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The Influence Of Risk Management Culture On Project Time Control In Construction Projects: A Random Forest Approach

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ABSTRACT

Managing time is crucial in construction projects, as schedule deviations caused by complexity and external risks often lead to costly delays. This study aims to analyze how risk management culture influences time control in high-rise building construction projects. A mixed-methods approach was employed: first, risk management culture variables were qualitatively identified through in-depth interviews; then, a quantitative analysis was conducted using questionnaires distributed to project managers, construction managers, and financial managers. The data were analyzed with the Random Forest algorithm, chosen for its predictive accuracy. Risk management culture variables (X1–X23) were adapted from ISO 31000:2018, while project time control was measured using the Schedule Performance Index (SPI). The results indicate that a risk management culture has a significant and positive impact on project time control. The most influential factors were the documentation of the risk register (X23), the integration of risk evaluation into decision-making (X16), and continuous monitoring and review (X20). Conversely, formal aspects, such as risk management policies (X2) and training programs (X11), showed a relatively lower influence. These findings suggest that active implementation of risk management culture in daily operations contributes more directly to improving schedule performance. The study highlights the importance of accurate risk documentation, risk-informed decision-making, and adaptive monitoring as priorities for achieving effective time control in construction projects.

1. Introduction

Time control is a key indicator of success in construction projects. Schedule overruns remain a fundamental challenge, often arising from project complexity, environmental uncertainty, and unforeseen risks [1] [2]. Such delays not only increase costs but also reduce project quality and damage the reputation of construction service providers. Therefore, effective time control is crucial to ensure projects are completed on schedule and within targets.

One approach that has gained increasing attention is strengthening the risk management culture within project organizations. A strong risk management culture serves as a foundation for systematically identifying, analyzing, and responding to risks, thereby reducing the likelihood of delays [3] [4]. Previous studies suggest that a strong risk management culture promotes proactive risk identification, enhances team communication [5], and contributes to achieving project cost, time, and quality objectives [6] [7] [8] [9]. ISO 31000:2018 also emphasizes the importance of embedding risk culture principles into the risk management framework, enabling organizations to address uncertainties throughout the project life cycle better [10].

A positive culture further strengthens the Enterprise Risk Management (ERM) process across the organization, supporting both strategic and operational goals, with its effectiveness heavily dependent on top management commitment [11]. Moreover, a strong risk management culture has been shown to affect project time control directly, leading to higher success rates and reducing the likelihood of schedule overruns [12] [13].

Although the literature acknowledges the importance of risk management culture, most previous studies remain general and descriptive. Many rely on conventional statistical models such as linear regression and Structural Equation Modeling (SEM) [9] [15], which inherently assume linear relationships among variables. These approaches are insufficient to capture the complex, dynamic, and non-linear interactions between elements of organizational culture. Consequently, prior findings tend to demonstrate correlation rather than producing predictive models capable of

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prioritizing the most influential cultural factors for project time control.

This study, therefore, seeks to address this gap by analyzing the influence of risk management culture on project time control through a more advanced predictive approach. Previous research has consistently highlighted that a positive risk management culture plays a crucial role in fostering proactive risk identification, strengthening communication, and improving overall project outcomes [15] [16] [17]. However, to date, no study has explicitly applied machine learning algorithms to develop predictive models while simultaneously generating a hierarchy of the most influential cultural factors in the context of construction projects.

To fill this gap, the present study applies the Random Forest algorithm, integrated with the ISO 31000:2018 framework, to identify and rank the most critical elements of risk management culture that support project time control. Random Forest is selected for its ability to detect non-linear patterns, capture variable interactions, and produce quantitative rankings of key factors—capabilities that conventional statistical models struggle to achieve [17]. In addition, variable validation was conducted through Focus Group Discussions (FGDs) with project stakeholders to ensure that the developed model is not only methodologically robust but also practically relevant.

Based on this background, the objectives of this study are twofold: (1) to analyze the influence of risk management culture on project time control using a predictive model based on Random Forest, and (2) to identify and establish a hierarchy of the most significant elements of risk management culture. The findings are expected to contribute academically by filling the methodological gap, while also providing practical, evidence-based guidance for construction practitioners to strengthen their risk management culture, thereby achieving timely project completion.

2. Method

2.1. Research Design and Data Collection

This research employs a mixed-methods approach. Qualitative data are collected through in-depth interviews with management and project teams to gain an understanding of the implementation of risk management culture and risk-related decision-making. Meanwhile, quantitative data are obtained from questionnaires distributed to project managers, technical departments, finance personnel, and field workers, aiming to evaluate their perceptions and attitudes towards risk management culture and its application.

2.1.1. Stage 1: Variable Identification and Validation

This stage aimed to identify the key risk management culture variables relevant to high-rise construction projects in Indonesia. First, an initial list of variables was generated from a systematic literature review of prior studies on risk management culture, project control, and ISO 31000:2018 principles. To refine and validate this list, semi-structured interviews were conducted with five senior professionals, including project managers and a project engineering manager. Each respondent had more than 10 years of professional experience and held key roles in the decision-making process of high-rise building projects. The interviews, conducted both face-to-face and online, were guided by the ISO 31000:2018 framework. This validation process confirmed the relevance of the proposed indicators, resulting in a final set of 23 independent variables to be used in the study.

2.1.2. Stage 2: Quantitative Survey and Data Collection

The quantitative stage aimed to examine the influence of 23 identified variables (independent variables) on project time control (dependent variable). Data were collected using a structured questionnaire consisting of three sections: (1) demographic information of respondents and projects, (2) 23 items measuring the independent variables on a 5-point Likert scale (1 = Very Uninfluential to 5 = Very Influential), and (3) project time control data. Respondents were selected through purposive sampling, with inclusion criteria of at least five years of professional experience and direct involvement in project decision-making. The final sample consisted of professionals directly involved in high-rise building construction projects, including project managers, construction managers, financial managers, project control staff, and consultants (**Table 1**).

2.2. Research Variables

The variables used in this study consist of independent and dependent variables. The independent variables are the elements of a risk management culture derived from the principles of ISO 31000:2018, including infrastructure, integration, planning, implementation, evaluation and improvement, communication and consultation, risk identification, analysis, evaluation, treatment, monitoring, and review, as well as risk reporting. These variables, comprising 23 indicators, were validated through a Focus Group Discussion (FGD) with construction experts. The dependent variable was measured using a 5-point Likert scale, ranging from 1 (Very Uninfluential) to 5 (Very Influential).

Table 1. Dependent variables in the study

Category	Code	Variable Description
Infrastructure	X1	Clarity of risk management governance structure [18] [19]
	X2	Risk management policies and procedures [18]
Integration	X3	Integration of the management system with risk management [20]
	X4	Integration of sustainability management system with risk management [21] [22]
Planning	X5	Project planning has considered risk management [23]
	X6	Risk management, sustainability management, planning [24]
Framework Implementation, Evaluation, and Improvement	X7	Periodic risk management governance review process [23]
	X8	Existing procedures are flexible to changes in the internal and external environment. [19]
Communication, Consultation, and Culture	X9	Information system support in achieving project goals [22]

Category	Code	Variable Description
	X10	Leader commitment [25]
	X11	Management competency training and certification program [22]
Risk Evaluation	X12	Risk identification includes sources, events, causes, and impacts. [23]
	X13	Risk identification involves historical data, theoretical analysis, expert opinion, and stakeholder needs [23]
Risk Analysis	X14	Risk management function assists in the risk analysis process [26] [27]
	X15	Periodic risk management performance assessment [23]
Risk Evaluation	X16	Risk evaluation is considered in managerial decision-making [26]
	X17	Risk appetite assists in the risk evaluation process. [26]
Risk Treatment	X18	The risk treatment plan is established by considering risk control [26]
	X19	The risk treatment plan created can be implemented [26]
Monitoring and Review	X20	Monitoring and review of project risk management [26] [22]
	X21	Review process of risk treatment plan design [23] [22]
Reporting	X22	Risk reporting assignment [28] [27]
	X23	The risk register has been documented. [22]

The dependent variable is project time control, measured using the Schedule Performance Index (SPI) value. SPI is a key indicator within the Earned Value Management (EVM) framework, which is adopted to assess project performance objectively [29]. The SPI formula is given (1):

$$SPI = \frac{\mathrm{EV}}{\mathrm{PV}} \quad (1)$$

Where:
EV is the budgeted value of work actually performed.
PV is the budgeted value of work scheduled to be performed.

The interpretation of SPI values is straightforward: SPI > 1.00 indicates the project is ahead of schedule; SPI = 1.00 means the project is on schedule; and SPI < 1.00 signifies the project is behind schedule. SPI is crucial for objectively monitoring time progress, providing early warnings of potential delays, and enabling proactive corrective actions.

2.3. *Data Analysis*

The survey results are then analyzed using the Random Forest (RF) algorithm to measure the influence of risk management culture on time control [30]. RF is an ensemble learning method that integrates numerous decision trees for accurate and stable predictions, trained via bootstrap sampling and random feature selection for each tree. The final prediction is aggregated through majority voting (for classification) or averaging (for regression), which effectively enhances model generalization [31] [32].

3. Result and Discussion

3.1. *Results*

The qualitative phase involved semi-structured interviews with experienced construction stakeholders (with a minimum of 5 years of experience) to identify risk management culture variables as independent variables. Subsequently, the quantitative phase involved distributing questionnaires to project managers, construction managers, project engineering managers, financial managers, project control personnel, and consultants. The composition of these respondents was primarily project control (24%), project engineering manager (23%), and construction managers (20%), followed by financial managers (13%), consultants (12%), and project managers (10%). The quantitative data were analyzed using the Random Forest (RF) Algorithm, selected for its ability to generate accurate and stable predictions regarding the relationship between risk management culture and project time control.

Fig. 1 presents the Feature Importance ranking of the 23 risk management culture variables generated by the Random Forest model. The graph clearly shows a hierarchy of influence, where each variable's contribution to project time control is not uniform. Elements related to active, on-the-ground practices, such as X23 (Risk register has been documented), X16 (Consideration of risk evaluation in decision-making), and X20 (Monitoring and review of risk management), were identified as the most dominant factors. Conversely, variables that are more procedural in nature, such as X11 (Training programs) and X2 (Risk management policies), showed the lowest influence, indicating that practical implementation has a more direct impact than the mere existence of a formal framework.

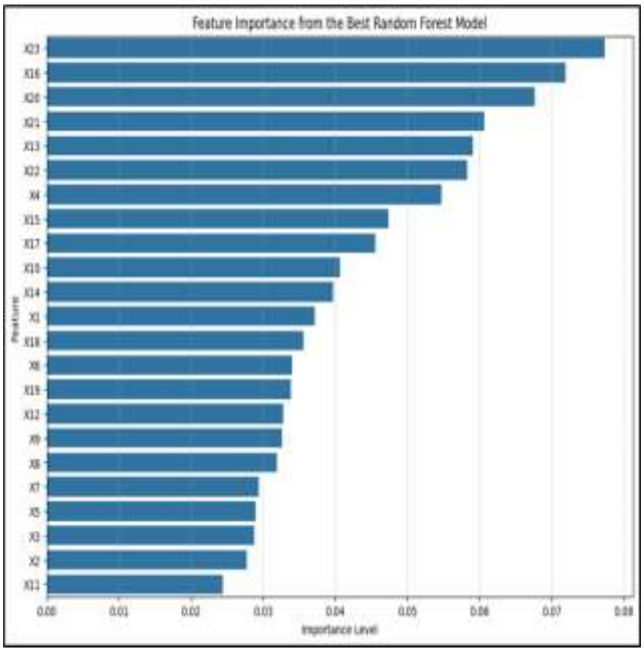

Fig. 1. Feature importance of risk management culture variables (Random Forest output)

The numerical output from the Feature Importance analysis, which provides precise quantitative scores for each variable, is shown in **Fig. 2**. This output clearly categorizes the variables into two groups based on a score threshold of 0.03: 'Most Influential Features' and 'Less Influential Features'. The data indicates that X23 (Risk register has been documented) has the highest score (0.077362), quantitatively confirming its position as the most dominant factor in the model. Conversely, variables such as X11 (Training programs), with a score of 0.024416, fall into the 'Less Influential' category. Thus, this output validates the influence hierarchy illustrated in **Fig. 1**, enabling researchers to firmly distinguish between crucial factors and those that are more supportive.

--- Most Influential Features (Importance >= 0.03) ---

	Feature	Importance
0	X23	0.077362
2	X16	0.071884
1	X20	0.067602
3	X21	0.060700
5	X13	0.059084
4	X22	0.058320
6	X4	0.054745
9	X15	0.047342
8	X17	0.045535
15	X10	0.040670
18	X14	0.039686
17	X1	0.037140
7	X18	0.035566
10	X6	0.033988
16	X19	0.033812
14	X12	0.032813
19	X9	0.032593
11	X8	0.031893

--- Less Influential Features (Importance < 0.03) ---

	Feature	Importance
21	X7	0.029354
20	X5	0.028970
12	X3	0.028793
13	X2	0.027734
22	X11	0.024416

Fig. 2. Most influential features (output from random forest)

The analysis identified the top five most influential features, which are presented below with their importance scores:

a. X23 (Risk register has been documented): 0.077362
b. X16 (Risk evaluation is considered in managerial decision-making): 0.071884
c. X20 (Monitoring and review of project risk management): 0.067602
d. X21 (Review process of risk treatment plan design): 0.060700
e. X13 (Risk identification involves historical data, theoretical analysis, expert opinion, and stakeholder needs): 0.059084

Other significant features with importance values greater than or equal to 0.03 include X22, X4, X15, X17, X10, X14, X1, X18, X6, X19, X12, X9, and X8. Conversely, variables such as X7, X5, X3, X2, and X11 showed a relatively low influence (importance value < 0.03).

--- PREDICTION COMPARISON TABLE ON TEST DATA ---

	Actual_Performance_Label	Predicted_Performance_Label
70	Longer than Schedule	Longer than Schedule
123	On Schedule	On Schedule
45	Faster than Schedule	Faster than Schedule
138	On Schedule	Faster than Schedule
2	Faster than Schedule	On Schedule
169	Longer than Schedule	Longer than Schedule
198	Faster than Schedule	Faster than Schedule
181	On Schedule	On Schedule
0	Faster than Schedule	Faster than Schedule
115	Faster than Schedule	Faster than Schedule
13	On Schedule	On Schedule
104	Faster than Schedule	Faster than Schedule
58	Longer than Schedule	Longer than Schedule
192	Faster than Schedule	Faster than Schedule
5	Faster than Schedule	On Schedule

Fig. 3. Feature importance from the Best Random Forest Model (Output from Random Forest)

Overall, **Fig. 3** indicates that the model has good predictive capability. Before conducting a more in-depth quantitative analysis, this figure provides a practical illustration of the model's performance. Additionally, Figure 3 displays the Prediction Comparison Table, which shows a sample of the Random Forest model's predictions on previously unseen data. The table directly compares the Actual Performance Label (the project's actual schedule performance) with the Predicted Performance Label (the schedule performance predicted by the model). Thus, this table provides a qualitative overview of the model's accuracy in a real-world scenario. The results indicate that the majority of predictions align with the actual data. For example, on row 70, the model accurately predicts that the project would be 'Longer than Schedule.' Similarly, on row 123, the 'On Schedule' prediction was also correct.

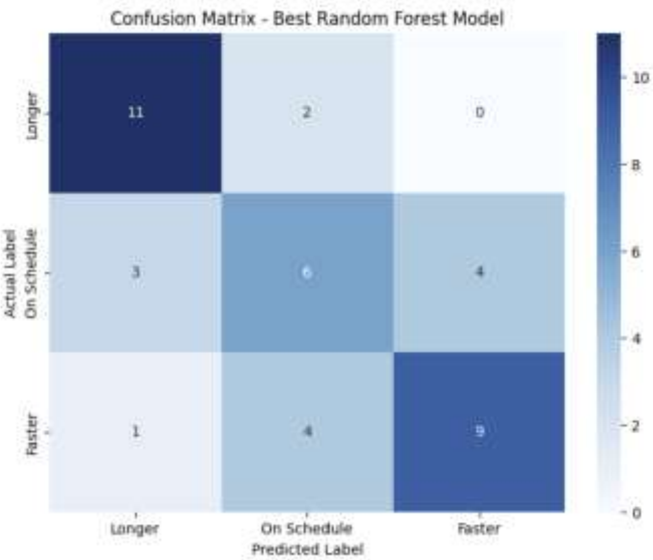

Fig. 4. Feature Importance from the Best Random Forest Model (Output from Random Forest)

Fig. 4 presents the Confusion Matrix, an evaluation tool used to assess the performance of the Random Forest classification model in more detail. This matrix provides a quantitative breakdown of prediction accuracy by comparing the Predicted Label to the Actual Label on the test data.

Key points can be interpreted from this matrix:

a. Vertical Axis (Actual Label): Shows the actual count of data in each category. For instance, 13 projects were truly "Longer than Schedule" (Longer).
b. Horizontal Axis (Predicted Label): Shows how the model classified that data—Main Diagonal (top-left to bottom-right).
c. The numbers on the diagonal (11, 6, 9) represent correct predictions (True Positives and True Negatives). For example, of the 13 projects with a "Longer" status, 11 were accurately predicted by the model.
d. Off-diagonal: The numbers (2, 0, 3, 4, 1, 4) represent prediction errors (False Positives and False Negatives). For instance, three projects were actually "On Schedule" but were incorrectly predicted as "Longer."

Overall, this Confusion Matrix provides a more detailed and measurable overview of the model's strengths and weaknesses. The high numbers along the main diagonal indicate that the model has good accuracy in classifying project time control, despite some misclassifications between categories.

3.2. Discussion

The findings from the Random Forest analysis offer valuable insights into the elements of a risk management culture that have the greatest impact on project time control. Variable X23 (Risk register has been documented) emerged as the most dominant factor, confirming that systematic documentation is not merely a formality but a fundamental foundation for maintaining a consistent understanding among project teams regarding potential threats and their mitigation status. This result is consistent with the literature emphasizing the role of a structured information base in enhancing project predictability and control [6] [9]Similarly, variable X16 (Risk evaluation is considered in managerial decision-making) highlights the strong link between risk management and organizational decision-making, supporting the argument that risk management must be integrated into the core of project governance rather than treated as a separate function [11] [15] Furthermore, the significance of X20 (Monitoring and review) and X21 (Review process of risk treatment) underscores the value of a continuous and dynamic approach to risk management, in line with ISO 31000:2018 principles and prior studies advocating proactive rather than reactive risk practices [13]These findings suggest that successful project time control depends not only on the existence of an initial plan but also on the ongoing vigilance and adaptability of project teams to monitor and adjust risk mitigation strategies as needed.

Interestingly, this study also reveals that variable X2 (Risk management policies and procedures) and X11 (Management competency training and certification program) have a relatively low influence on project time control. It is important to contextualize this result, not as an indication of irrelevance, but as a new insight for construction risk management practice. Recent literature confirms that risk policies and training programs remain essential foundations for project governance. Policies and training only generate significant impact when supported by adequate monitoring, supervision, and operational adaptation. Effective policies and procedures are those that are flexible and contextually implemented, rather than static documents without oversight. Policies become key enablers only when integrated with communication skills, leadership, and a culture of active engagement [33] [34]. Policies become key enablers only when integrated with communication skills, leadership, and a culture of active engagement [35] . Thus, the relatively low influence of X2 and X11 in this study may indicate that these elements have already become standardized practices across most partner organizations. As a result, the differentiating factors of project time control lie more in practical execution, such as risk documentation, adaptive monitoring, and the active use of the risk register in decision-making processes—evidenced by the dominance of X23, X16, and X20.

The practical implication of these findings is that organizations should not only focus on drafting policies and delivering formal training, but also actively monitor and evaluate their implementation, while tailoring training programs to the actual needs and dynamics of projects. In this way, policies and training will not remain at the level of baseline requirements, but instead function as effective enablers of adaptive risk management practices that ultimately strengthen project time control [33] [34] [35].

4. Conclusion

This research aimed to analyze how risk management culture influences time control in construction projects and to identify the most influential factors. Based on the analysis using the Random Forest model, this study concludes that risk management culture has a significant and positive influence on project time control. The model successfully predicted project time control categories, confirming that the presence of an actively integrated and implemented risk management culture is a crucial determinant of project execution time.The study's key finding is a quantitative hierarchy of the most influential factors. The analysis revealed that hands-on implementation of risk management actions is more critical than formal procedural elements. Specifically, the Risk register has been documented (X23), emerging as the most dominant factor, highlighting its fundamental role as a foundation for effective project oversight. This is followed by the integration of risk evaluation into decision-making (X16) and the practice of continuous monitoring and review (X20). Conversely, formal aspects such as policies (X2) and training programs (X11) showed a lower influence, suggesting that while they are foundational, it is their practical application in daily operations that has a direct and measurable impact on project timeliness. Thus, the relatively low influence of X2 and X11 in this study may indicate that these elements have already become standardized practices across most partner organizations. As a result, the differentiating factors of project time control lie more in practical execution, such as risk documentation, adaptive monitoring, and the active use of the risk register in decision-making processes.

In addition, the feature importance analysis, prediction comparison table, and confusion matrix collectively confirm the robustness of the Random Forest model. These results demonstrate that the model not only identifies the most relevant predictors but also achieves strong predictive accuracy in real-world scenarios, with the majority of predictions aligning with actual project performance.

This research contributes to the existing body of knowledge by providing a clear, evidence-based hierarchy of risk management culture elements from the ISO 31000:2018 framework that are most critical for project time control. The findings offer a valuable guide for construction stakeholders, enabling them to prioritize efforts on actionable practices rather than on formal, less impactful procedures.

This study has several limitations. First, the number of respondents is limited. Second, the study only considers 23 variables derived from ISO 31000, while other potential risk-related factors were not included. Third, the research is confined to high-rise building projects in Indonesia, which restricts the applicability of the results to other types of infrastructure projects or different contexts. For future research, it is recommended that this model be applied to a larger and more diverse dataset to validate the current findings and enhance the model's generalization capabilities. The survey scope could be expanded to include various project types, not only high-rise buildings but also infrastructure and industrial projects from different geographical contexts, to explore how the influence of these factors may vary. Furthermore, the current model can be enriched by adding other relevant predictor variables beyond risk management culture. Variables such as project characteristics (scale or contract value, duration, and technical complexity) and team characteristics (project manager experience and team turnover rate) can provide additional context that may interact with the risk culture, and are thus expected to improve the model's predictive power significantly

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Author Declaration

Authors' contributions and responsibilities

The authors collectively made substantial contributions to the conception and design of the study. All authors were involved in the data analysis, interpretation of results, and drafting of the manuscript. They have all read and approved the final version of the manuscript and assume joint responsibility for its content.

Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interests.

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