Research Article

Evaluating Drone Impact on Construction Monitoring and Operational Efficiency at Pt. Total Kinerja Mandiri

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Abstract

The adoption of drone technology is gaining attention in the construction industry, but empirical evidence on its impact on operational efficiency - particularly in emerging economies like Indonesia - remains scarce. Traditional on-site monitoring is often costly and logistically difficult, especially in remote project locations. This study addresses the gap by evaluating the effectiveness of drone-based monitoring compared to conventional methods. Using a qualitative case study at PT. Total Kinerja Mandiri, data were collected from five key experts - including project managers, a drone operator, and a company director - through in-depth interviews and direct observation. A decision tree framework supported by expert judgment was applied to assess three monitoring alternatives (drone monitoring, on-site monitoring, and no monitoring) under two project scenarios: remote and accessible sites. The findings indicate that drone monitoring achieved the highest effectiveness, with an expected value score of 8.49, outperforming on-site monitoring (7.22) and no monitoring (1.00). This proves that drones can enhance time efficiency, reduce operational costs, and improve remote coordination. However, experts emphasized that drone usage should complement, rather than fully replacing on-site (physical) monitoring to ensure accountability and real-time verification. This study contributes empirical evidence on construction digitalization in Indonesia and offers practical insights for contractors operating in geographically challenging areas. Nevertheless, the scope is limited to one company and relies primarily on expert judgment. Future research should incorporate quantitative cost–benefit analysis across multiple firms to strengthen generalizability.

Keywords

Drone Technology, Construction Monitoring, Operational Efficiency, Expert Judgment, Decision Tree.

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Introduction

The construction industry is one of the pillars of infrastructure development and economic growth. In Indonesia, the value of completed construction projects has shown consistent growth, reaching IDR 1,626.3 trillion in 2023 (BPS, 2023). Despite this impressive figure, the industry still lags behind in adopting digital technologies (Siju, Shafiyia, & Ben Maaouia, 2022). Drone technology has recently emerged as a promising tool to support construction management, particularly in project monitoring activities.

Project monitoring is critical in ensuring timely completion and coordination among stakeholders. Many construction sites are located in remote areas, far from city centers. This geographic challenge often complicates site visits by project owners or managers. Furthermore, a single project manager is frequently responsible for overseeing multiple ongoing projects simultaneously. This condition creates inefficiencies in field monitoring and coordination, especially when the manager cannot be physically present at all project sites (Prihantara, Hartono, & Wardani, 2018). Traditional monitoring methods like on-site inspections are often time-consuming, costly, and logistically challenging.

Although the potential of drones is widely discussed, empirical studies that evaluate their actual effectiveness in improving project efficiency remain limited. Most existing research highlights general benefits such as time savings, improved safety, and lower monitoring costs. However, little is known about how drones perform in the daily operations of construction companies in Indonesia, especially when compared to conventional monitoring methods. In the context of PT Total Kinerja Mandiri (PT TKM), a contractor specializing in jetty construction, piling, and steel structures, this gap becomes more pressing since many of its projects are located in remote and hard-to-access areas.

This situation makes the study relevant both academically and practically. Academically, the research contributes to the growing literature on digitalization in the construction sector, particularly in developing countries where adoption has been relatively slow. Practically, it provides insights for companies like PT TKM to design more efficient monitoring strategies, reduce operational costs, and improve coordination in geographically challenging environments.

Based on this background, the study addresses three research questions:

1. How does drone technology contribute to the efficiency of construction project monitoring, especially in project coordination?
2. Can drones reduce operational monitoring costs in PT TKM projects?
3. What factors determine the successful implementation of drone technology in construction projects?

Accordingly, the study aims to evaluate the role of drone technology in enhancing project monitoring efficiency, reducing costs, and improving coordination, while also identifying the key factors that support its successful implementation in PT TKM.

The scope of this research is limited to the use of drones for monitoring purposes only. It does not cover other potential applications such as surveying, logistics, or quality control. The analysis is also focused on internal operational aspects, based on the perspective of project implementers, without considering external factors like regulatory issues or terrain variations.

The remainder of this paper is structured as follows. The next section reviews the theoretical background and previous studies relevant to drone technology and project monitoring. The methodology section then explains the research design, data collection, and analytical approach. Findings and discussion are presented in the following section, before concluding with the main results, implications, and suggestions for future research.

Conceptual Framework

Previous Studies Review

Several previous studies are examined to identify patterns, gaps, and consistencies in the literature regarding drone utilization in construction project monitoring and operational efficiency, supporting the development of the conceptual framework.

Zhou & Gheisari (2018) conducted a study on the application of drones in construction activities such as inspection, mapping, and monitoring. Their research highlights that drones are more efficient, safer, and more economical than traditional methods. However, they also note the challenges of safety risks and limitations in autonomous capabilities. This study is valuable in showing the potential of drones to improve real-time decision-making in complex project environments.

Albeaino et al. (2019) focused on the role of drones in architecture, engineering, and construction (AEC). Their review concluded that drones improve accuracy, reduce monitoring time, and increase site safety. Most notably, rotary drones with cameras are widely adopted due to their ability to move easily and visual data capabilities. Their research also supports integration with advanced technologies like Building Information Modeling (BIM) and Artificial Intelligence (AI), which expands future opportunities for smart project management.

Yoo (2021) explored barriers to drone implementation in construction, highlighting issues such as a lack of data processing systems, safety concerns, privacy regulations, and the need for specialized personnel. The study underscores the importance of regulatory frameworks and internal policy support to ensure the successful adoption of drone systems in real projects.

Kim, Irizarry, and Costa (2016) comprehensively analyzed drone usage for safety inspections through a survey involving construction professionals. Their findings suggest that user-friendliness and high visual data quality are crucial for drone effectiveness. They also propose 17 performance indicators to evaluate drone adoption success, supporting the idea that both technical and human factors must be aligned.

In summary, these studies consistently show that drone technology has the potential to transform monitoring practices in construction. They highlight several critical points:

1. Drones increase operational efficiency by reducing time and labor.
2. They improve data accuracy, leading to better coordination and faster decision-making.
3. Implementation success is influenced by technical readiness, user acceptance, and regulatory support.

However, most studies focus on generalized contexts or theoretical models. This current research seeks to build upon existing literature by applying the concepts specifically to PT. Total Kinerja Mandiri, comparing two distinct operational conditions - remote vs. accessible project sites - and evaluating drone effectiveness using a decision tree model. This adds practical, evidence-based insights that are particularly relevant for companies operating in geographically diverse regions with limited human resources.

Construction Projects

A construction project refers to a series of coordinated activities to deliver physical infrastructure within a defined scope, time, and budget. Kerzner (2017) defines a project as a temporary endeavor undertaken to create a unique product, service, or result, constrained by time, cost, and resources. In the construction industry, projects are typically complex, resource-intensive, and involve multiple stakeholders.

According to Ervianto (2023), construction projects consist of two main dimensions: construction technology (methods and tools) and construction management (coordination of people, materials, time, and budget). These projects are subject to unique challenges, including uncertainty, dynamic environmental conditions, and high dependency on field execution. As such, successful management demands a structured and strategic approach.

Project Management

Project management is the process of applying knowledge, skills, tools, and techniques to project activities to meet project requirements. The classical framework of Planning, Organizing, Actuating, and Controlling (POAC) is widely applied to ensure effective project execution (TERRA, 2016).

Heizer, Render, and Munson (2020) emphasize that modern project management involves the integration of time scheduling, budgeting, and resource allocation. In construction, this becomes critical due to the need for synchronization across various phases, such as design, procurement, construction, and handover. Proper project management minimizes risks and ensures alignment with project objectives.

Monitoring in Project Controlling

Monitoring is an essential element of the controlling function in project management. It involves systematic collection, analysis, and use of information to track project progress and detect deviations from plans (Heizer et al., 2020). Monitoring tools help measure performance, allocate resources effectively, and initiate corrective actions when necessary.

According to Firdaus (2020), monitoring activities in construction are often associated with both direct and indirect costs, such as equipment operation, labor, transportation, and reporting. Ineffective monitoring can lead to delays, cost overruns, and quality issues. Therefore, integrating efficient monitoring systems is vital for maintaining control over project execution.

Drone Technology

Drone or Unmanned Aerial Vehicle (UAV) technology has gained significant traction in the construction industry due to its ability to perform aerial surveys, inspections, and real-time data capture. Rao, Gopi, and Maione (2016) note that drones enhance site visibility, safety, and decision-making efficiency.

Zhou and Gheisari (2018) found that over 60% of construction firms have adopted drones for site monitoring, significantly reducing inspection time and improving data accuracy. However, limitations such as battery life, weather sensitivity, and regulatory constraints remain key considerations (Zhang et al., 2020).

Construction Project Coordination

Coordination in construction projects involves aligning schedules, responsibilities, and communications among multiple stakeholders, including owners, contractors, and subcontractors. According to Kuntadi and Rosdiana (2022), effective coordination minimizes conflicts and ensures timely completion.

Dwipratama (2020) identified poor coordination as one of the main causes of project delays. Drones play a critical role by providing consistent and up-to-date site information, thereby enabling remote stakeholders to make faster, better-informed decisions.

Operational Efficiency

Operational efficiency refers to an organization's ability to deliver products or services using the fewest possible resources while maximizing output. Stevenson (2021) defines it as achieving optimal results with minimal input, focusing on time, cost, and quality.

In construction, efficiency can be measured by productivity ratios, resource utilization, and process speed (Slack et al., 2020). Albeaino et al. (2019) showed that drones significantly enhance operational efficiency by reducing field visits, automating inspections, and cutting down on manual labor requirements.

Success of Drone Technology Implementation

Implementation success is defined by how much a new technology achieves its intended objectives in practice. Sufa (2012) states that key indicators include time savings, cost efficiency, improved quality, and stakeholder satisfaction.

Kim, Irizarry, and Costa (2016) emphasized that ease of use, technical reliability, and user satisfaction are critical to drone adoption success in construction. Moreover, organizational readiness, such as the availability of trained operators and supportive management, is essential for effective integration.

Decision Tree

A decision tree is a visual analytical tool for evaluating options and outcomes in decision-making. It helps structure complex decisions by illustrating choices, possible events, probabilities, and payoffs (Heizer et al., 2020).

Decision trees are especially useful in conditions of uncertainty, such as determining the most efficient monitoring method depending on project site conditions. This study uses decision trees to compare drone-based monitoring and conventional methods under two “states of nature”: (1) remote project sites and (2) nearby, easily accessible locations, thereby identifying the most optimal strategy using Expected Monetary Value (EMV) calculations.

Theoretical Framework

This study’s theoretical framework is constructed to explain the logical relationships among key concepts relevant to the research topic: "Evaluating Drone Impact on Construction Monitoring and Operational Efficiency at PT. Total Kinerja Mandiri." It is designed to address three primary research questions: how drones contribute to construction monitoring efficiency and coordination, whether drones reduce operational costs, and what factors influence the successful implementation of drone technology in construction projects.

The framework begins with the concept of construction projects, as the research is situated within the construction industry. According to Kerzner (2017), a project is a series of activities to achieve specific objectives within defined time, cost, and resource constraints. In the context of construction, projects involve both physical development and managerial activities. Ervianto (2023) highlights two main dimensions of construction projects: construction technology, which pertains to technical execution methods, and construction management, which focuses on the efficient and effective utilization of various resources. These projects are inherently complex, unique, risk-laden, and constrained by the classic project management triangle of quality, time, and cost.

To manage these challenges, construction projects typically employ structured project management approaches, one of which is the POAC principle - Planning, Organizing, Actuating, and Controlling. Within this framework, the controlling function is vital in ensuring that project execution aligns with initial plans. A key activity within this function is monitoring, which involves the regular collection of field data, performance evaluation, and corrective action when deviations occur. Monitoring processes require resource allocation, including direct costs such as equipment and labor, as well as indirect costs like training and administrative expenses (Firdaus, 2020).

In recent years, monitoring practices have been increasingly supported by drone technology. Drones enable faster and more accurate data collection, minimize the need for manual site inspections, reduce occupational risks, and offer real-time visual inputs that assist in decision-making. These features contribute to operational efficiency by reducing work time, lowering labor requirements, and optimizing the use of project resources. Additionally, drones enhance project coordination by enabling rapid and precise communication of site conditions among stakeholders. This improvement reduces the risk of miscommunication and delays due to fragmented or unclear information, thereby strengthening project integration and supporting overall operational effectiveness.

To address the question of implementation success, the framework refers to the theory of implementation effectiveness, which defines successful implementation as achieving intended goals with positive impacts on performance. Sufa (2012) suggests that successful technology implementation can be measured through timely project completion, improved quality outcomes, cost savings, and stakeholder satisfaction. In the context of this research, the success of drone implementation is evaluated through comparative performance analysis before and after the integration of drones into the project monitoring process.

Furthermore, the study employs a decision tree approach to guide the decision-making process regarding the adoption of drone technology. This analytical tool facilitates the evaluation of alternative actions under uncertainty by mapping out possible outcomes and estimating their associated benefits. It provides a structured means for determining whether drone-based monitoring offers advantages over traditional methods in terms of cost efficiency, timeliness, and overall project effectiveness.

In conclusion, the theoretical framework is built upon an understanding of construction project systems, project management practices, monitoring processes and costs, and the integration of drone technology. It also incorporates concepts related to implementation success and decision-making under uncertainty. Altogether, this framework offers a comprehensive basis for analyzing the impacts of drone usage and provides a structured lens through which to answer the study’s research questions.

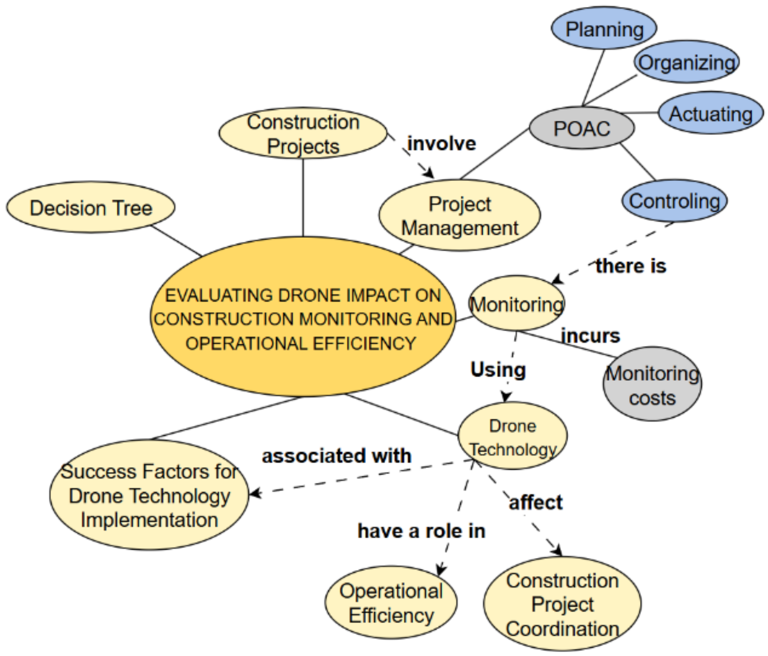


Figure 1: Mind Map of Conceptual Framework
Source: Author's data processing 2025

Methodology

Research Type

This study adopts a qualitative case study approach to explore and understand in-depth phenomena based on non-numerical data. The case study design was selected to allow the researcher to investigate a specific program or activity - in this case, drone-assisted project monitoring - within a real-life context at PT. Total Kinerja Mandiri (Kusumastuti & Khoiron, 2019). The qualitative approach is appropriate for uncovering meaning, lived experiences, and social dynamics that cannot be captured solely through quantitative measures (Sugiyono, 2023).

According to Creswell (2014), qualitative research is descriptive and narrative in nature, using interviews, observations, and documentation to capture participants' subjective experiences. The approach is inductive, allowing theories to emerge from the field rather than being predefined (Charmaz, 2014). It is also flexible and context-sensitive, as Denzin and Lincoln (2018) emphasized, making it ideal for complex, exploratory topics such as technology implementation in construction.

Data Collection Techniques

Data was collected using two primary qualitative techniques: in-depth interviews and direct observation.

In-depth Interviews: Semi-structured interviews were carried out with five experts from PT. Total Kinerja Mandiri, selected purposively based on their roles and experience in construction project monitoring and drone utilization. The interview guide covered themes such as monitoring efficiency, operational cost, project coordination, and implementation success. Experts were also asked to rate various monitoring scenarios using an evaluative scale from 1 to 10. These ratings supported the development of the decision tree model.

Direct Observation: Non-participatory observations were conducted to analyze documentation and operational activities related to drone use in the field. This included workflow mapping, operational procedures, and the scope of drone monitoring. These observations provided contextual reinforcement for the interview data and clarified how drone technology is integrated into daily construction practices.

By combining these two techniques, the research ensured methodological triangulation to enhance the validity and reliability of findings.

Data Sources

The data used in this study were obtained from both primary and secondary sources. Primary data was collected through interviews with internal experts at PT. Total Kinerja Mandiri who are directly involved in the execution of construction projects and the operation of drone technology. These informants included project managers, drone operators, and technical staff with hands-on experience in project monitoring. In addition, secondary data was gathered from internal company documents, project reports, and various relevant scientific sources such as books, journal articles, and previous studies. These secondary materials were used to support the development of the conceptual framework and provide contextual background that strengthens the interpretation of the primary data.

Data Analysis Techniques

This study applied a qualitative-interpretive analysis supported by a decision tree approach to evaluate alternatives in project monitoring methods under conditions of uncertainty, referred to as states of nature. The decision tree is a decision-support tool that systematically compares options based on projected outcomes, helping visualize how different alternatives perform in varying conditions (Heizer, Render, & Munson, 2020).

The primary data for this analysis was obtained from expert interviews. Respondents provided both open-ended responses and numerical ratings using a 1–10 evaluative scale for several key indicators: time efficiency, operational cost, data quality, implementation success, and remote coordination. The average scores across respondents were calculated for each alternative–scenario combination to build the payoff table.

Two states of nature were identified as commonly encountered project conditions:

S1: Remote and difficult-to-access project locations
S2: Nearby and easily accessible project locations

These formed the basis for expert scoring and scenario modeling. The Expected Monetary Value (EMV) method was then used to assess which alternative had the best expected outcome. While traditionally EMV relates to monetary values, in this study, it is adapted to represent evaluative scores, calculated using the formula:

$$\text{EMV} = \sum [P(S_i) \times \text{Payoff}(S_i)]$$

Where:

P(S_i) = probability of occurrence of state *S_i*

Payoff (*S_i* = average expert score for the alternative under the state *S_i)*

Although the decision tree and EMV method are often associated with quantitative analysis, in this study they are applied within a qualitative research framework. The numeric scores used are not statistical data, but expert judgments collected through in-depth interviews. The scoring serves to structure expert insights into a visual and comparative format, enabling informed interpretation rather than statistical generalization. Thus, the decision tree is used as a qualitative modeling tool, maintaining the interpretive and exploratory nature of the study, as supported by Denzin and Lincoln (2018).

Through this combined approach, the research does not merely describe expert perceptions but also provides a structured recommendation framework that supports data-informed decision-making for PT. Total Kinerja Mandiri regarding drone investment and monitoring strategy.

Operationalization of Variables

This study applied a qualitative approach based on the Delphi method to gather expert assessments regarding the effectiveness of drone usage in construction project monitoring. To ensure that the interviews are focused and that the responses can be systematically analyzed, a set of variables and indicators was determined, reflecting the four main focuses of the study: monitoring efficiency, cost efficiency, project coordination, and technology implementation success. These variables serve as a guideline to reduce ambiguity in expert responses and to facilitate the subsequent data analysis process.

Expert assessments were obtained through open-ended questions accompanied by a numerical evaluation scale ranging from 1 to 10, where:

- 1 represents the least optimal condition (e.g., highly inefficient, unhelpful, unsatisfactory, or costly), and
- 10 represents the most optimal condition (e.g., very efficient, highly supportive, highly satisfactory, or cost-saving).

The evaluation was based on two predetermined states of nature, representing project conditions that are common at PT. Total Kinerja Mandiri:

- S1: Projects located remotely and are difficult to access
- S2: Projects located nearby and are easily accessible

These two states serve as the foundation for the decision tree's payoff table, as they directly influence the perceived effectiveness of each monitoring method. In remote locations (S1), drone deployment offers significant benefits by reducing the need for frequent travel, saving both time and operational costs. However, these areas may also present challenges such as weak internet connectivity, unstable signal reception, and environmental constraints like weather, which can limit the smooth operation of drone systems. Conversely, in nearby projects (S2), on-site monitoring remains relatively practical and cost-effective, while the added value of drones may be perceived as less pronounced.

These contextual differences illustrate that the success of drone implementation is not uniform but highly dependent on project conditions and technological familiarity. For projects in remote and logistically challenging areas, drones provide substantial efficiency gains, yet they require supporting infrastructure and skilled operators to overcome technical barriers. In contrast, for projects in accessible locations, drones may serve more as a complementary tool rather than a primary monitoring method.

Below is a summary of the operationalized variables and their respective dimensions and indicators, developed from the results of preliminary exploratory interviews and used as a reference for the expert interviews.

As shown in Table 1, data obtained from these 1–10 scale evaluations were used to indicate the relative effectiveness of each monitoring alternative under specific project conditions (states of nature). These data were not converted into monetary values, as such conversions would be largely assumptive and lack precise financial data. Instead, expert scoring was deemed more representative and practical for evaluating efficiency in terms of time, cost, and coordination.

The expert scores were then compiled into a payoff table, which became the basis for the decision tree analysis and the calculation of Expected Monetary Value (EMV). The EMV was calculated without converting scores into currency, allowing the final decision to be based on the highest average evaluative score. Consequently, the alternative with the highest EMV score is considered the most optimal choice for dealing with uncertain project conditions.

This approach enables qualitative data from interviews to be systematically analyzed using a structured decision-making model, while avoiding forced or unjustifiable conversion to nominal figures. Therefore, the decision model used in this research remains aligned with evidence-based qualitative analysis, while still enabling measurable and actionable recommendations for PT. Total Kinerja Mandiri.

Table 1: Operationalization of Variables

Variable	Dimension	Indicator (Expert Interview Questions)	Evaluation Scale (1–10)
Monitoring Efficiency	Monitoring Time	How quickly can this method provide monitoring results under the stated project conditions?	1 = Very slow → 10 = Very fast
	Site Accessibility	How effectively does this method cover the entire project site under the given conditions?	1 = Not effective at all → 10 = Very effective
	Data Quality	How accurate, complete, and real-time is the monitoring data provided by this method?	1 = Inaccurate and slow → 10 = Highly accurate and real-time
Cost Efficiency	Monitoring Operational Cost	How cost-effective is this method compared to its benefits?	1 = Very wasteful and not worth it → 10 = Very cost-efficient
	Transport and Labor Cost Efficiency	How efficiently is this method reducing travel, manpower, and logistics needs?	1 = Not efficient → 10 = Highly efficient
Project Coordination	Remote Coordination Support	How effective is this method in supporting coordination between internal and external project teams?	1 = Not supportive at all → 10 = Very supportive
	Transparency of Project Progress	To what extent does this method assist project owners in remotely tracking the project's progress independently?	1 = Not helpful at all → 10 = Very helpful
Implementation Success	Ease of Implementation	How easily can this method be implemented given the current resources and systems?	1 = Very difficult to implement → 10 = Very easy to implement
	Risk of Technical Issues	What is the likelihood of technical problems occurring when using this method under the given conditions?	1 = Very likely to occur → 10 = Very unlikely to occur
	Internal User Satisfaction	Overall, how satisfied are you with the results of using this method for project monitoring so far?	1 = Very unsatisfied → 10 = Very satisfied

Source: Author's Data Processing

Research Discussion and Results

Evaluation of Project Monitoring Alternatives

This study involved five expert informants from PT. Total Kinerja Mandiri will evaluate the effectiveness of various project monitoring methods. The panel consisted of one company director, one drone operator, and three project managers actively supervising construction projects.

During the interview process, respondents were asked to evaluate three monitoring alternatives:

- Using Drone Technology
- On-Site Monitoring (Physical Site Visits)
- No Monitoring at All

Each alternative was assessed under two commonly encountered project conditions (states of nature) within the company:

- S1: Remote and difficult-to-access project locations
- S2: Nearby and easily accessible project locations

Evaluations were based on 10 indicators, such as time efficiency, site accessibility, data quality, cost efficiency, ease of implementation, and internal user satisfaction. All indicators were scored on a 1–10 evaluative scale, with 1 indicating the poorest performance and 10 representing optimal performance.

The following table shows the payoff matrix with average scores - calculated as the mean of each alternative in every state of nature - and standard deviations, based on interview data:

Table 1: Pay-off Table

Alternative	State of Nature	Expert Scores	
		Average Score	Standard Deviation
Using Drones	S1: Remote Projects	8.48	5.02
	S2: Nearby Projects	8.50	4.85
On-Site Monitoring	S1: Remote Projects	6.93	9.11
	S2: Nearby Projects	7.95	6.16
No Monitoring	S1: Remote Projects	1.00	0.00
	S2: Nearby Projects	1.00	0.00

Source: Author's Data Processing

Based on Table 2, drone technology emerged as the most highly rated monitoring method in both project conditions. The average scores above 8.4 indicate a strong consensus among experts that drone-based monitoring is highly effective and efficient, regardless of the project's location. Experts highlighted drones' ability to provide real-time visual data, reduce travel time, and facilitate remote decision-making, which is especially valuable in geographically challenging environments.

In contrast, on-site monitoring still received relatively favorable scores, particularly for easily accessible projects (S2), where the average score reached 7.95. However, its effectiveness declined for remote locations (S1), scoring below 7. This suggests that traditional site visits may still be practical in urban or nearby areas, but they become significantly less efficient and more resource-intensive in remote conditions.

The third alternative, “no monitoring,” consistently received the lowest possible score of 1.00 under both conditions. All five experts unanimously agreed that this alternative is entirely unacceptable in the context of construction project execution. This consensus reflects a shared understanding that monitoring is not an optional activity, but rather a mandatory function in every construction project. Regardless of the project’s location or scale, monitoring ensures accountability, progress tracking, and early detection of problems. The complete agreement among experts emphasizes that omitting monitoring activities is incompatible with professional and operational standards upheld by the company.

In addition to the average scores, this study also examined the standard deviation of total expert assessments for each monitoring alternative under both project conditions. Rather than evaluating each individual indicator separately, the analysis considered the overall evaluation score given by each expert, which reflects their combined judgment across all ten performance dimensions. This approach provides a clearer picture of how closely aligned or dispersed the experts’ perceptions were regarding each alternative.

The results show that drone-based monitoring exhibits the lowest variation, with a standard deviation of 5.02 for remote projects (S1) and 4.85 for nearby projects (S2). These relatively low values suggest a strong degree of agreement among experts, reinforcing the perception that drone usage is a consistently reliable monitoring method across different conditions. On the other hand, on-site monitoring showed much greater variability, particularly in remote projects where the standard deviation reached 9.11, indicating that expert opinions were more divided - likely due to differing field experiences or operational interpretations. Even for nearby projects, the variation remained significant (SD = 6.16), suggesting that while more acceptable than in remote contexts, perceptions about on-site monitoring are still relatively inconsistent. Meanwhile, the “no monitoring” alternative maintained a standard deviation of 0.00, confirming unanimous rejection by all experts across both conditions.

These findings highlight that alternatives with high average scores and low standard deviations - such as drone monitoring - are not only effective but also enjoy a high degree of expert confidence, making them more suitable for standardized applications. Conversely, alternatives with higher variability require more careful, context-specific consideration due to the uncertainty in expert agreement.

In the case of on-site monitoring, the relatively high variation in expert assessments may be attributed to differing perspectives on its necessity. While some experts viewed drone technology as a sufficient and modern replacement for traditional site visits, others emphasized that physical monitoring must still be conducted, regardless of whether drones are used or not. This divergence in interpretation led to varied scoring - depending on how essential each expert perceived the role of conventional monitoring in project supervision. As a result, the higher variability in ratings reflects the broader debate over the complementary versus substitutive nature of these monitoring methods.

In summary, the findings indicate a clear preference for drone-based monitoring, especially in complex and remote project environments. While on-site monitoring remains a viable option under certain conditions, its limitations make it less favorable when compared to the adaptability and efficiency offered by drone technology. Nevertheless, despite the advantages of drones and regardless of how remote or challenging the project location may be, routine on-site monitoring should still be conducted. While it may not be necessary for directors, owners, or senior project managers to be physically present at all times, these responsibilities can be delegated to local field teams or company staff stationed near the project area. This ensures that physical oversight and operational discipline are maintained alongside digital monitoring efforts, preserving accountability and accuracy in project execution. Furthermore, the results and findings from on-site observations - whether related to progress, issues, or safety - should be routinely reported to directors, owners, or senior project managers as key decision-makers who require accurate, timely, and verifiable information for strategic oversight and resource planning.

Risk Discussion Based on Expert Score Variation

In addition to using average scores to construct the payoff table, this study also calculated the standard deviation for each evaluation indicator to better understand the consistency and variability of expert opinions. Standard deviation in this context serves to identify the level of perceptual uncertainty or disagreement, which may represent potential risks when making strategic decisions regarding the implementation of monitoring methods.

The interpretation of standard deviation in this research is categorized as follows:

- Low standard deviation (<1.0): Indicates strong agreement among experts, suggesting consistent perceptions toward the indicator.
- High standard deviation (>1.5): Implies significant variability in expert opinions, reflecting uncertainty or differing interpretations of the indicator.
- Standard deviation = 0: Indicates complete agreement, where all experts assigned the same score.

Several indicators revealed noteworthy variations in perception among the experts:

Transport and Labor Cost Efficiency (Drone – S1):

This indicator for the drone method under remote project conditions (S1) recorded a standard deviation of 3.36, a high value that suggests considerable variation among expert opinions. Some experts believe that drones significantly reduce logistical and personnel costs, as project managers, company directors, or owners no longer need to visit sites as frequently, relying instead on aerial documentation provided by drones. However, others argued that regardless of drone usage, direct on-site monitoring remains indispensable. As a result, they viewed the overall cost savings as limited, since travel and labor allocation cannot be fully eliminated.

Remote Progress Tracking (On-Site Monitoring – S1 & S2):

The highest standard deviation, 3.76, was observed in the indicator assessing the capability of on-site monitoring to support remote progress tracking. This wide variation reflects differing assumptions about the role of direct on-site monitoring. While some experts valued manual reporting and documentation as still relevant for ensuring accuracy, others considered physical monitoring unsuitable for remote projects due to its dependence on on-site presence. The divergence stems from contrasting perspectives on whether on-site methods can adapt to modern digital requirements or whether they remain inherently limited by physical constraints.

Technical Issues (Drone – S1):

The indicator measuring potential technical disruptions in drone usage for remote projects recorded a standard deviation of 2.54, indicating diverse experiences among experts. Some perceived drones as highly vulnerable to risks such as weak signal connectivity, weather instability, and hardware limitations. Others, however, reported that with proper operator training and supportive infrastructure, drone systems perform reliably even in remote contexts, leading to less concern about technical risks.

Site Accessibility (On-Site Monitoring – S1):

The standard deviation of 2.30 for this indicator suggests differing views regarding the effectiveness of physical monitoring in reaching remote or challenging project locations. Some experts believe that while traditional monitoring is still capable of covering most areas, it is time-consuming and inefficient; others argue that drones may still miss certain blind spots, and that physical inspection is less practical and may lack comprehensive visual scope.

Overall, the variability in expert assessments is closely tied to contextual differences such as project location, personal experience with drone technology, and differing assumptions about the balance between digital tools and traditional practices. Experts who are more familiar with digitalization and drone operations tend to emphasize efficiency and cost-saving benefits, while those with stronger reliance on conventional monitoring stress the irreplaceable role of on-site monitoring or supervision. This divergence underscores that the successful implementation of drone technology depends not only on technical capability but also on organizational mindset, contextual demands, and the integration of drones with established monitoring practices.

In contrast, specific indicators revealed greater consensus:

Monitoring Data Quality (Drone – S2):

This indicator showed a standard deviation of 1.00, at the upper boundary of the “low” category. Most experts agree that drones provide accurate, comprehensive, and real-time data, even in nearby and accessible project settings.

Internal User Satisfaction (Drone – S1 & S2):

The indicator for internal user satisfaction shows relatively consistent responses, with a standard deviation of 1.00. Experts commonly agreed on the benefits of drones in remote and accessible projects, both in terms of monitoring quality and user experience.

No Monitoring (All Indicators):

All indicators related to the “no monitoring” alternative received a standard deviation of 0, indicating complete agreement among experts. Every respondent assigned the lowest possible score (1) across all dimensions. This reflects a unanimous rejection of this alternative, reinforcing that monitoring is essential in any construction project and non-negotiable regarding efficiency, coordination, and accountability.

High standard deviation values suggest perceptual risk and potential inconsistency in real-world implementation. These differences may stem from varying project locations, levels of technological familiarity, or personal field experiences. Therefore, alternatives with high average scores but high standard deviation should be approached cautiously, as their effectiveness may vary greatly depending on context and execution.

On the other hand, alternatives that score high and maintain low standard deviation - such as drone usage - are generally safer to adopt, as they are not only perceived as effective but also enjoy a high degree of confidence and consistency among experts. This implies lower risk in implementation and a greater likelihood of producing reliable outcomes across different project scenarios.

Results of Decision Tree and Expected Monetary Value (EMV) Analysis

After obtaining the average scores from five experts on the three project monitoring alternatives - drone usage, on-site monitoring, and no monitoring - under two different project conditions (states of nature), the data were further processed using a decision tree model. The purpose of the decision tree is to visualize expert evaluations and calculate the Expected Monetary Value (EMV) of each alternative, thereby identifying which option yields the most benefit under varying project scenarios.

The decision tree in this study is based on two defined states of nature:

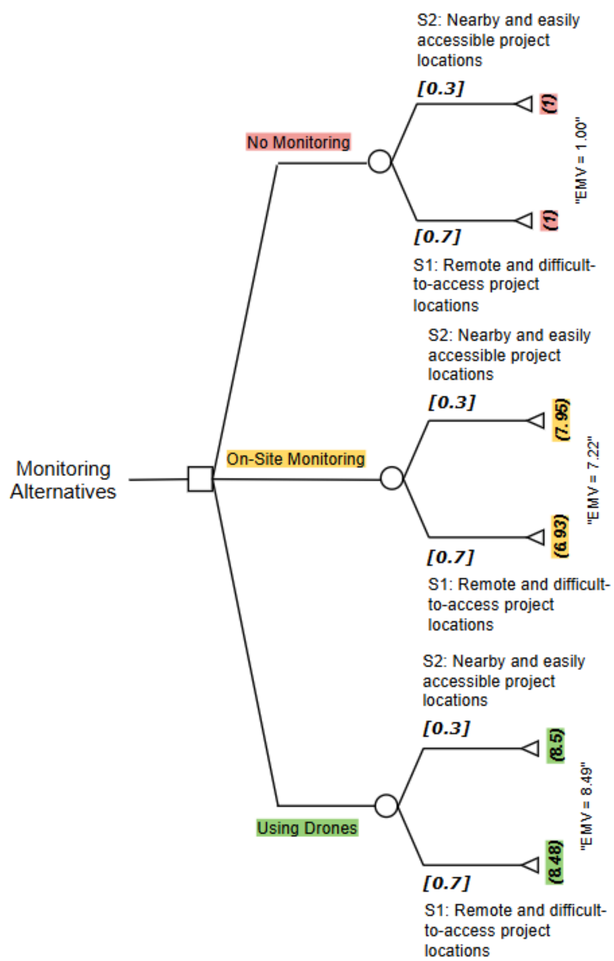
- S1: Projects located in remote and hard-to-access areas
- S2: Projects located nearby and easily accessible.

The probability of each state was determined through expert interviews at PT. Total Kinerja Mandiri. Based on these discussions, the majority of experts agreed that most of the company’s projects are located in areas with challenging access. Accordingly, the probability of S1 was set at 0.7 (70%), while the probability of S2 was set at 0.3 (30%).

Based on the constructed decision tree, the following Expected Monetary Value (EMV) calculations were obtained for each monitoring alternative:

- EMV (Drone Monitoring) = (0.7 × 8.48) + (0.3 × 8.50) = 8.49
- EMV (On-Site Monitoring) = (0.7 × 6.93) + (0.3 × 7.95) = 7.22
- EMV (No Monitoring) = (0.7 × 1.00) + (0.3 × 1.00) = 1.00

These results clearly indicate that using drone technology is the most favorable option, yielding the highest expected monetary value (EMV = 8.49). This means that, considering both expert evaluation scores and the likelihood of each project condition, drone monitoring offers the greatest and most consistent benefits among the three alternatives. Although on-site monitoring remains reasonably viable - particularly in easily accessible projects - it is still less effective overall when compared to drone usage. Meanwhile, the "no monitoring" alternative scored the lowest EMV of 1.00, reinforcing that this method is highly discouraged in any project condition.



Note: Numbers in parentheses represent average expert scores.

Figure 2: Decision Tree
Source: Author's data processing 2025

By applying the decision tree approach, the decision-making process becomes more systematic and data-driven, as it incorporates the probability of real-world conditions and evaluates the quantitative impact of each monitoring strategy. This model supports evidence-based recommendations and enhances strategic planning for construction monitoring practices at PT. Total Kinerja Mandiri.

Conclusion

This study demonstrates that the use of drone technology is the most favorable alternative for construction project monitoring when compared to traditional on-site monitoring or the absence of monitoring altogether. Based on interviews with five experts from PT. Total Kinerja Mandiri - consisting of one company director, one drone operator, and three project managers - the drone method received the highest scores across almost all evaluative indicators. The average scores ranged between 8.48 and 8.50 for both project conditions: S1 (remote and difficult-to-access projects) and S2 (nearby and easily accessible projects). These findings reflect that drones are perceived as highly effective in saving time, improving data quality, and supporting overall project coordination.

The decision tree analysis using the Expected Value (EV) approach also reinforces this conclusion. The drone alternative achieved the highest expected monetary value (EMV = 8.49), outperforming on-site monitoring (7.22) and no monitoring (1.00). This confirms that drone monitoring delivers the most consistent and substantial benefits across various project conditions. While on-site monitoring remains viable in specific contexts - particularly in easily accessible locations - it is not as effective overall. Meanwhile, the "no monitoring" option consistently received the lowest scores across all indicators, reaffirming that it is strongly discouraged in any construction project context.

Nonetheless, all experts agreed that drone usage cannot entirely replace physical monitoring. Rather, drone technology should be seen as a complementary tool within a broader project monitoring system. Although directors, owners, or senior project managers do not need to be physically present on-site, field teams are still required to carry out routine reporting and verification. Drones play a vital role in supporting field supervision - especially in large or inaccessible project areas - by enhancing visual documentation, improving coordination, and enabling remote tracking. In fact, several project owners now require drone-based updates as part of the daily progress reports submitted by contractors.

The analysis of standard deviation further strengthens these conclusions. Drone-based monitoring alternatives generally showed low standard deviation values, indicating consistent expert evaluations and high confidence in their effectiveness. Conversely, on-site monitoring exhibited higher variability in several indicators, suggesting differing perceptions and experiences among experts. The "no monitoring" alternative, with a standard deviation of zero, reflected unanimous expert rejection.

In response to the first research question, the study concludes that drones significantly improve monitoring efficiency, particularly by enhancing project coordination. Their ability to deliver real-time visual data from remote sites enables management, owners, and contractors to monitor progress effectively from a distance - thereby accelerating information flow, minimizing communication delays, and supporting data-driven decision-making. These efficiency gains also signal a broader shift in the construction industry toward digitalization and automation, paving the way for wider impacts that extend beyond this case study such as reducing occupational risks, lowering environmental impact through fewer site visits, and improving transparency in stakeholder communication.

Regarding the second research question, the findings confirm that drones can substantially reduce operational monitoring costs. By minimizing travel frequency, labor requirements for site inspections, fuel usage, and time spent on mobilization, drone usage leads to more efficient monitoring expenditures - especially in remote project settings.

For the third research question, the study shows that several factors affect the success of drone implementation in construction projects. These include the readiness of human resources, the availability of supporting technology, and the experience of operators in flying drones and processing data. Technical challenges such as poor weather, weak signals, and equipment limits are also important to consider. In this case, skilled operators are very important. They can handle problems like connectivity issues, bad weather, or short battery life while still ensuring accurate data results. Without the right expertise, drone monitoring may not be effective even if the tools and infrastructure are available. On the other hand, trained and experienced operators can maximize the use of drones, maintain good data quality, and turn the potential of the technology into real project benefits.

Beyond technical skills, differences in project context also play a big role. Project location is a key factor: for remote and hard-to-reach sites, drones give large efficiency gains by cutting travel costs and giving faster access to data, although they may face signal or environmental problems. For nearby and easy-to-reach sites, the added benefit of drones is smaller, because direct on-site monitoring is still quite practical. Another important factor is how familiar the company and operators are with drone technology. Companies with higher readiness and more experience in using digital tools can integrate drones more smoothly into their daily work, while teams with less experience may find it harder to get the full benefits.

But in the end, the success of drone implementation does not only depend on the technology itself, but also on the organization's mindset, the project's context, and how well drones are combined with existing monitoring practices. These findings confirm the experts' view that adopting drones is relatively easy, but only when supported by the right preparation and suitable project conditions.

Overall, the use of a decision tree–based evaluative approach in this study offers a structured, quantitative, and evidence-based framework for assessing and recommending project monitoring alternatives. These findings are expected to provide managerial insight for PT. Total Kinerja Mandiri in developing a more adaptive project supervision system that aligns with field realities and technological developments. It is recommended that the company continues to expand the use of drone technology - particularly for projects in remote or hard-to-reach locations - as an integral part of its monitoring system. However, drone usage should not stand alone; it should be integrated with on-site monitoring carried out by field teams responsible for verification and daily reporting. The company is also encouraged to provide regular training for relevant personnel in drone operation and data interpretation to maximize its benefits.

Beyond this case study, the adoption of drone technology in construction reflects a broader industry trend toward digitalization and automation, and based on the findings of this research, drones are gaining wider recognition as tools that not only enhance project efficiency but also contribute to safety improvements by reducing the need for human presence in hazardous areas. They also support environmental and social benefits, such as minimizing fuel consumption for site visits and enabling more transparent communication with stakeholders through visual documentation. By aligning with these wider industry and societal trends, companies that adopt drone-based monitoring can position themselves as more competitive, sustainable, and technologically adaptive players in the market.

Last, for future research, it is suggested to broaden the scope by considering a wider range of project types, external factors such as weather and terrain, and incorporating quantitative analysis using actual time and cost data to strengthen the evaluation results and generate more practical recommendations.

References

Albeaino, G., Gheisari, M., & Franz, B. W. (2019). A systematic review of unmanned aerial vehicle application areas and technologies in the AEC domain. *Journal of Information Technology in Construction, 24*, 381-400. https://www.itcon.org/2019/20

Badan Pusat Statistik (BPS). (2023). *Statistik penduduk dan urbanisasi Indonesia*.

Charmaz, K. (2014). *Constructing grounded theory* (2nd ed.). SAGE Publications.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches*. SAGE Publications.

Denzin, N. K., & Lincoln, Y. S. (2018). *The SAGE handbook of qualitative research* (5th ed.). SAGE Publications.

Dwipratama, A. A. (2020). *Analisa risiko faktor keterlambatan pada proyek konstruksi* [Undergraduate thesis, Universitas Bakrie]. Universitas Bakrie Repository. https://repository.bakrie.ac.id/id/eprint/3501

Ervianto, W. I. (2023). *Manajemen proyek konstruksi*. Andi.

Firdaus, F., & Yulia, H. (2015, February 1). *Sistem Monitoring Biaya Proyek Konstruksi.* https://repository.unsri.ac.id/18193/

Heizer, J., Render, B., & Munson, C. (2020). *Operations management: Sustainability and supply chain management* (13th ed.). Pearson Education.

Kerzner, H. (2017). *Project management: A systems approach to planning, scheduling, and controlling* (12th ed.). Wiley. ISBN 978-1-119-16535-6

Kim, S., Irizarry, J., & Costa, D. B. (2016). Potential factors influencing the performance of unmanned aerial system (UAS) integrated safety control for construction worksites. *Construction Research Congress 2016*. https://doi.org/10.1061/9780784479827.260

Kuntadi, C., & Rosdiana, D. (2022). Factors influencing the effectiveness of education budget absorption: Budget planning, regulation, and coordination (Literature review). *Jurnal Ekonomi Manajemen Sistem Informasi, 4*(2), 142–152.

Kusumastuti, A., & Khoiron, A. M. (2019). *Metode penelitian kualitatif*. ISBN: 978-623-7253-64-8.

Mary, N., Shafiyia, S., & Ben Maaouia, M. (2022). Applications of drone technology in construction projects: A systematic literature review. *International Journal of Research - Granthaalayah, 10*(10), 1–14. https://doi.org/10.29121/granthaalayah.v10.i10.2022.4810

Prihantara, A., Hartono, A. A., & Wardani, P. M. (2018). Case study on the development of construction project management information systems. *Bangun Rekaprima, 4*(2), 1–10. https://doi.org/10.31933/bangun_rekaprima.v4i2.1196

Rao, B., Gopi, A. G., & Maione, R. (2016). The societal impact of commercial drones. *Technology in Society, 45*, 83–90. https://doi.org/10.1016/j.techsoc.2016.02.009

Slack, N., Brandon-Jones, A., & Johnston, R. (2020). *Operations and process management* (5th ed.). Pearson Education Limited.

Stevenson, W. J. (2021). *Operations management* (14th ed.). McGraw-Hill Education.

Sugiyono. (2023). *Metode penelitian kualitatif*. Alfabeta.

Sufa, M. F. (2012). Identification of project success criteria. *Performa, 11*(1), 19–22.

TERRA. (2016, November 26). POAC: Planning, organizing, actuating, and controlling | Organizational management. *Medium*. https://medium.com

Yoo, S. (2021). Proposal of improvement measures according to the limiting factors of the use of drone technology: Cases in the construction field. *International Journal of Internet, Broadcasting and Communication, 13*(4), 30–38.

Zhang, C., Cui, L., Xu, D., & Song, X. (2020). A review of commercial drone regulations and applications. *IEEE Access, 8*, 120438–120452.

Zhou, S., & Gheisari, M. (2018). Unmanned aerial system applications in construction: A systematic review. *Construction Innovation, 18*(4), 311–323. https://doi.org/10.1108/CI-02-2018-0010.