Global Journal of Emerging Science, Engineering & Technology, 3 (2) November 2025, pp.74-83

Content lists available at Scientia Global Academia Services

Global Journal of Emerging Science, Engineering & Technology

Journal homepage: ejournals.scieglobal-academia.com/gjeset

*Original Article*

# Risk Prioritization in Road Rehabilitation Projects Using a Schedule-Integrated Matrix Approach

**Evan Dwianto Rante Tondok [1], Maraden Panjaitan [1] and Zony Yulfadli [1,*]**

[1] Department of Civil Engineering, Faculty of Engineering, Universitas 17 Agustus 1945 Samarinda, 75124 Kalimantan Timur, Indonesia.
* Correspondence: zony@untag-smd.ac.id (Z.Y.)

**Citations:** Tondok, E.D.R., Panjaitan, M., & Yulfadli, Z. (2025). Risk Prioritization in Road Rehabilitation Projects Using a Schedule-Integrated Matrix Approach. *Global Journal of Emerging Science, Engineering & Technology*, 3(2), 74-83.

**Academic Editor:** Assoc. Professor Dr. Agus Sukoco.

Received: 17 August 2025 Revised: 15 October 2025 Accepted: 6 November 2025 Published: 30 November 2025

**Abstract:** Road rehabilitation projects are crucial for maintaining transportation network functionality; however, they are frequently exposed to schedule delays and cost overruns due to technical complexity, site dependency, and constrained implementation periods. Although previous studies have applied probabilistic simulations and multicriteria decision-making models for construction risk assessment, such approaches often require advanced tools and extensive data, limiting their practical application at the planning stage. This study aims to develop and apply a schedule-based risk matrix approach that integrates project schedule characteristics and cost-weighted activity data to prioritize implementation risks. The research adopts a descriptive–analytical design using secondary data derived from initial contract documents, including the implementation schedule and cost distribution of major work items. Risk likelihood is assessed based on schedule attributes, while impact is determined from the relative cost weight of each activity; risk levels are calculated using a probability–impact matrix. The results indicate that risk exposure is concentrated in high-value and long-duration activities, with structural concrete work classified as extreme risk, non-structural concrete and aggregate base course works categorized as high risk, and reinforcement steel and earthworks identified as medium risk. These findings suggest that integrating schedule and cost data into a structured risk matrix provides a transparent, practical tool for early-stage risk prioritization in road rehabilitation projects.

Keywords: Risk Matrix; Road Rehabilitation; Schedule-Based Risk Analysis; Construction Risk Management; Cost-Weighted Activities.



## 1. Introduction

Road rehabilitation projects play a critical role in sustaining transportation infrastructure performance, ensuring network reliability, and supporting regional socio-economic development. Unlike new construction projects, rehabilitation works are typically executed under ongoing traffic operations, tight contractual deadlines, budgetary constraints, and strong dependence on existing pavement and subgrade conditions.

These characteristics generate greater uncertainty and operational complexity. As highlighted in contemporary highway risk research, transportation projects are inherently exposed to dynamic interactions between schedule, cost, and contextual uncertainties (Zhasmukhambetova et al., 2025). In rehabilitation settings, where site conditions are often only partially known and work sequences are tightly constrained, this uncertainty becomes even more pronounced.

In construction project management, risk refers to uncertain events or conditions that may adversely affect project objectives, particularly time, cost, and quality performance. Recent empirical studies in road and highway construction consistently demonstrate that inadequate early-stage risk identification is a primary driver of schedule overruns and budget escalation (Antoniou, 2021; Rezaee Arjoody et al., 2023). Quantitative investigations further confirm that variations in the probability of risk occurrence significantly influence time–cost deviations (Rezaee Arjroody et al., 2024; Ariza Flores & Zavala Ascaño, 2025). These findings reinforce the argument that systematic, structured risk assessment at the planning stage is not optional but essential to improving project reliability.

To address uncertainty, a wide spectrum of risk assessment methodologies has been developed. Advanced quantitative techniques, such as Monte Carlo simulation, fuzzy FMEA, regression modeling, and Bayesian belief networks, have been widely adopted to estimate schedule and cost contingencies (Rezaee Arjoody et al., 2023; Mohamed & Tran, 2021). Hybrid multicriteria approaches integrating TOPSIS, AHP, and simulation tools have also been proposed to improve prioritization accuracy and predictive capability (Koulinas et al., 2021; Koulinas et al., 2023). In addition, structured frameworks such as the Risk Breakdown Matrix (RBM) and Schedule Risk Analysis (SRA) embed risk evaluation directly within project planning processes (Jeon et al., 2023; Kostrzewa-Demczuk & Rogalska, 2023). While these approaches enhance analytical rigor and decision support, they often require extensive historical data, expert-based pairwise comparisons, probabilistic modeling skills, or specialized software platforms. Consequently, their practical implementation may be challenging in routine project environments, particularly in rehabilitation projects characterized by limited data continuity and site-specific uniqueness.

Among the available tools, the risk matrix remains one of the most widely applied methods in engineering practice due to its intuitive structure and managerial interpretability. Its logic combines likelihood and impact to classify risk levels. It provides a clear and communicable framework for prioritization. The systematic review by Zhasmukhambetova et al. (2025) acknowledges the continued relevance of probability–impact models within integrated scheduling environments, while Koulinas et al. (2021) demonstrate how risk matrices can serve as the qualitative foundation of more advanced hybrid systems. However, despite its simplicity and popularity, the risk matrix method is frequently criticized for its subjectivity in assigning likelihood and impact values, as these assessments rely solely on expert judgment. Several prior applications have depended primarily on expert scoring systems or historical delay databases (Antoniou, 2021), which may not always be available or reliable in rehabilitation contexts.

A critical observation across the literature is that, although many studies integrate risk analysis with scheduling or cost estimation, relatively limited attention has been paid to deriving likelihood and impact parameters directly from the intrinsic structure of project planning documents. For instance, Yin et al. (2022) integrate schedule, cost, traffic, and risk to determine optimal contract times, yet their framework emphasizes macro-level contract optimization rather than activity-level risk zoning. Kowacka et al. (2021) allocate risk values within schedules using the MORAG method for geodetic tasks, but their scope is domain-specific. Inspection-oriented models (Jeon et al., 2023; Mohamed & Tran, 2021) and safety-focused multicriteria assessments (Koulinas et al., 2023) further demonstrate the feasibility of structured risk categorization, though their emphasis lies in quality and safety management rather than schedule–cost exposure at the planning stage.

These developments reveal an important research gap. While sophisticated probabilistic and multicriteria models enhance predictive precision, and inspection-based frameworks strengthen operational control, there remains limited exploration of a data-driven yet operationally simple approach that directly utilizes two universally available planning elements: project schedules and cost-weighted activity structures. Project schedules encapsulate temporal sequencing, duration, and criticality of activities, thereby offering an objective basis for estimating the likelihood of disruption. Simultaneously, cost weights embedded in contract documents reflect the relative financial exposure associated with each activity, providing a rational foundation for impact assessment. Integrating these two dimensions within a structured risk matrix framework offers the potential to bridge the gap between theoretical sophistication and practical applicability.

In conjunction with background, the present study aims to analyze implementation risks in road rehabilitation projects using a schedule-based risk matrix method. Specifically, the research derives risk likelihood from schedule characteristics and determines impact based on cost-weighted activity contributions drawn from initial contract documents. The calculated risk levels are subsequently mapped into a structured 5×5 matrix to define clear risk zones for managerial prioritization. By grounding probability–impact assessment in objective schedule and cost data, this study advances data-driven yet practical risk analysis approaches in road rehabilitation project management. It responds to calls in the literature for integrated, transparent, and implementable risk-informed scheduling frameworks that enhance early-stage decision-making without requiring complex probabilistic modeling tools (Zhasmukhambetova et al., 2025; Ariza Flores & Zavala Ascaño, 2025).

## 2. Literature Review

Risk analysis in highway and road construction projects has evolved from conventional probability–impact assessments toward more integrated and simulation-based decision frameworks. A recent systematic review by Zhasmukhambetova et al. (2025) highlights that traditional scheduling techniques such as the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) remain widely applied in highway projects; however, their deterministic assumptions limit their capacity to address dynamic uncertainty. The review demonstrates a growing trend toward hybrid methodologies that combine risk assessment tools with scheduling models, including Monte Carlo simulation (MCS), Fuzzy Set Theory (FST), the Analytic Hierarchy Process (AHP), and Bayesian Networks (BNs). This shift reflects recognition that schedule reliability cannot be separated from structured risk quantification. Nevertheless, while these advanced techniques enhance analytical rigor, they often increase methodological complexity and software dependency, potentially constraining their practical adoption in routine project management contexts.

Empirical studies in road construction have largely operationalized risk assessment through multicriteria and simulation-based approaches. Antoniou (2021) developed Delay Risk Assessment Models (DRAMs) using Risk Priority Number (RPN) calculations and the TOPSIS multicriteria decision-making method to rank delay factors across 120 road projects. Similarly, Koulinas et al. (2021) proposed an integrated framework combining a risk matrix, TOPSIS, and Monte Carlo simulation to evaluate time deviations in engineering projects. These approaches extend traditional probability–impact logic by incorporating structured ranking and uncertainty modeling. However, they remain heavily dependent on expert scoring systems and multicriteria normalization procedures. While such techniques improve prioritization accuracy, they also introduce subjectivity and methodological intricacy that may limit transparency and reproducibility at the contract administration level.

Quantitative simulation has become a dominant paradigm in schedule–cost risk research. Rezaee Arjoody et al. (2023) applied Failure Mode and Effects Analysis (FMEA) to identify critical risks and subsequently used Monte Carlo simulation to quantify their impacts on project time and cost. Their sensitivity analysis demonstrated a strong relationship between the probability of risk occurrence and time–cost deviations, reinforcing the argument that probabilistic modeling enhances forecasting reliability. Extending this line of inquiry, Rezaee Arjroody et al. (2024) integrated Delphi techniques, FMEA prioritization, Monte Carlo simulation, and regression modeling to estimate cost and time outcomes in Iranian road projects with relatively small deviations from realized values. Likewise, Ariza Flores and Zavala Ascaño (2025) developed a practical quantitative risk analysis (QRA) framework combining Monte Carlo simulation and schedule risk analysis (SRA), validated in Peruvian road projects. Collectively, these studies demonstrate the analytical strength of probabilistic frameworks in improving contingency estimation and predictive accuracy. Yet, despite their methodological robustness, they require substantial historical data, statistical expertise, and specialized software, which may not always be accessible in resource-constrained project environments.

Another stream of research focuses on integrating risk considerations directly into scheduling and contract-time determination. Yin et al. (2022) developed a seven-step integrative framework that combines schedule, cost, traffic impact, and risk analyses to determine optimal contract durations under accelerated construction conditions. Their work expands risk analysis beyond project-internal variables to incorporate external mobility and user-cost considerations, thereby enhancing strategic decision-making at the agency level. Similarly, Kostrzewa-Demczuk and Rogalska (2023) employed Schedule Risk Analysis in Risky Project Professional to incorporate design risks into construction planning, estimating realization probabilities between 75% and 90%. While these approaches demonstrate the benefits of embedding risk within scheduling decisions, they rely on advanced modeling platforms and focus primarily on forecasting project completion probabilities rather than systematically zoning activity-level risks for early managerial prioritization.

Parallel developments have emerged in risk breakdown and inspection-oriented frameworks. Jeon et al. (2023) introduced a Risk Breakdown Matrix (RBM) to identify and rank activity-level risks for transportation infrastructure projects, supporting risk-based inspection resource allocation. Mohamed and Tran (2021) combined fuzzy set theory with Bayesian belief networks to model causal relationships between inspection activities and pavement quality outcomes in hot mix asphalt projects. These studies shift attention toward operational monitoring and quality control during construction. Their emphasis on probabilistic updating and causal inference enhances adaptive inspection management; however, the primary objective is quality assurance rather than schedule reliability or cost-weighted exposure assessment. Thus, although activity-level risk structuring is present, its linkage to contract cost structure and schedule criticality remains limited.

Task-specific risk allocation has also been examined within specialized domains. Kowacka et al. (2021) proposed the MORAG method to quantify and allocate risk factors for geodetic tasks within construction schedules, demonstrating measurable schedule extensions resulting from survey-related errors. This contribution underscores the importance of early-stage task correctness in preventing downstream disruptions. Nevertheless, its application is confined to geodetic activities and does not generalize across broader work packages in road rehabilitation projects. In contrast, broader multicriteria safety-focused assessments, such as the AHP-based framework developed by Koulinas et al. (2023), evaluate health and safety risks in highway construction, including psychosocial factors. While vital for occupational risk management, these models prioritize worker safety dimensions rather than schedule and cost interdependencies embedded within contract activity structures.

Across these twelve studies, several patterns emerge. First, there is a strong consensus that risk assessment must be integrated with scheduling processes to improve project reliability (Zhasmukhambetova et al., 2025; Yin et al., 2022). Second, probabilistic simulation methods, particularly Monte Carlo simulation, have become the dominant analytical tool for quantifying time–cost uncertainty (Rezaee Arjoody et al., 2023; Rezaee Arjroody et al., 2024; Ariza Flores & Zavala Ascaño, 2025; Koulinas et al., 2021). Third, multicriteria and hierarchical methods such as AHP and TOPSIS enhance prioritization consistency but depend heavily on expert judgment (Antoniou, 2021; Koulinas et al., 2023). Fourth, inspection- and breakdown-oriented models improve operational risk allocation but are often focused on quality and safety management rather than on schedule–cost exposure (Jeon et al., 2023; Mohamed & Tran, 2021).

Despite these advancements, a gap remains in developing a contract-structure-driven, schedule-integrated risk framework that is analytically systematic yet operationally simple. Many existing models either emphasize predictive accuracy through complex probabilistic simulation or focus on specific domains such as inspection, safety, or geodesy. Relatively limited attention has been given to directly deriving risk likelihood from schedule characteristics and risk impact from cost-weighted activity contributions embedded in contract documents. A structured 5×5 risk matrix grounded in schedule criticality and cost proportionality offers a transparent, replicable alternative for early-stage risk zoning without reliance on advanced simulation tools. By integrating scheduling logic with cost-weighted exposure at the activity level, this approach can bridge the gap between theoretical sophistication and practical applicability in road rehabilitation project management.

## 3. Materials and Methods

This study employs a descriptive–analytical research design to examine implementation risks in a road rehabilitation project using a schedule-based risk matrix. The descriptive component aims to systematically identify and characterize the dominant risk sources embedded in the project's activity structure, while the analytical component quantifies and prioritizes those risks using a structured probability–impact evaluation. The risk matrix approach was selected for its conceptual clarity, managerial interpretability, and widespread adoption in construction risk management, particularly on projects where schedule performance and cost exposure are primary concerns. Unlike advanced probabilistic simulations that require extensive historical datasets and specialized modeling tools, the risk matrix framework allows structured classification of risks based on clearly defined likelihood and impact criteria, making it suitable for early-stage planning and contract-based evaluation contexts.

The study utilizes secondary data obtained from the initial contract documents of an ongoing road rehabilitation project. These documents include the detailed project implementation schedule (time schedule), the work breakdown structure (WBS), the cost weight of each work item relative to the total contract value, and the planned progress distribution over the project duration. The schedule provides a temporal representation of activity sequencing, duration, concurrency, and interdependencies, while the cost-weight structure reflects the proportional financial contribution of each activity to overall project expenditure. By integrating these two planning instruments, the research establishes an objective data foundation for assessing both the probability of disruption (likelihood) and the magnitude of its potential consequences (impact). Since the study relies exclusively on documented project planning data and does not involve human participants, interviews, or experimental procedures, ethical approval is not required.

Risk identification is conducted through a structured examination of the project's work breakdown structure and cost distribution profile. Activities are screened and categorized based on criteria that reflect exposure to schedule and cost uncertainty. Specifically, risks are identified for activities that exhibit relatively high-cost weights, extended implementation durations, critical positioning within the activity network, simultaneous execution with multiple parallel tasks, or dependence on external conditions such as weather variability, supply chain reliability, and material availability. This multi-criteria identification process ensures that both temporal vulnerability and financial exposure are considered. Based on these criteria, the analysis concentrates on major work packages commonly associated with rehabilitation projects, including structural concrete works, aggregate pavement layers, earthworks, and reinforcement steel installation. These categories are selected due to their substantial cost contribution, technical complexity, and strong interdependence within the project schedule.

Risk likelihood is assessed using a qualitative, structured scoring approach grounded in measurable schedule characteristics. Rather than relying solely on subjective expert perception, likelihood evaluation considers observable parameters in the project schedule, including activity duration, technical complexity, network interdependence, concurrency with other tasks, and susceptibility to potential implementation disruptions. Activities with longer durations, higher technical demands, or critical interconnections are assigned higher likelihood scores because of their greater exposure to delay-propagation effects. Risk impact is quantified based on the cost weight of each activity relative to the total contract value. The underlying assumption is that disruptions affecting activities with larger financial proportions will generate more significant consequences for both project cost performance and schedule continuity. By operationalizing impact as a function of cost-weighted exposure, the study establishes a measurable, contract-based basis for impact assessment. Similar to likelihood, impact is classified into five levels ranging from 1 (very low impact) to 5 (very high impact), with thresholds determined according to proportional cost contribution. This approach enhances objectivity and reduces dependence on purely perception-based evaluation. The overall risk level for each activity is calculated using the conventional probability–impact multiplication formula:

$$R = P \times I \quad (1)$$

Where (R) represents the risk level, (P) denotes the likelihood score, and (I) indicates the impact score. The resulting composite values are subsequently categorized into four hierarchical risk zones: low, medium, high, and extreme. These categories are visualized within a structured 5×5 risk matrix, providing a graphical representation of the interaction between likelihood and impact levels. The matrix enables systematic prioritization of activities requiring immediate managerial attention and supports the allocation of risk-mitigation resources based on exposure severity. By integrating schedule-derived likelihood assessment with cost-weight-based impact measurement, the methodological framework offers a transparent, replicable, and data-driven approach for early-stage risk zoning in road rehabilitation project management.

## 4. Results

### 4.1. Identified Project Risks

Based on the risk identification process, which analyzed the project implementation schedule and the distribution of cost weights, five major risk items were identified as representing the dominant activities within the road rehabilitation project. These risks correspond to structural concrete works, non-structural concrete works, aggregate base course (pavement layer), reinforcement steel works, and earthworks. The identification results indicate that potential project disruptions are primarily concentrated in activities characterized by substantial cost proportions and extended implementation durations. In contrast, activities with relatively smaller cost contributions and shorter durations exhibit lower exposure to significant risk escalation. This pattern suggests that financial weight and schedule intensity are key determinants of risk concentration within the rehabilitation project structure.

### 4.2. Likelihood, Impact, and Risk Level Assessment

The calculated values of likelihood, impact, and overall risk level for each identified activity are summarized in Table 1. Likelihood scores reflect the probability of disruption inferred from schedule-related characteristics, including activity duration, technical complexity, and interdependence within the project network. Impact scores are determined by the proportional cost weight of each activity relative to the total contract value, reflecting the magnitude of potential financial and schedule consequences. Table 1 presents the integrated results of this assessment, showing the computed risk levels ($R = P \times I$) and their corresponding classifications within the predefined risk categories.

**Table 1.** Likelihood, Impact, and Risk Level of Identified Risks

| Risk Code | Activity | Likelihood (P) | Impact (I) | Risk Level (Eq.1) | Risk Category |
|---|---|---|---|---|---|
| R1 | Structural concrete fc'20 MPa | 4 | 5 | 20 | Extreme |
| R2 | Concrete fc'10 MPa | 3 | 5 | 15 | High |
| R3 | Aggregate base course (LPA) | 2 | 5 | 10 | High |
| R4 | Reinforcement steel | 3 | 3 | 9 | Medium |
| R5 | Earthworks | 3 | 3 | 9 | Medium |

Table 1 presents the calculated likelihood (P), impact (I), composite risk level (R = P × I), and corresponding risk category for the major activities identified in the road rehabilitation project. The table demonstrates that risk exposure is not uniformly distributed across work items but is concentrated in activities characterized by high-cost weight, technical complexity, and schedule sensitivity. The highest risk level is observed in R1 – Structural concrete fc'20 MPa, which obtained a likelihood score of 4 and an impact score of 5, resulting in a composite risk value of 20 and classification as Extreme Risk. The relatively high likelihood reflects the technical complexity of structural concrete works, strict quality requirements, dependency on weather conditions, curing time constraints, and coordination with reinforcement and formwork activities. The maximum impact score (5) indicates that this activity carries a substantial cost weight within the contract and plays a structurally critical role in project performance. Any disruption to this activity is likely to entail high costs and cascade delays across dependent tasks. Therefore, structural concrete works represent the primary risk driver in the project and require intensive monitoring, strict quality control, and proactive mitigation strategies.

The second-highest risk category is R2 – Concrete fc'10 MPa, which has a risk level of 15 (Likelihood = 3; Impact = 5) and is classified as High Risk. Although its likelihood is slightly lower than that of structural concrete, the impact remains very high due to its significant cost contribution and integration across multiple segments of the rehabilitation process. Delays in this activity may not be as technically complex as structural concrete works but can still significantly influence progress distribution and financial performance.

Similarly, R3 – Aggregate base course (LPA) is categorized as High Risk, with a risk score of 10 (Likelihood = 2; Impact = 5). Despite its lower likelihood score, the activity carries a maximum impact value due to its high-cost proportion and its foundational role in pavement structure. As a base-layer component, delays or quality failures in this stage can affect subsequent surfacing and finishing works. The classification as High Risk indicates that even activities with moderate probability can become critical when financial exposure is substantial. In contrast, R4 – Reinforcement steel and R5 – Earthworks both fall within the Medium Risk category, each with a composite risk score of 9 (Likelihood = 3; Impact = 3). These activities exhibit a moderate likelihood due to operational variability, labor coordination requirements, and site-specific conditions. However, their impact scores are lower because their cost weights are smaller than those for structural concrete and aggregate base works. Although categorized as Medium Risk, these activities remain important because delays in reinforcement can indirectly influence structural concrete execution, and earthworks are often sensitive to weather and soil conditions. Thus, while they do not pose extreme financial exposure, their schedule interdependence warrants structured monitoring.

### 4.3. Risk Matrix Visualization

The results of the risk assessment are presented in a structured risk matrix with clearly defined risk zones, as illustrated in Figure 1. This visualization displays the relative positioning of each identified activity by plotting the combined likelihood and impact scores, thereby enabling clear differentiation of risk levels across project components.

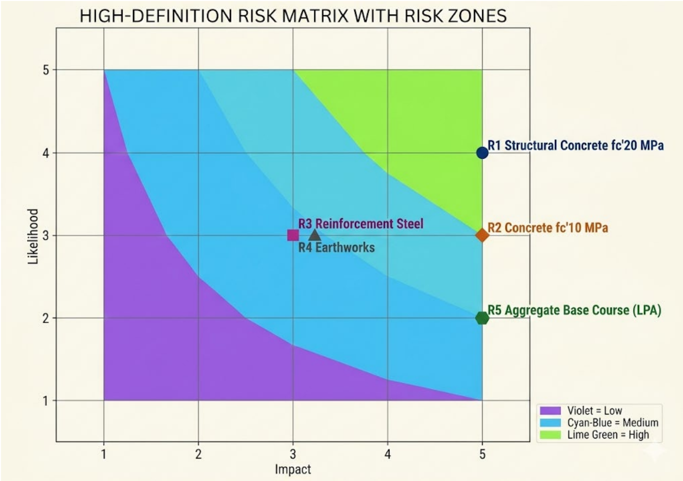


**Figure 1.** Risk matrix with risk zones based on likelihood and impact assessments derived from the project schedule and cost-weighted construction activities

As shown in Figure 1, structural concrete work (fc' = 20 MPa) falls within the extreme-risk zone, reflecting a combination of a high disruption probability and a very high-cost impact on overall project performance. Concrete work (fc'10 MPa) and aggregate base course (LPA) activities are positioned within the high-risk zone, indicating substantial financial exposure despite moderate to varying likelihood levels. In contrast, reinforcement steelwork and earthworks are categorized in the medium-risk zone, suggesting manageable risk levels relative to other major activities. This distribution demonstrates that risk exposure within the road rehabilitation project is unevenly concentrated rather than uniformly distributed. High-value and schedule-sensitive activities emerge as dominant risk drivers, emphasizing the importance of prioritizing control measures on activities with significant cost weight and structural influence on overall project execution.

## 5. Discussion

### 5.1. Interpretation of Schedule-Based Risk Matrix Results

The findings of the schedule-based risk matrix analysis demonstrate that risk exposure within the road rehabilitation project is not uniformly distributed across activities but is concentrated in a limited number of dominant work packages. Structural concrete work (fc'20 MPa) exhibits the highest composite risk score (R = 20), resulting from a high likelihood value (P = 4) and a very high impact value (I = 5). This classification places the activity in the extreme-risk zone and identifies it as the project's principal risk driver. The elevated likelihood is associated with prolonged duration, technical complexity, strict quality requirements, curing dependencies, and coordination with reinforcement and formwork activities. The maximum impact score reflects its substantial cost contribution and structural significance within the rehabilitation framework. This pattern aligns with the broader construction risk literature, which emphasizes that economically significant activities often dominate overall risk exposure even when probability levels are not at their maximum. Zhasmukhambetova et al. (2025) highlight that integrated risk–schedule assessments frequently reveal risk concentration in technically complex and cost-intensive activities.

Similarly, Antoniou (2021) found that a limited number of delay factors disproportionately influence overall project performance in road construction contexts. The dominance of structural concrete in the present analysis reinforces the argument that risk prioritization should focus on activities combining high financial exposure and strong schedule interdependencies. Moreover, prior studies employing simulation-based approaches confirm the strong relationship between high-impact activities and overall project deviation. Rezaee Arjroody et al. (2023) and Rezaee Arjroody et al. (2024) demonstrate through Monte Carlo modeling that variations in probability parameters for critical activities significantly amplify time and cost outcomes. Although the present study adopts a structured risk matrix rather than probabilistic simulation, the results are conceptually consistent: activities with substantial cost weights and central schedule positions exert disproportionate influence on project reliability. The cost-weighted impact of structural concrete, which accounts for the largest share of the contract value, means that even moderate schedule disruptions may cascade into significant financial and temporal consequences.

## 4.2. High- and Medium-Risk Activities within the Schedule Structure

Beyond the extreme-risk classification, two additional activities—non-structural concrete (fc’10 MPa) and aggregate base course (LPA) are categorized as high risk. Although their likelihood scores are lower than those of structural concrete, their impact values remain high due to significant cost proportions. This finding supports the argument advanced by Ariza Flores and Zavala Ascaño (2025) that cost concentration plays a decisive role in determining contingency requirements and overall exposure to uncertainty. Even when the disruption probability is moderate, substantial financial weight elevates the overall risk category. The aggregate base course illustrates how foundational pavement activities can serve as critical schedule anchors. Yin et al. (2022) emphasize that pavement-related tasks significantly affect contract time determination and downstream construction sequencing. Similarly, Jeon et al. (2023) demonstrate that activity-level risk ranking improves the efficiency of resource allocation in transportation infrastructure projects.

The present results complement these findings by showing that aggregate base works, despite lower disruption likelihood, remain high-risk due to their cost magnitude and structural positioning within the work breakdown structure. In contrast, reinforcement steel work and earthworks fall within the medium-risk category, with balanced likelihood and impact scores. These activities are operationally sensitive and subject to environmental and logistical variability, yet their relative cost contribution is lower than that of concrete and pavement layers. The medium classification suggests that risks associated with these activities can be managed through routine operational monitoring, schedule buffering, and coordination control. This distinction is consistent with the perspective of Koulinas et al. (2021), who note that not all technically variable activities warrant strategic-level mitigation; prioritization should be proportional to combined probability–impact exposure.

Furthermore, inspection- and safety-focused studies provide additional interpretive context. Mohamed and Tran (2021) illustrate how risk prioritization improves quality outcomes when high-exposure activities are systematically identified. Likewise, Koulinas et al. (2023) demonstrate that multicriteria assessments help distinguish between critical and manageable risks in highway construction environments. Although these studies focus on quality and safety rather than schedule–cost integration, their conclusions reinforce the principle that risk management effectiveness depends on accurate differentiation of severity levels. Thus, the risk distribution observed in this study confirms that construction project risk is multidimensional and cannot be determined solely by frequency of occurrence. Instead, risk severity emerges from the interaction between disruption probability and consequence magnitude, particularly when activities are highly interdependent within the schedule network. This observation aligns with the integrated scheduling perspective articulated by Zhasmukhambetova et al. (2025), who advocate for risk-informed planning frameworks that link schedule logic with impact evaluation. By deriving likelihood from schedule characteristics and impact from cost-weighted contract values, the present study offers a structured yet practical approach for identifying dominant risk clusters in road rehabilitation projects.

## 6. Conclusions

The findings of this study confirm that risk exposure in road rehabilitation projects is primarily concentrated in activities characterized by substantial cost weights and extended implementation durations. Structural concrete work (fc' = 20 MPa) was identified as the dominant risk driver, achieving the highest composite score (R = 20) and classification in the extreme-risk zone. Non-structural concrete work (R = 15) and aggregate base course work (R = 10) were categorized as high risk due to their significant financial contribution and schedule relevance. In contrast, reinforcement steel work and earthworks, each with a risk score of R = 9, were classified as medium risk, indicating manageable exposure under standard operational controls. These results demonstrate that integrating schedule-derived likelihood assessment and cost-weighted impact evaluation provides a coherent basis for differentiating risk severity across major construction activities.

From a methodological perspective, the study shows that the schedule-based risk matrix approach provides a practical, transparent framework for early-stage risk prioritization using readily available project-planning data. Unlike simulation-intensive or multicriteria probabilistic models, this approach does not require advanced software tools or extensive historical datasets. Instead, it leverages contract schedules and cost structures to produce structured risk zoning outputs that are directly interpretable by project managers. This enhances managerial decision-making by enabling focused allocation of monitoring efforts, contingency planning, and mitigation resources toward high- and extreme-risk activities during the planning phase. In terms of policy implications, the findings suggest that contracting agencies and infrastructure authorities should encourage the incorporation of structured, data-driven risk zoning procedures into pre-construction planning guidelines. Embedding schedule-based risk matrix assessments within standard contract documentation processes may improve transparency in risk allocation and strengthen proactive control mechanisms. For public infrastructure projects, particularly in contexts where probabilistic modeling capacity is limited, such structured yet accessible approaches can support more accountable and evidence-based project governance.

However, several limitations should be acknowledged. First, the analysis relies exclusively on initial contract data and planned schedule information, which represent static conditions at the outset of the project. Dynamic factors such as unforeseen site conditions, weather variability, market fluctuations, and supply-chain disruptions during implementation were not incorporated into the model. Second, the likelihood assessment, although structured around schedule characteristics, still involves qualitative judgment in scoring activity vulnerability. Third, the study focuses on a single road rehabilitation case, which may limit generalizability across different project scales, procurement systems, and geographic contexts. Future research is therefore recommended to extend this framework by integrating real-time project progress data and performance indicators to capture dynamic risk evolution throughout the project lifecycle. Combining the schedule-based risk matrix with quantitative techniques such as Monte Carlo simulation, Bayesian updating, or sensitivity analysis could further enhance predictive accuracy while maintaining operational simplicity. Comparative multi-project studies are also needed to validate the robustness and scalability of the approach across diverse infrastructure environments. By bridging structured risk zoning with adaptive and data-enriched methodologies, future investigations can strengthen the reliability and strategic value of risk-informed scheduling in road rehabilitation project management.

**Author Contributions:** Conceptualization, E.D.R.T. and M.P.; methodology, E.D.R.T.; software, E.D.R.T.; validation, M.P. and Z.Y.; formal analysis, E.D.R.T.; investigation, E.D.R.T. and M.P.; resources, E.D.R.T.; data curation, M.P. and Z.Y.; writing—original draft preparation, E.D.R.T.; writing—review and editing, M.P. and Z.Y.; visualization, E.D.R.T.; supervision, M.P. and Z.Y.; project administration, Z.Y.; funding acquisition, Z.Y. All authors have read and agreed to the published version of the manuscript.

**Author initials:**
E.D.R.T.: Evan Dwianto Rante Tondok
M.P.: Maraden Panjaitan
Z.Y.: Zony Yulfadli

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Acknowledgments:** The authors would like to thank Universitas 17 Agustus 1945 Samarinda, Indonesia, for its support of this research and publication. We also thank the reviewers for their constructive comments and suggestions.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

Antoniou, F. (2021). Delay risk assessment models for road projects. *Systems, 9*(3), 70. https://doi.org/10.3390/systems9030070

Ariza Flores, V. A., & Zavala Ascaño, G. (2025). Quantitative risk analysis framework for cost and time estimation in road infrastructure projects. *Infrastructures, 10*(6), 139. https://doi.org/10.3390/infrastructures10060139

Aven, T. (2016). Risk assessment and risk management: Review of recent advances on their foundation. *European journal of operational research*, *253*(1), 1-13. https://doi.org/10.1016/j.ejor.2015.12.023

Cox, L. A. (2008). What's wrong with risk matrices? *Risk Analysis, 28*(2), 497–512. https://doi.org/10.1111/j.1539-6924.2008.01076.x

Duijm, N. J. (2015). Recommendations on the use and design of risk matrices. *Safety science*, *76*, 21-31.https://doi.org/10.1016/j.ssci.2015.02.014

Flyvbjerg, B. (2014). What you should know about megaprojects and why: An overview. *Project management journal*, *45*(2), 6-19. https://doi.org/10.1002/pmj.21409

Jeon, J., Zhang, Y., Yang, L., Xu, X., Cai, H., & Tran, D. (2023). Risk breakdown matrix for risk-based inspection of transportation infrastructure projects. *Journal of Construction Engineering and Management, 149*(4), 04023007. https://doi.org/10.1061/JCEMD4.COENG-13298

Kostrzewa-Demczuk, P., & Rogalska, M. (2023). Planning of construction projects taking into account the design risk. *Archives of Civil Engineering, 69*(4), 613–626. https://doi.org/10.24425/ace.2023.146760

Koulinas, G. K., Demesouka, O. E., Marhavilas, P. K., Orfanos, N. I., & Koulouriotis, D. E. (2023). Multicriteria health and safety risk assessments in highway construction projects. *Sustainability, 15*(12), 9241. https://doi.org/10.3390/su15129241

Koulinas, G. K., Demesouka, O. E., Sidas, K. A., & Koulouriotis, D. E. (2021). A TOPSIS—risk matrix and Monte Carlo expert system for risk assessment in engineering projects. *Sustainability, 13*(20), 11277. https://doi.org/10.3390/su132011277

Kowacka, M., Skorupka, D., Duchaczek, A., Waniewska, A., & Dudziak-Gajowiak, D. (2021). Allocation of risk factors for geodetic tasks in construction schedules. *Open Engineering, 11*(1), 956–962. https://doi.org/10.1515/eng-2021-0091

Mohamed, M., & Tran, D. Q. (2021). Risk-based inspection model for hot mix asphalt pavement construction projects. *Journal of Construction Engineering and Management, 147*(6), 04021045. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002074

Rezaee Arjoody, A., Hosseini, S. A., Akhbari, M., Safa, E., & Asadpour, J. (2023). Analyzing the effects of critical risk occurrence probability on time and cost of road construction projects using a schedule plan. *International Journal of Transportation Engineering, 10*(3), 1121–1137.

Rezaee Arjroody, A., Hosseini, S. A., Akhbari, M., Safa, E., & Asadpour, J. (2024). Accurate estimation of cost and time utilizing risk analysis and simulation (Case study: Road construction projects in Iran). *International Journal of Construction Management, 24*(1), 19–30. https://doi.org/10.1080/15623599.2022.2039345

Yin, Y., Choi, K., Jeong, H. D., & Touran, A. (2022). Integration of schedule, cost, traffic, and risk into the determination of construction contract times. *Journal of Management in Engineering, 38*(6), 04022061. https://doi.org/10.1061/(ASCE)ME.1943-5479.0001087

Zhasmukhambetova, A., Evdorides, H., & Davies, R. J. (2025). Integrating risk assessment and scheduling in highway construction: A systematic review of techniques, challenges, and hybrid methodologies. *Future Transportation, 5*(3), 85. https://doi.org/10.3390/futuretransp5030085