphasis on coordination compared to PUPR agency 2 and PUPR agency 3.

After analyzing the sub-criteria under the schedule delay criterion, the FAHP procedure was continued by evaluating the sub-criteria associated with executive manager support. This stage was intended to determine which managerial support dimension was perceived as the most influential in strengthening project implementation and reducing the risk of delay. For this purpose, the respondents compared four

sub-criteria, namely communication, organizational structure, availability of resources, and expertise that across all respondent groups and in the combined assessment. The resulting priority distribution is presented in Fig. 3.

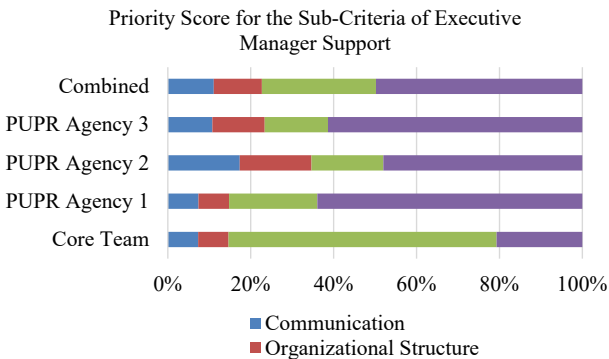


Fig. 3. Priority scores for sub-criteria under the executive manager support criterion

Based on the priority scores of the sub-criteria within the project manager support criterion, the expertise sub-criterion received the highest weighting across nearly all respondent groups. PUPR agency 1, PUPR agency 2, and PUPR agency 3 consistently assigned substantial importance to managerial expertise, with weights approaching or exceeding 50%. This underscores the perception that the technical competence of the project manager is the most critical element in providing effective support for project execution. Resource availability generally ranked second among the sub-criteria. The core team assigned the greatest emphasis to this factor, with a weight exceeding 50%, indicating that adequate resources are viewed as the primary driver of effective on-site management from their perspective. In contrast, the communication and organizational structure sub-criteria received relatively lower priority compared to expertise and resource availability. Communication typically accounted for approximately 10–15% of the total weight, suggesting that while it remains important, it is not regarded as a decisive factor in the context of project manager support.

As the final step in the FAHP procedure, the study calculated the synthesis scores of the proposed alternatives based on the combined weights of the criteria and sub-criteria. This step aimed to determine the most preferred mitigation option in the overall decision model. The resulting synthesis scores are shown in Fig. 4.

Based on the composite criterion scores, alternative 1 (adoption of project management software such as Microsoft Project for developing planning and scheduling models) achieved the highest overall score of approximately 0.6, thereby emerging as the most preferred alternative in the decision-making process. Alternative 2 (evaluating employee performance using key performance indicators (KPI)), ranked second with a composite score of around 0.23. This indicates that while the alternative remains relevant, its

relative contribution is considerably lower than that of alternative 1. In contrast, alternative 3 (optimizing and managing project resources based on project status) obtained the lowest composite score, approximately 0.17, positioning it as the least favored option among the evaluated alternatives. The substantial disparity in scores, particularly between alternative 1 and the remaining alternatives, demonstrates that Alternative 1 consistently outperforms the others across the set of criteria applied in the synthesis stage. To further evaluate the robustness of these results, the sensitivity values for the three alternatives are presented as follows.

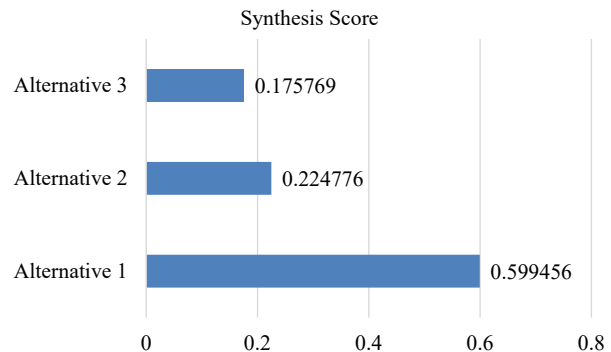


Fig. 4. Synthesis priority scores for criteria across alternatives

To validate the stability of the FAHP results, the study conducted a sensitivity analysis after calculating the synthesis scores of the decision alternatives. This analysis was used to determine whether variations in criterion weights would change the ranking order of the proposed mitigation options. The resulting sensitivity pattern is shown in Fig. 5.

The FAHP sensitivity analysis results illustrated in the graph indicate that variations in the weights of the main criteria do not substantially affect the priority ranking of the three evaluated alternatives. This is reflected in the relatively flat trajectories of all three lines across the full weight variation range from 0 to 1.

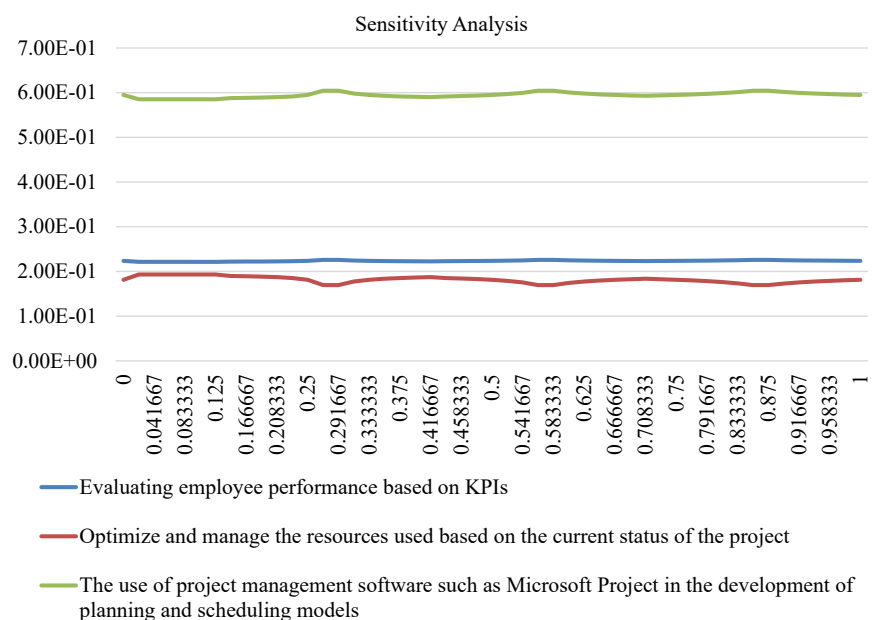


Fig. 5. Sensitivity of each criterion to the alternatives and the overall result

The black line consistently occupies the highest position, with values around 0.6, followed by the red line ranging approximately between 0.2 and 0.25, while the blue line remains at the lowest level, around 0.15–0.2. The absence of any line intersections confirms that the ranking order of the alternatives remains unchanged despite adjustments to the criterion weights. The dotted vertical line denotes the baseline condition; however, even when the weights deviate from this reference point, the priority levels of each alternative remain largely stable. These results demonstrate that the FAHP model exhibits strong robustness and low sensitivity to uncertainty in criterion weighting, with the highest-ranked alternative maintaining consistent dominance throughout the decision-making process.

5. 3. Policy and managerial implications for improving delay management in road construction projects

Based on the constraints frequently encountered in construction projects in East Kalimantan, as identified in the RCA results, and weights and alternatives obtained from the FAHP analysis, the urgency of addressing these constraints was determined using the RII analysis method. The relative

importance index (RII) method was employed to quantify and rank the significance of delay factors based on respondent evaluations. The analysis began with the collection of primary data through structured questionnaires distributed to relevant project stakeholders. Each respondent rated the importance of delay indicators using a Likert scale. The collected responses were then aggregated and converted into numerical scores, which were used to calculate the RII value for each indicator by applying a standardized formula that considers the total weighted score relative to the maximum possible score. The resulting RII values were subsequently ranked to determine the relative importance of each factor, and classified into predefined importance levels based on established intervals. This step-by-step approach allows for transparent and replicable quantification of factor significance, ensuring that the prioritization reflects the collective perception of stakeholders.

Prior to conducting further statistical analysis, all questionnaire indicators were tested for validity to confirm their suitability for measuring the study variables. The test results for the material, tools, time, cost, labor, and weather factors are summarized in Table 3.

Table 3

Validity for RII

Variables	Description	r (calculation)	r (table)	P-value	Criteria
X1	Materials factor				
X1.1	Material deliveries are often late	0.627	0.334	0.000	Valid
X1.2	Materials do not meet specifications	0.577	0.334	0.000	Valid
X1.3	Material shortages on-site	0.588	0.334	0.000	Valid
X1.4	Material damage due to on-site conditions	0.394	0.334	0.019	Valid
X1.5	Inaccurate material requirements planning	0.680	0.334	0.000	Valid
X2	Tools factor				
X2.1	Equipment frequently breaks down	0.579	0.334	0.000	Valid
X2.2	Equipment is not mobilized on time	0.626	0.334	0.000	Valid
X2.3	Equipment is not suitable for the job	0.465	0.334	0.005	Valid
X2.4	Equipment is shared with other projects	0.603	0.334	0.000	Valid
X3	Time Factor				
X3.1	Delays in the initial project mobilization	0.527	0.334	0.001	Valid
X3.2	Work duration deviates from the plan	0.643	0.334	0.000	Valid
X3.3	Overlapping work activities	0.474	0.334	0.004	Valid
X3.4	Schedule coordination is not yet optimal	-0.075	0.334	0.669	Invalid
X4	Cost factor				
X4.1	Delays in progress payments	0.596	0.334	0.000	Valid
X4.2	Limited implementation funds	0.699	0.334	0.000	Valid
X4.3	Ineffective financial management	0.824	0.334	0.000	Valid
X4.4	Unexpected costs have arisen	0.745	0.334	0.000	Valid
X5	Labor Factor				
X5.1	Insufficient workforce	0.418	0.334	0.012	Valid
X5.2	Workers do not understand the work methods	-0.198	0.334	0.253	Invalid
X5.3	Unclear division of tasks	0.607	0.334	0.000	Valid
X5.4	Insufficient worker attendance	0.338	0.334	0.047	Valid
X6	Weather factor				
X6.1	Heavy rainfall	0.664	0.334	0.000	Valid
X6.2	Weather conditions are hindering the transport of materials	0.582	0.334	0.000	Valid
X6.3	Work has been suspended due to weather conditions	0.594	0.334	0.000	Valid
X6.4	Weather conditions are reducing work efficiency	0.388	0.334	0.021	Valid

Based on the results of the validity and reliability testing, it was found that most of the variables were deemed valid. However, there were two variables that did not meet the validity criteria. Next, a reliability test was conducted by removing the two invalid indicators. To ensure the consistency of the research instrument, a reliability test was carried out after the validity assessment had been completed. In this stage, the indicators belonging to each factor group were evaluated using Cronbach's Alpha in order to determine whether the instrument produced stable and consistent measurements across the observed variables. The test covered six main factor groups, namely material factors, equipment factors, time factors, cost factors, labor factors, and weather factors. Results of the reliability test in this study are shown in Table 4.

Table 4
Validity for RII

Code	Factor	Cronbach Alpha	Description
X1	Material factors	0.720	Reliable
X2	Equipment factors	0.616	Reliable
X3	Time factors	0.641	Reliable
X4	Cost factors	0.792	Reliable
X5	Labor factors	0.765	Reliable
X6	Weather factors	0.867	Very reliable

The internal consistency of the research instrument was evaluated using Cronbach's Alpha coefficients across six measurement scales: material, equipment, time, cost, labor, and weather factors. The analysis revealed that all factors yielded alpha values exceeding the recommended threshold of 0.60, ranging from 0.616 for Equipment Factors to 0.867 for weather factors. Specifically, weather factors demonstrated the highest level of reliability, while the remaining variables exhibited solid internal consistency. These results indicate that the instrument is statistically reliable and provides a stable foundation for subsequent empirical analysis. To interpret the RII results more clearly, the obtained values were grouped into five levels of importance according to their interval range. The classification used in this study is shown in Table 5.

Table 5
RII categorize

Value interval	Level of importance
1.000–0.800	Very high
0.799–0.600	High
0.599–0.400	Medium
0.399–0.300	Low
0.199–0.000	Very low

After confirming the validity and reliability of the research instrument, the relative importance index (RII) was calculated to determine the relative significance of each indicator and factor affecting project delays. This analysis was carried out at both the item level and the aggregated factor level in order to identify which variables were perceived as having the greatest influence on project performance. The resulting total scores, RII values, and corresponding levels of importance are presented in Table 6.

The delay-causing factor with the highest RII value is X1.1 (frequent delays in material delivery) with an RII value of 0.779, and the delay-causing factor with the lowest RII value is X1.2 (materials not meeting specifications) with

an RII value of 0.479. Overall, there were 15 high-category delay factors (RII 0.799–0.600) and 8 medium-category delay factors (RII 0.599–0.400).

Table 6
RII score for each variable

Code	Total score	RII	Description
X1.1	109	0.779	High
X1.2	67	0.479	Medium
X1.3	102	0.729	High
X1.4	89	0.636	High
X1.5	79	0.564	Medium
X1	446	0.637	High
X2.1	87	0.621	High
X2.2	98	0.700	High
X2.3	71	0.507	Medium
X2.4	104	0.743	High
X2	360	0.643	High
X3.1	96	0.686	High
X3.2	106	0.757	High
X3.3	76	0.543	Medium
X3	278	0.662	High
X4.1	77	0.550	Medium
X4.2	84	0.600	High
X4.3	97	0.693	High
X4.4	99	0.707	High
X4	357	0.638	High
X5.1	68	0.486	Medium
X5.3	77	0.550	Medium
X5.4	78	0.557	Medium
X5	223	0.531	Medium
X6.1	106	0.757	High
X6.2	100	0.714	High
X6.3	97	0.693	High
X6.4	105	0.750	High
X6	408	0.729	High

The relative importance index (RII) analysis identifies weather factors (X6) as the most critical dimension with the highest score of 0.729, followed by time factors (X3) and equipment factors (X2) with scores of 0.662 and 0.643, respectively. At the indicator level, X1.1 emerged as the most significant individual variable across all factors, yielding an RII of 0.779. However, the labor factor (X5) had the lowest RII value at 0.531, meaning that all of its sub-indicators fell into the "moderate" category. Of all the factors considered, only the labor factor fell into the "moderate" category, indicating that labor is not a major issue in road construction projects in East Kalimantan.

Based on the results of the analysis, there are several substantive policies that are theoretically sound and of high urgency for implementation in order to reduce delays in road construction projects in East Kalimantan. These policies are not merely normative but are based on empirical evidence demonstrating how delays in road construction projects occur. The following are the proposed policies based on the results of the analysis in Table 7.

Table 7

Policies proposed based on the analysis results

Policy	Evidence analysis	Policy implications	Objectives of policy implementation
Responsibilities in the Implementation of a digital-based scheduling and project management system	FAHP ranks the use of technology-based project management systems as the policy option with the highest priority	Local governments need to mandate the use of standardized digital scheduling systems for all road projects, which should include: <ul style="list-style-type: none"> – integrated schedule planning, – real-time progress monitoring, – delay reporting based on early warning indicators 	To serve as a preventive control mechanism to minimize delays from the early stages of project implementation
Standardization of project performance evaluation based on integrated key performance indicators (KPI)	RII demonstrates that the quality of monitoring, accountability structures, and logistical efficiency are of the utmost importance	Policies are needed that establish standardized KPIs as the basis for contract evaluation, to be used for: <ul style="list-style-type: none"> – measuring the performance of service providers and project management, – serving as the basis for granting incentives and disincentives, – selecting and developing contractors based on their performance track record 	A shift in project evaluation from mere administrative compliance toward results-based management (performance-based policy)
Tightening of the time extension mechanism and elimination of automatic time tolerance	RCA indicates that granting extensions does not address the root cause of the delays	Extensions are no longer granted automatically; instead, they must: <ul style="list-style-type: none"> – based on a root cause analysis, – linked to specific KPI failures, – accompanied by a verified project management improvement plan 	Shifting the paradigm from a delay tolerance policy to a delay accountability policy

Based on the results of the root cause analysis (RCA), it was found that the policy of granting extensions did not solve the fundamental problem of delays, but instead reinforced the habit of tolerance for project delays. This explanation emphasized that extensions appeared to hide recurring structural problems, especially in planning, coordination, and decision-making. The results of this analysis provide a proposal to tighten the granting of extensions with conditional approval based on evidence. The extensions granted must be based on root cause analysis, KPI checking, and a completion plan with additional time that is verified and fully controlled by the bureaucracy [16].

The FAHP results identified the adoption of a technology-based project management system as the policy alternative with the highest priority score. This illustrates the dominance of planning quality and monitoring effectiveness. Interpretation of the FAHP results indicates that project delays are systemic, not incidental, stemming from planning practices that are not based on field conditions and control mechanisms that tend to be reactive. Therefore, the policy implication that can be implemented is to emphasize mandatory standards that must be followed by all construction projects. This requires integrated schedule planning, monitoring, and real-time delay reporting to provide technical solutions as quickly as possible [17].

The RII results also indicate that monitoring, accountability, and logistical efficiency are high priorities among the factors associated with delays. This explanation supports the interpretation that low performance is related to repeated technical errors, and is also related to weak governance and evaluation, thus the proposed policy shift from compliance-based assessment to a performance-based evaluation system [18].

6. Discussion of the results integrated interpretation of RCA-FAHP-RII findings research contributions and study limitations

The discussion of the results of this study confirms that there are several differences from previous studies that linked road construction delays to technical problems or performance deficiencies. The findings of this study indicate that schedule delays in road projects in East Kalimantan were caused by weaknesses in the overall project implementation

system [2]. This perspective shifts the perspective from implementation problems in the field to an integrated understanding of institutional, operational, and logistical aspects that produce optimal output. Root cause analysis (RCA) in this study identified four dominant causes, namely operational control and planning problems, material and equipment supply chains, productivity, and external factors. These four factors are interrelated and mutually supportive. Therefore, a solution is needed that can address these four factors to prevent delays from occurring in the future.

Table 1 reveals that management and administration issues, as well as material procurement and logistics, were recurring issues throughout the three-year observation period. This explains why poor project and supply chain controls were the primary cause of delays, surpassing technical failures or incidental disruptions. Furthermore, delayed project mobilization, reliance on manual scheduling, and disrupted material deliveries also occurred repeatedly, contributing to delays. The numerous key issues underscore the fact that the delays are systemic errors that recur annually in the implementation of road construction projects in East Kalimantan.

While previous studies often propose mitigation measures without validating their effectiveness, the FAHP results from this study allow for a direct comparison between alternative strategies. Based on the FAHP alternative, it was found that mandatory adoption of a digital-based project management and scheduling system outperformed the other two alternatives. This result differs from studies that prioritize on-the-ground measures, as delays are caused by deficiencies in structured planning, real-time monitoring, and early warning mechanisms, rather than by execution alone. Fig. 1 shows that schedule delays are assigned the highest combined weight, confirming that deficiencies in planning quality can be a driver of delays. Fig. 2 further illustrates that planning is the highest priority among the sub-criteria for schedule delays across all respondent groups. Therefore, deficiencies in planning quality are a driver of delays. Fig. 4 shows that alternative 1 achieved the highest synthesis score, suggesting the need for a digitalized project planning system. Fig. 5 illustrates that varying the criteria's weights does not change the ranking order, indicating that the FAHP results are insensitive to weight changes.

This prioritization can be achieved by incorporating expert assessments into a multi-criteria decision-making framework, then tested through sensitivity analysis. The results indicate that the selected alternative remains superior even though the criteria weights change [7]. In contrast to study that emphasizes technical aspects of construction delays, the RII results in this study confirm that the most influential factors are quality monitoring, timely procurement, material quality management, storage efficiency, and clarity of responsibilities. Tables 4–6 explain that governance and supply chain management are the main contributors to delays. Table 4 shows that the instruments used are reliable, so the ranking results are statistically reliable. Table 6 confirms that delays in material delivery, weather conditions, and time deviations have high RII values, making them important factors in project delays. Table 6 also shows that materials, equipment, time, cost, and weather are in the "high" importance category, while labor is in the medium category. This pattern indicates that delays are more influenced by the quality of supervision, procurement accuracy, and logistics effectiveness, rather than solely by the technical capabilities of the workforce.

The results of this comparison indicate that delays are more influenced by governance and supply chain performance than purely technical implementation issues. This finding differs from the general view that tends to emphasize technical aspects, as the results of this study confirm that reducing road construction delays is more dependent on planning discipline, procurement process synchronization, and clear institutional accountability [19]. Table 7 illustrates how the integration of the RCA-FAHP-RII results is translated into practically applicable policy recommendations. The table demonstrates a clear link between empirical evidence and policy direction, thus understanding the rationale for the proposed mandatory implementation of a digital scheduling system, standardized performance evaluation, and a more stringent time extension mechanism. These policies directly address the root causes identified in Table 1 and align with the alternative priorities shown in Fig. 4.

Compared with previous studies, this study demonstrates a more comprehensive and integrated approach to analyzing construction delays. Previous studies generally focused on specific aspects, such as causal factor identification, project performance evaluation, or mitigation proposals. While providing important initial insights, these approaches failed to systematically link root causes, solution priorities, and decision-making outcomes. This study combines root cause analysis (RCA), the fuzzy analytical hierarchy process (FAHP), and the relative importance index (RII) into a single, integrated framework. This integration allows for a clear and sequential relationship between problem identification, prioritization, and policy-based recommendations. This approach offers a key advantage because it helps decision-makers understand delay mechanisms in a more structured way and determine appropriate solutions. However, this study has several limitations. The limited number of expert respondents used in the FAHP stage may affect the generalizability of the results. The observational and perception-based nature of data from the RCA and RII stages can potentially introduce subjective bias. Furthermore, this framework focuses more on prioritization and decision support, making it incapable of predicting the magnitude or timing of project delays.

Based on these findings, the study suggests the need for a shift in public construction management, from a previously accepted approach to delays to a more preventative, perfor-

mance-based approach that emphasizes accountability. The proposed framework provides a methodological contribution by providing a robust multi-criteria decision-making tool, as well as practical contributions by providing evidence-based policy recommendations to improve planning quality, monitoring effectiveness, and institutional accountability. These findings are particularly relevant for regions experiencing accelerated infrastructure development. These conditions generally present a systemic risk of delays inherent in project implementation processes, necessitating a more structured and integrated approach.

However, this study still has several limitations. The findings are relevant to road construction projects in East Kalimantan, which have similar institutional characteristics, procurement systems, and environmental conditions. The FAHP phase relied on a limited number of expert respondents, while the RCA and RII phases utilized data from completed projects and perception-based assessments. This suggests that the resulting framework is best understood as a contextual decision-support tool, rather than a general model that can be readily applied across all construction sectors or regions. Furthermore, another limitation is the depth of the data used. This study did not utilize real-time project data, such as actual procurement lead times, the duration of weather disruptions, or equipment usage records. However, the framework is more robust in prioritizing factors and solutions than in predicting the magnitude or duration of project delays.

Compared with previous developments, the results of this study point to a broader and more integrated development direction. The framework's application can be expanded to other provinces, comparing public and private road projects, and integrated with digital monitoring systems and project performance dashboards. However, this implementation could potentially face several challenges, such as differing project documentation standards, limited data access, and the increased complexity of combining empirical field data with predictive or multi-criteria analytical models. Nevertheless, these findings provide a strong foundation for driving change in public construction management.

7. Conclusion

1. From completed road construction projects in East Kalimantan that experienced negative schedule deviations (progress < 100%) during the 2022–2024 period, weak project control and operational planning as the most persistent root causes of delay, followed by material procurement constraints, unstable productivity in critical activities, and unanticipated external factors.

2. FAHP analysis demonstrated that the mandatory adoption of project management software such as Microsoft Project for developing planning and scheduling models are the most effective mitigation strategy, and significantly outperforming alternative managerial and resource-based solutions. Sensitivity analysis further verified the robustness of this result, indicating high model stability under varying criterion weights.

3. The results of the RII analysis indicate that the priority issues to be addressed are weather, time management, and equipment limitations. Delays in material delivery are an operational constraint that must be prioritized for resolution, even though material-related factors as a whole do not rank highest. For future road projects, the factors of material delivery delays, weather, time management, and equipment limitations must be addressed from the start of construction.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, whether financial, personal, authorship, or otherwise, that could affect the study and its results presented in this paper.

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The study was performed without financial support.

Data availability

Manuscript has associated data in a data repository (https://drive.google.com/drive/folders/124yNQ_Em-0qxzPoya1v6tMeXrrex1J5j).

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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Authors' contributions

Amir: Conceptualization, Data Curation, Resource, Software, Visualization, Methodology, Investigation, Formal analysis, Writing-original draft; **Sutanto Hidayat:** Methodology, Validation, Supervision, Writing – review & editing; **Jimmy:** Investigation, Validation, Formal analysis, Writing – review & editing, Supervision.

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