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Evaluating on Application of Lean Construction of Toll Road Projects in Indonesia

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Abstract

Lean construction boosts productivity, reduces costs, and enhances overall project performance. This research looks at how PT Nindya Karya implements lean construction in a toll road project. The study site is the Bayung Lencir-Tampino Toll Road project. The approach taken is quantitative, including statistical analysis and a final report document. The study found that implementing lean construction concepts in this project had a beneficial impact. The project was completed faster than projected, taking 415 days instead of 574 days, resulting in a time savings of roughly 27.7%. The Just-in-Time approach and the Last Planner System both helped to reduce time waste and material delays. The project team used a target value design, which ensures that resources are used in accordance with specified criteria and there is no excess or deficit of materials. Lean construction has resulted in significant cost savings for the project, with expenses lower than expected, resulting in an 8.67% surplus on the contract value. As a suggestion, future research could look into the impact of lean construction on projects other than toll highways.

Keywords*: construction; cost; lean construction, time management; waste material*

Abstrak

Konstruksi ramping meningkatkan produktivitas, menurunkan biaya, dan meningkatkan kinerja proyek secara keseluruhan. Studi ini meneliti bagaimana PT Nindya Karya menggunakan konstruksi ramping pada proyek konstruksi jalan tol. Lokasi studi ialah proyek Jalan Tol Bayung Lencir-Tampino. Metode yang digunakan adalah kuantitatif, dengan analisis statistik, dokumen laporan akhir, dan kuesioner. Hasil penelitian mengungkapkan bahwa penerapan prinsip konstruksi lean dalam proyek ini berdampak positif. Proyek ini selesai lebih cepat dari yang diharapkan, dengan total durasi 415 hari dibandingkan dengan jangka waktu awal 574 hari, sehingga menghemat waktu sekitar 27.7%. Metode Just-in-Time dan Last Planner System membantu menghilangkan pemborosan waktu dan keterlambatan material. Tim proyek mengadopsi desain nilai target, yang memastikan bahwa material digunakan berdasarkan kebutuhan yang ditentukan dan tidak ada kelebihan maupun kekurangan material. Konstruksi ramping telah menghasilkan penghematan biaya yang signifikan untuk proyek dengan biaya yang lebih rendah dari yang diantisipasi, sehingga menghasilkan surplus sekitar 8.67% dari nilai kontrak. Sebagai saran untuk penelitian selanjutnya disarankan untuk meneliti pengaruh Konstruksi ramping pada berbagai proyek selain jalan tol dan sebagainya.

Kata kunci: *konstruksi; biaya; konstruksi ramping, manajemen waktu; bahan limbah*

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1. Introduction

Road construction projects in Indonesia frequently confront significant obstacles such as tight schedules, lengthy design lifetimes, and high material quality requirements to save maintenance costs and traffic delays (Aisyah et al., 2023; Anastasiu et al., 2023; Amalia et al., 2024; Thoengsal, 2023). To solve these constraints, projects frequently incur considerable cost overruns (Amalia et al., 2024). One of the most common causes is a mismatch between the initial estimate and the actual use of materials as a result of poor feasibility testing and planning (Ansell et al., 2009; Michał & Piotr, 2020). This condition has an influence on budget efficiency and adds to an increase in building waste, which is bad for both the economy and the environment.

Furthermore, Adhitama and Saraswati, (2023) mentioned that traditional project implementation technique generates a lot of waste, such as excessive material consumption, repetitive work (rework), material loss and damage, unemployed personnel, wrong instructions, and workplace accidents. The impact of this waste further worsens the efficiency of the project, both in terms of time, cost, and quality of work results (Aravindh et al., 2022; Arunizal et al., 2024).

As a solution, the government, through the Directorate General of Construction Development (DJBK) of the Ministry of Public Works and Public Housing (PUPR), introduced lean construction as a solution in managing aspects of time, cost, quality, and sustainability in road construction projects (Arunizal et al., 2024; Thoengsal, 2023). This concept is adapted from the manufacturing industry, which has succeeded in reducing waste by up to 12% and is applied in the construction industry with the potential to reduce waste by up to 57% (Bajjou & Chafi, 2021). Aziz and Irfan, (2020) revealed that the lean concept addresses the problem of managing aspects of time, cost, quality, and sustainability in road construction projects for two main reasons: highlighting and measuring various types of construction process waste and identifying and testing potential improvements in system performance with minimal risk, cost, and time. This makes the lean concept an opportunity to overcome the problem of time and cost overruns in road construction projects.

Several developed countries, such as the United States, Australia, China, and Singapore (Bhargav et al., 2015; Dowson et al., 2024; Dytczak et al., 2013; Elmalky et al., 2024) have successfully implemented lean construction to improve the efficiency of road construction projects. Lean construction minimizes construction waste in construction implementation and maximizes value through the systematic elimination of waste with sustainable improvements (Aravindh et al., 2022). These sustainable or ongoing improvements maximize the value felt by road users.

Although the lean concept has been introduced in Indonesia, its implementation is still not optimal. Previous studies have examined various aspects of lean construction, but there are still gaps in its practical implementation, especially in infrastructure projects in Indonesia. Some studies only focus on the development of SMART-based KPIs without discussing the challenges of their implementation (Bigwanto et al., 2024a). In contrast, other studies have not explored the obstacles in government projects or lean integration in the planning and implementation phases (Bigwanto et al., 2024b). In addition, waste material management strategies in lean construction are still under-researched, especially regarding the causes of non-value-added activities (Dara et al., 2024; Prieto &

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Alarcón, 2023). One example is the Probolinggo-Banyuwangi Toll Road project, Probolinggo-Besuki section 2, whose construction began in 2023 and is planned to be completed in 2025. This project experienced various challenges, so PT Nindya Karya continuously made improvements to meet the specified deadline. Therefore, the authors are interested in researching the evaluation of Lean Construction Applications in Toll Road Construction Projects by PT Nindya Karya. Thus, this study formulated research questions; 1. How does the implementation of lean construction principles in the Bayung Lencir-Tampino Toll Road Section 2 project 2. Does lean construction practice affect the application of the Bayung Lencir-Tampino Toll Road Section 2 construction project.

2. Research Method

This research implements a case study at PT. Nindya Karya. PT Nindya Karya utilised lean construction methods in its toll road construction projects. Nindya Karya is one of the developed construction companies in Indonesia. A case study aims to provide a comprehensive understanding of the subject in its real-world context (Gaio & Cachadinha, 2011). Case studies are commonly used in research and education to investigate complex issues and gain valuable insight, such as the evaluation of application of lean construction in the road construction project by PT. Nindya Karya. This study employed quantitative method to analyse project report data, and document projects from PT Nindya Karya's Bayung Lencir-Tampino Toll Road Section 2 construction to corroborate the conclusions. There are six principles of lean construction include the Last Planner System (hereafter LPS), Just -In-Time Procedure, 5S (Sort, Set in Order, Shine, Standardize, Sustain), Value Stream Mapping (henceforth, VSM), Visual Management, and Continuous Improvement. Then there are three lean construction practices: cost indicator, time indicator, and quality indicator.

The Bayung Lencir-Tampino Toll Road Section 2 project is an integral part of the construction of the Trans Sumatra Toll Road (JJTS), which connects South Sumatra Province and Jambi Province. Connecting these two provinces made travel time more efficient than conventional national roads. This significantly reduces logistics costs and increases accessibility for goods and passengers. This toll road is expected to grow the economy of the Betung-Tempino-Jambi region. The Bayung Lencir-Tempino section as a whole has a length of 35.5 km which is divided into three sections, namely section 1 with a length of 7.625 km, section 2 with a length of 11.004 km, and section 3 with a length of 17.331 km. Section 2, which is being worked on by PT Nindya Karya together with PT PP Tbk in the Joint Operation (KSO), includes the construction of a toll road with a length of 11.004 km with the technical specifications of the JTTS standard toll road. This project is funded through the support of the 2023-2024 State Budget (APBN), with the contract value for the section 2 package recorded at around IDR 1.31 trillion. The section 2 work contract was signed in June 2023, and its implementation is scheduled for 415 calendar days, namely from June 6, 2023, to August 2, 2024, indicating a relatively fast completion target for an infrastructure project of this size. The study’s location is in figure 1.

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Figure 1. The Bayung Lencir-Tampino Toll Road Section 2 project of Nindya Karya

3. Results and Discussion

3.1 Lean construction principles

The Buyung Lencir-Tempino Toll Road Section 2 construction project by PT Nindya Karya applies various lean construction principles to improve implementation efficiency. Lean construction principles that focus on eliminating waste and increasing value included six factors; the Last Planner System, Just -In-Time, 5S, Value Stream Mapping, Visual Management, and Continuous Improvement.

3.1.1 Last Planner System

Last Planner System (LPS) is a collaborative production planning system that involves the "last planner", the person closest to the job called site supervisor/foreman, to create a realistic short-term plan (Salam et al., 2023; Li et al., 2021). This principle emphasizes collaborative and detailed preparation close to the time of execution, ensuring that obstacles are resolved together, and reliable work commitments (Wibowo, 2023). The LPS principle encourages intensive communication of the project team through weekly and daily coordination, so that the workflow is more reliable and free from disruptions (Luh et al., 2021) .

In the Bayung Lencir-Tempino Toll Road project, practices in line with LPS are seen in the routine planning and monitoring. The project team used Microsoft Office Project software to create a detailed schedule and update progress, and conducted daily monitoring to ensure field work was on track. Progress was evaluated daily and obstacles were resolved in a short time to maintain daily workflow. The active involvement of foremen and subcontractors in coordination meetings (e.g. weekly meetings) ensured that the agreed weekly schedule could be implemented. Through this mechanism, a mechanism similar to pull planning , the team only promised work that was ready and could be done, so that commitments were met on time. As a result, the project was able to run 159 days faster than the initial plan to meet the inauguration target. The LPS principle contributed to this timely achievement by increasing scheduling collaboration and reducing delays due to unrealistic plans.

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3.1.2 Just-In-Time procedure

Just-In-Time (hereafter, JIT) is a strategy for preparing materials exactly when they are needed, in order to minimize excess stock, material accumulation, and wasted time and storage costs (Sui & Joo, 2001). In construction, JIT means scheduling the delivery and production of materials as close as possible to the time of their installation in the field (Lorenza et al., 2024; Zalfi et al., 2013). This increases efficiency and keeps the work area neat and safe and free from piled-up materials.

The Bayung Lencir-Tempino Toll Road Project applies the JIT concept, especially in the management of materials and equipment. One of the project lessons in the final report notes that the use of materials must be adjusted to the activity schedule so that resources are optimal. This means that the project team arranges material deliveries in line with schedule needs, so that materials arrive and are used on time. A concrete example is the establishment of an on-site batching plant (self-managed batching plant) for concrete supply (Luh et al., 2021; Marhani et al., 2018). This step ensures that concrete supplies can be produced according to daily needs or just-in-time without depending on external deliveries, so that work is not delayed waiting for materials. As a result, work progresses faster because materials are always available when needed (Mishra & Aithal, 2022). JIT practices also avoid the accumulation of materials that can block work space and reduce the risk of material damage during the waiting process. As a result, in addition to shorter construction times, the project was successfully completed under the planned budget thanks to the efficiency of procurement.

3.1.3 5S (Sort, Set in Order, Shine, Standardize, Sustain)

The 5S principle is a method of arranging and maintaining order in the workplace which consists of: sort (selecting necessary items and removing unnecessary ones), set in order (arranging neatly), shine (cleaning), standardize (standardizing 5S procedures), and *sustain* (maintaining the sustainability of 5S discipline). In the Indonesian context, 5S is known as the 5R program (*Ringkas;* brief, *Rapi*; cleanliness, *Resik*; hard-working, *Rawat*; well-managed; *Rajin;* diligent). The purpose of 5S is to create an organized, clean, and safe work environment so that workers can be more productive and quality is maintained. (Mishra & Aithal, 2022) With a neat work area, workers do not waste time looking for tools/materials, minimize unnecessary movements, and reduce the potential for errors or accidents (Sugianto & Putra, 2022) .

In this project, the implementation of 5S is reflected in the housekeeping culture and high HSE (Health, Safety, Environment) standards. The final project report shows the existence of a routine HSE program and monitored HSE KPIs, which generally include aspects of neatness and cleanliness of the field. According to the Lean Construction Institute, the implementation of 5S in the field reduces chaos, prevents the use of damaged materials, and makes workers more focused so that productivity increases (Unnikrishnan & Sudhakumar, 2024; Yuniar et al., 2023). This is in line with the findings in this project, the absence of open problems or major rework at the end of the project shows the effectiveness of maintaining order from the beginning. With 5S, the project runs safer, smoother, and more efficiently because every resource is in the right place and at the right time.

3.1.4 Value Stream Mapping

Identification of value flows and waste is mapped through lean techniques value stream mapping (VSM), from upstream to downstream. With VSM, teams can see the process holistically, find bottlenecks or non -value-added activities , then eliminate them and improve them for a more efficient workflow. In construction, this means analysing the stages from planning, procurement, construction, to handover, then eliminating activities that only cause delays, idle time, or duplication of work (Arunizal et al., 2024; Salam, et al, 2023) .

The application of the VSM principle to this toll road project is evident from the technical analysis and changes in work methods carried out to facilitate the flow of the project (Rumane, 2017; Singh & Kumar, 2021). For example, from the beginning, facing the risk of delays due to preloading because it takes a long time. The team identified this preloading process as a step that does not provide direct value to the final product but takes months. Therefore, a change in the foundation design was made from the conventional preloading method to a slab on pile foundation that eliminates the need for preloading altogether (Prieto & Alarcón, 2023; Rahayu et al., 2024; Lorenza et al., 2024). This is in accordance with the essence of VSM which eliminates inefficient processes and replaces them with value-added steps, namely by building a solid foundation without delay. In addition, the project team also carried out value engineering on the embankment design or reducing the elevation of the embankment finish grade so that the volume of work is reduced without sacrificing function, which accelerates the completion of earthworks. The concrete result of the VSM approach is the acceleration of project completion almost 28% faster than the original plan. Academic research on similar toll projects in Indonesia also found that eliminating non-value-added activities through coordination and standardization can reduce project duration by up to 19% (Aziz & Irfan, 2020; Poojesh, et al, 2024) .

3.1.5 Visual Management

Visual communication and transparency with visual management is a lean strategy to convey information visually in the workplace so that all teams can easily understand it at a glance. The goal is to make the expected work conditions and standards visible so everyone can immediately see deviations or problems. (Salam et al., 2023; Pamungkas et al., 2024). Examples of visual management in construction include Kanban boards or weekly lookahead schedules posted on site, S-curve graphs of actual progress compared to the predetermined plan, colour coding for work zones or equipment, safety boards showing the number of days without an accident, and the use of visual technologies such as BIM to model work progress. With visualization, team communication becomes fast and transparent because everyone involved can see the project status in real time without waiting for long reports (Elmalky et al., 2024; Rahayu et al., 2024). Visual cues help identify problems and encourage immediate corrective action.

3.1.6 Continuous Improvement

In the context of lean, kaizen refers to the philosophy of continuous improvement – the continuous effort to improve processes gradually every day (Nikakhtar et al., 2015; Pedrosa et al., 2023). The principle of kaizen encourages all team members, from management to field workers, to proactively seek more

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efficient, safer, and higher-quality ways of working. The culture of kaizen is manifested through, among other things, regular evaluation meetings, end-of-project lessons learned, a system of employee feedback, and kaizen events. No process is considered perfect; there is always room for improvement, and failures/obstacles are seen as learning opportunities. In lean construction, kaizen often goes hand in hand with other methods, such as VSM, 5S, and A3 problem-solving to solve problems systematically.

The current project demonstrated the spirit of continuous improvement through method adaptation and evaluation conducted throughout the implementation. The Summary Learning Analysis in the final report summarizes the various lessons learned that the project team explored. For example, when the slab cast in situ work was time-consuming, the team tried a precast half-slab solution, which produced faster work results and increased profit margins. However, adjustments were required to the design details at the lifting point to avoid sagging. Similarly, the decision to lower the embankment specifications was taken to speed up the schedule, resulting in reduced volume and flood risk that needed to be assessed. Each of these changes reflects the Plan-Do-Check-Action (PDCA) cycle of kaizen: planning innovations, trying them out in the field, evaluating the results and their impacts (positive and negative), and then standardizing what works.

Based on the reliability test conducted with IBM SPSS 25, the managerial category has a Cronbach's Alpha value of 0.782 and a waste category of 0.733. This value indicates that both categories of lean construction based on the preferences of people involved in the Bayung Lencir-Tempino Toll Road Project Section 2 have good internal consistency (Situmorang et al., 2023). The instruments measuring the managerial and waste categories can be considered reliable or trustworthy.
This indicates that, although management is aware of lean concepts and tools, the practical use of specific lean tools in the field may still be limited. This finding can be interpreted as meaning that this project emphasizes general lean principles, such as waste elimination and efficiency, rather than the formal application of specific lean tools.

3.2 Lean Construction Practices

There are three lean construction practices which are cost, time and quality indicators.

3.2.1 Cost Indicator

Lean construction aims to reduce waste so that project costs are more efficient (Hermina et al., 2014). Variable X6 confirms that management is aware of the influence of lean on cost reduction. This is evident in the project's achievements: Bayung Lencir-Tempino Toll Road Section 2 was successfully completed under budget. The final report indicated that the project obtained a surplus of 8.67% of the contract value in line with the lean principle of seeking to reduce production costs without sacrificing quality (Lubis, 2021).

Several variables related to cost and efficiency show interesting patterns. Questions about potential cost waste due to errors were considered less significant by data. For example, variable X39, “Errors in selecting heavy equipment resulted in increased costs in the project” has a very low correlation ($r = 0.046$; $p = 0.809$),

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indicating that this item is not valid for measuring lean perceptions in this project. This is because there was no significant increase in costs due to errors in selecting equipment in the field. Equipment management was running well so that there was no such cost waste. Likewise, changes in prices/wages (X42) and errors in preparing the cost budget (X43) were not significant. Careful cost planning and tight control through value engineering contributed to keeping the budget under control.

Interestingly, the lean initiatives implemented in this project actually resulted in cost savings through innovation. The project report noted a change in foundation from preloading to slab on pile to speed up time. This step not only has an impact on time, but has the potential to reduce maintenance costs and risks in the future. Setting material standards from the start is a lean practice to prevent wasteful costs due to materials not meeting specifications. Target costing in lean encourages teams to work according to target costs without sacrificing value.

3.2.2 Time Indicator

Lean construction focuses on improving workflow and eliminating time waste. The Bayung Lencir-Tempino Toll Road Section 2 project has proven to be a success in terms of time. Although the initial contract gave 574 days, the project was accelerated to 415 days for the President's inauguration target, and was actually completed according to the commitment. In fact, data shows that the project was completed two days ahead of the revised schedule. The success of this faster completion is in line with lean principles that emphasize time efficiency and schedule reliability. Lean Construction through techniques such as the Last Planner System and Just-In-Time seeks to improve plan reliability and avoid delays. In theory, lean projects should be completed faster than conventional methods (Lubis, 2021). and the results of this project are in line with lean principles. This is in accordance with the concept of flow in lean construction, maintaining a stable daily work flow is essential to avoid delay accumulation. The project results confirm this, with a project completion time of 415 days, any small deviations need to be addressed immediately. The absence of schedule deviations means that the team is able to maintain a good daily workflow.

Some potential time wasters were not considered significant by data. For example, variable X22 is invalid ($r = 0.312$; $p = 0.093$). This indicates quite good internal project coordination, workers do not experience idle time waiting for orders. Possibly, the project team implements efficient communication so that there is no time wasted waiting for instructions. Findings generally do not see teamwork problems, variable X21 is not significant with $p = 0.674$. This is in line with project acceleration only possible to achieve with solid team collaboration. Lean emphasizes collaboration and team involvement, for example through cross-functional collaboration in integrated project delivery.

One item related to changes and rework, variable X23 is also invalid ($r = 0.228$; $p = 0.226$). In general, sudden design changes often cause delays. In this project, there were indeed design changes by the owner (slab on pile foundation) and rework due to landslides. However, both of these were not perceived negatively by findings because design changes actually accelerated the project, not as waste but as a lean solution. Landslide rework was considered a force majeure that was handled quickly. This shows an awareness that not all changes are bad. If managed

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with lean principles to focus on value and be adaptive to risk, the project can still be profitable.

3.2.3 Quality Indicators

Lean construction essentially seeks to improve quality by preventing defects and variability, so that the final result is better (Pamungkas et al., 2024). According to the Lean Construction Institute, the goal of lean is to achieve optimal quality without waste. In this toll road project, there were no open quality issues during handover and all work was acceptable according to specifications. Data strongly emphasized the importance of consistent material quality, for example in variable X25 with a correlation of r = 0.664 and p = 0.000. This indicates an agreement that the use of materials according to standards without excessive variability is part of the implementation of lean. Lean strategy recommends standardization of materials and processes to ensure quality and prevent waste due to inconsistent quality. Implementation in the project is in line with the statement in the variable, pavement and structural materials follow strict specifications as seen from quality control in the field and supplier evaluation in project documents. Variable X28, "The incoming material does not comply with existing quality standards" is valid (r = 0.579 and p = 0.001). This means that findings acknowledge that out-of-spec material is a waste issue. The positive correlation of this variable indicates that the more findings realize the importance of lean, the more they tend to criticize the presence of non-standard materials. Cases of materials that do not meet specifications can be minimized in the project, there are no reports of material quality failures. If there are materials that do not match, the team immediately rejects or replaces them according to QC procedures, so that the impact does not become an open problem at the end of the project. Lean construction awareness of this indicates the implementation of quality control that is in line with the lean principle of "build quality at the source".

The quality aspect also includes material storage and tool maintenance to prevent damage that reduces quality. Findings agree that poor material management is wasteful. Variable X29, "Poor material storage management resulting in damage and loss" is valid (r = 0.618 and p = 0.000). The project managed to avoid this right by implementing 5R / 5S in the warehouse. Lean recognizes the 5S method (Sort, Set in order, Shine, Standardize, Sustain) to keep the workplace tidy and prevent loss/damage. The implementation of 5S is also seen in variable X20 which, although not statistically significant, has a moderate positive correlation. This means that most findings agree on the importance of housekeeping. In fact, the project work area is monitored to be quite neat and safe, there were no reports of fatal work accidents during the project. This is consistent with the 5S principle that a clean and orderly work environment reduces the risk of accidents (Adhitama & Saraswati, 2023). Field facts support that productivity in this project is relatively high. Next, multiple linear regression analysis was conducted to see the effect of the sub-categories methods, machinery, waiting, material, and workforce on waste. The R square value obtained was 0.885, which shows that 88.5% of the variance in the waste category can be explained by the independent variables, namely methods, machinery, waiting, material, and workforce. The standard error value obtained was 1.44. The F value obtained was 36.759 with a significance of 0.000 (Table 4.3). The results show that the overall regression model significantly explains data variability.

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The workforce has a significant positive coefficient, with p <0.05 (Table 4.4), meaning that the variables in the workforce sub-category significantly affect waste. The same is true for the material and machiners sub-categories that significantly affect waste. Meanwhile, the waiting sub-category has a p-value = 0.871 and the methods sub-category has a p-value = 0.190, which means that these two sub-categories do not contribute significantly to the implementation of lean construction related to waste in the Bayung Lencir-Tempino Toll Road Section 2 project.

4. Conclusion And Suggestion

4.1 Conclusion

Lean construction principles were conclusive based on the final report of the Bayung Lencir-Tempino Toll Road Section 2 construction project. A final completion time of 415 days as opposed to the original target of 574 days, this project was finished ahead of schedule by about 27.7%. Time waste brought on by idle time and material delays is lessened by the Just-in-Time and Last Planner System methods. Reducing material waste in this project is another benefit of using lean construction. The application of Lean Construction has succeeded in reducing project costs significantly. This project was completed at a lower cost than the budget, with a surplus of around 8.67% of the contract value. The main factors influencing lean construction practices for this project include workforce, materials, and machinery (heavy equipment). Section 2 of the Bayung Lencir-Tempino Toll Road prioritizes waste reduction and resource optimization. Meanwhile, the waiting and methods sub-categories do not show significant influence. Time efficiency has been positively impacted by the implementation of Lean Construction principles in the Bayung Lencir - Tempino Toll Road Section 2 construction project, based on statistical analysis, and final report documents completed by PT Nindya Karya. waste reduction and resource optimization. Meanwhile, the waiting and methods sub-categories do not show significant influence.

4.2 Suggestion

As a suggestion, future research could look into the impact of lean construction on projects other than toll highways. The use of Lean tools like Value Stream Mapping and Last Planner System, which have not yet been fully implemented optimally in the field, should be further studied. Research can also look more closely at how lean adoption affects safety and job quality, particularly how it can reduce workplace accidents and enhance project quality. Lastly, it's critical to create a more thorough lean construction assessment model that takes sustainability, quality, cost, and time into account.

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