

Waste Aggregate Control Strategy through the Implementation of Building Information Modeling (BIM) and Load Scanner Technology to Improve Cost Efficiency Onthe Trans-Sumatra Toll Road Project

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ABSTRACT: *This study examines the impact of integrating Building Information Modeling (BIM) and Load Scanner technology on material management efficiency and waste reduction in large-scale infrastructure projects. T-test results show that key relationships, such as BIM's influence on planning and design, Load Scanner's impact on construction and material procurement, and material monitoring's role in waste management, are statistically significant ($p < 0.05$). These technologies have proven to enhance project efficiency by reducing material waste and accelerating project timelines. However, the integration between BIM and material monitoring, as well as planning and procurement, requires further improvement. The proposed strategy, based on BIM and Load Scanner integration, involves clear implementation phases, staff training, and post-project evaluation. The approach is adaptable for various infrastructure projects, offering a sustainable model for effective material management and waste reduction.*

KEYWORDS -BIM, Load Scanner, Material Management, Waste Reduction, Project Efficiency, Infrastructure, T-test, Procurement, Technology Integration

I. INTRODUCTION

The development of toll road infrastructure is a key element in improving connectivity and mobility within a region, as it not only accelerates access between cities and areas but also facilitates the smooth transportation of goods and services, reduces travel time, and boosts local productivity and economic growth while alleviating traffic congestion on major urban routes [1].

One tangible manifestation of the Indonesian government's commitment to infrastructure development is the Trans-Sumatra Toll Road (JTTS) Rengat-Pekanbaru Section, particularly the Pekanbaru Ring Road Section, which plays a strategic role in enhancing connectivity between regions and serves as a catalyst for surrounding area development, as well as promoting transportation efficiency and safety.

However, both operational and under-construction JTTS projects face significant challenges, particularly related to waste material issues, especially aggregate or sand, which show substantial deviations between the planned and actual on-site execution. This material wastage phenomenon highlights the importance of developing a systematic and integrated waste control strategy. PT XYZ, as the contractor, reports significant deviations in Pay Items such as Separator/Caping Layer and Drainage Layers, indicating the need for strict monitoring to prevent wastage and enhance resource efficiency. In the construction industry, waste management is crucial as it impacts efficiency, profitability, and environmental outcomes, making Lean Construction principles, which emphasize waste reduction, highly relevant [2].

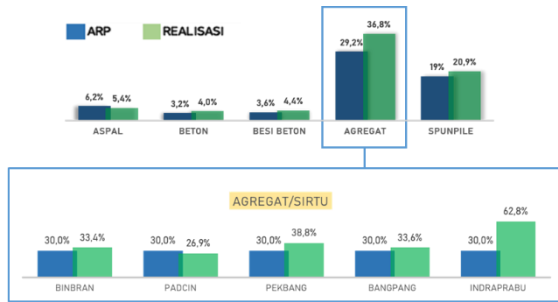


Figure 1. Waste Monitoring PT XYZ, 2023

Source :PTXYZ, 2023

The use of technologies such as Building Information Modeling (BIM) and Load Scanner is believed to enhance project efficiency by minimizing material waste, boosting productivity, and supporting project sustainability. These technologies align with Lean principles and promise improved economic and environmental outcomes[3].

This study specifically proposes the use of BIM and Load Scanner to control aggregate waste in the Trans-Sumatra Toll Road Rengat-Pekanbaru project, an approach that has not been extensively explored in previous research, thus offering a novel technological approach to waste management [4][5][6][7][8][9][10][11][12].

The primary focus of this research is the waste control strategy at the material acceptance stage, specifically utilizing Load Scanner technology to minimize deviations from the plan and significantly reduce excess waste during the project implementation, contributing to cost efficiency and enhanced effectiveness in toll road construction.

II. THEORY

2.1.Effective Material Waste Management

Effective Material Waste Management refers to a systematic approach to managing the waste generated during the construction process. This variable encompasses a series of strategies, policies, and practices designed to reduce, recycle, and minimize the environmental impact of construction waste. It includes identifying sources of waste, planning waste management, sorting and processing waste, as well as implementing technologies and innovations to manage waste efficiently. The primary goal is to optimize resource use, reduce waste, extend the lifespan of the project, and promote sustainable construction practices (Ahsan et al., 2023).

2.2.Applicationof Building Information Modeling (BIM)

In the current Industry 4.0 era, numerous construction technologies have emerged, one of which is Building Information Modeling (BIM). BIM is a system that regulates the lifecycle of a project. It is a technology-based approach to managing construction projects, involving the creation and use of digital models of physical and functional assets. BIM allows stakeholders to collaborate in an integrated environment, facilitating more efficient information exchange throughout the project lifecycle, from planning, design, construction, to the operation and maintenance of buildings or infrastructure [14].

According to Succar (2009), BIM is a 3D model-based process that enables architects, engineers, and other construction professionals to design, build, and operate infrastructure assets more efficiently. BIM not only includes three-dimensional models but also incorporates a fourth and fifth dimension: time management (4D) and cost management (5D), which enable more effective project planning and management. In the context of construction, BIM facilitates better collaboration among all project stakeholders by integrating design information, physical data, and functional data.

III. RESEARCH METHODOLOGY

This research adopts a quantitative descriptive method to explore waste material control in toll road construction projects using BIM and Load Scanner through a Lean Construction approach. The research strategy was designed based on Robert Yin's framework, selecting appropriate methods such as surveys, archival analysis, and case studies according to the type of research questions posed. The research process follows Kumar's three-phase model: identifying the research problem, designing the study, and executing the plan including data collection and analysis.

The data analysis includes descriptive statistics, non-parametric homogeneity tests (Kruskal-Wallis and Mann-Whitney), adequacy tests, and comprehensive validity and reliability evaluations. Validity is assessed through content, convergent, AVE, and discriminant analyses, while reliability uses composite reliability and

Cronbach's Alpha (acceptable if > 0.7). Structural model evaluation applies R-square, and significance testing through full-model SEM using SmartPLS, where hypotheses are accepted if the T-statistic exceeds the critical value. This methodology ensures robust, systematic, and scientifically valid conclusions regarding aggregate waste control strategies in toll road projects [15].

IV. RESULT AND DISCUSSION

4.1. Homogeneity Test

The homogeneity test is a statistical procedure used to determine whether two or more sample groups originate from populations with the same variance (Sugiyono, 2019). In this study, the homogeneity test was applied to three respondent categories: work experience, job position, and last education level. The work experience category includes three groups (5–10 years, 10–15 years, and >15 years), job position consists of four groups (Officer/Engineer, Supervisor/Assistant Manager, Manager, and Project Manager), and education level includes two groups (D4/S1 and S2). Since the test involves three or more groups, the Kruskal-Wallis H test was used. Data are considered homogeneous if the Asymp. Sig. value is greater than 0.05 (Nuryadi et al., 2017). Data processing was carried out using SPSS software, and the following are the results of the analysis.

Based on the results of the homogeneity test using the Kruskal-Wallis H Test for the categories of work experience, job position, and educational background, all Asymp. Sig. values for each indicator were above 0.05. The lowest Asymp. Sig. value for work experience was 0.565, for job position was 0.210, and for educational background was 0.323. Therefore, it can be concluded that the data is homogeneous, indicating that there are no significant differences in perception among respondent groups based on work experience, job position, or educational background.

4.2. Outer Loading Test

The following is the result of the outer model test which presents the outer loading values using the SmartPLS v3 analysis tool.

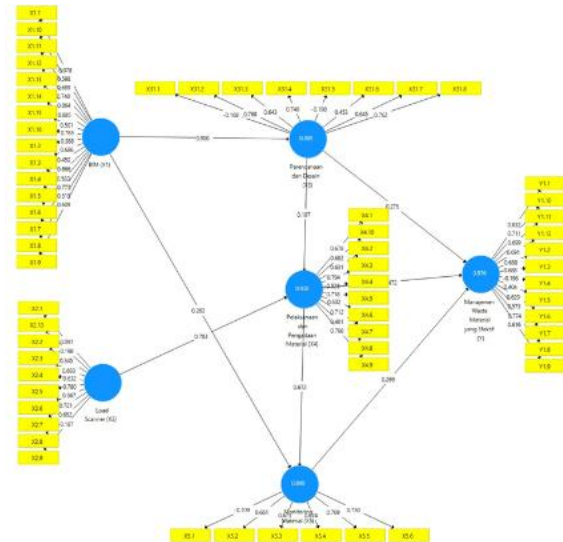


Figure 2. Outer Model Test Results

4.3. Hypothesis Testing with SmartPLS

To assess the significance of the influence between variables, a bootstrapping procedure was conducted. The bootstrap method uses the entire original sample, followed by resampling. In this resampling method, the significance value (two-tailed) used for the t-value is 1.67065 at a 5% significance level. Table 1 presents the t-statistic results used to test the significance of indicators on latent variables within the second-order construct. Structural model evaluation aims to predict the relationships between latent variables based on substantive theory. The structural model is evaluated using the R-square value for the dependent constructs. The R-square test results obtained from the SmartPLS analysis can be seen in the following table.

Table 1. R-square Test Results

Variable	R Square	R Square Adjusted
Effective Waste Material Management (Y)	0,678	0,677
Material Monitoring (X5)	0,583	0,580
Construction and Material Procurement (X4)	0,651	0,650
Planning and Design (X3)	0,562	0,560

Source: Author's Data Processing (2025)

The R-square test results in Table 1 indicate the explanatory power of the independent variables on the dependent variable and other

constructs in the model. The variable *Effective Waste Material Management (Y)* has an R-square value of 0.678, meaning that approximately 67.8% of the variation in this variable is explained by the model, with the adjusted R-square of 0.677 showing a minimal decrease when accounting for the number of predictors. The *Material Monitoring (X5)* variable has an R-square of 0.583, indicating that 58.3% of its variance is explained, while the adjusted value is slightly lower at 0.580.

The *Construction and Material Procurement (X4)* variable has an R-square of 0.651 (adjusted 0.650), suggesting that about 65.1% of its variance is explained by the model. Finally, *Planning and Design (X3)* has an R-square value of 0.562 and an adjusted value of 0.560, indicating that 56.2% of its variance is accounted for. These results show that the model explains a substantial portion of the variation in the variables, with *Effective Waste Material Management (Y)* being the most strongly explained construct in the model.

Overall, the high R-Square values for the four variables indicate that the model developed in this study is highly effective in explaining the relationship between the application of technology (BIM and Load Scanner) and various aspects of material and waste control in highway construction projects. Next, a T-test was conducted using SmartPLS, and the results are presented in Table 2 as follows.

Table 2. T-Test Results

Variable	Original Sample (O)	Sample Mean (M)	StandDeviation (STDEV)	T Statistics (O/STDEV)	P Values
BIM (X1) -> Planning and Design (X3)	0.900	0.898	0.043	20.910	0.000
BIM (X1) -> Material Monitoring (X5)	0.263	0.380	0.261	1.010	0.313
Load Scanner (X2) -> Construction and Material Procurement(X4)	0.783	0.756	0.103	7.577	0.000
Planning and Design (X3) -> Construction and Material Procurement(X4)	0.197	0.227	0.107	1.840	0.066

Variable	Original Sample (O)	Sample Mean (M)	StandDeviation (STDEV)	T Statistics (O/STDEV)	P Values
Construction and Material Procurement(X4) -> Material Monitoring (X5)	0.672	0.548	0.273	2.461	0.014
Planning and Design (X3) -> Effective Waste Material Management (Y)	0.276	0.298	0.117	2.362	0.019
Construction and Material Procurement(X4) -> Effective Waste Material Management (Y)	0.472	0.464	0.106	4.458	0.000
Material Monitoring (X5) -> Effective Waste Material Management (Y)	0.269	0.256	0.065	4.137	0.000

Source: Author's Data Processing (2025)

Based on the T-test results above, this test was used to measure the significance of the relationships between variables within the structural model. It is crucial for identifying statistically significant connections that indicate meaningful contributions to improving material management efficiency and reducing waste.

1. H1: BIM (X1) → Planning and Design (X3)

The hypothesis is accepted, with a t-statistic value of 20.910 and a p-value of 0.000. This result indicates that the implementation of BIM has a highly significant impact on the effectiveness of project planning and design. In practice, BIM can support the development of more precise design plans and synchronization across technical disciplines from the early stages of a project. The use of BIM in planning can lead to *time savings* through reduced design revisions and *cost reduction* via more efficient resource utilization. Implementation strategies should involve the design team, main contractors, and IT stakeholders from the outset.

2. H2: BIM (X1) → Material Monitoring

(X5)

The hypothesis is rejected (t-statistic = 1.010; p-value = 0.313), indicating that BIM's role in supporting material monitoring activities on-site is not yet statistically significant. This suggests that the integration of BIM with monitoring systems is not yet optimal, potentially due to a lack of training or integrated systems. For implementation in other projects, a roadmap is needed for integrating BIM with field technologies such as IoT or RFID, alongside targeted training for logistics teams.

3. H3: Load Scanner (X2) → Construction and Material Procurement (X4)

The hypothesis is accepted, with a t-statistic of 7.577 and a p-value of 0.000. Load Scanners are proven to significantly enhance the efficiency of construction and material procurement, particularly in terms of load volume accuracy and aggregate supply control. This can lead to cost savings by minimizing over-ordering and material waste. For replication, steps should include equipment calibration, operator training, and well-documented daily use SOPs.

4. H4: Planning and Design (X3) → Construction and Material Procurement (X4)

The hypothesis is rejected (t-statistic = 1.840; p-value = 0.066). Although good planning is conceptually expected to support efficient material procurement, the data shows that this relationship is not yet statistically strong. A likely explanation is a gap between design translation and actual field needs. Improvements are needed in coordination between planning and procurement teams, including the use of BIM-based digital Material Take-Offs (MTOs) to ensure more accurate demand predictions.

5. H5: Construction and Material Procurement (X4) → Material Monitoring (X5)

The hypothesis is accepted (t-statistic = 2.461; p-value = 0.014). This result demonstrates that a structured system for construction and material procurement

directly contributes to monitoring activities on-site. Implementation in other projects can involve the use of tracking dashboards, QR-code material labeling, and real-time reporting. These measures enhance material flow visibility and reduce the risk of stockouts or material loss.

6. H6: Planning and Design (X3) → Effective Waste Material Management (Y)

The hypothesis is accepted (t-statistic = 2.362; p-value = 0.019). This indicates that comprehensive planning and design have a direct impact on effective waste material management. Strategic implementation includes integrating waste flow simulations into BIM during the design phase and modeling design alternatives that minimize potential material leftovers. This is essential for achieving a *zero-waste design* target in large-scale projects.

7. H7: Construction and Material Procurement (X4) → Effective Waste Material Management (Y)

The hypothesis is accepted (t-statistic = 4.458; p-value = 0.000). Timely and demand-driven construction and procurement processes are critical in avoiding overstocking that can lead to waste. Recommended implementation includes a *Just-In-Time delivery system*, validation of the material schedule, and close collaboration with local suppliers. Implementation risks may arise from dependency on accurate field data and the stability of the supply chain.

8. H8: Material Monitoring (X5) → Effective Waste Material Management (Y)

The hypothesis is accepted (t-statistic = 4.137; p-value = 0.000). This reinforces the notion that a good monitoring system—including digital records and routine inspections—can significantly reduce material waste. Implementation strategies may involve a *cloud-based inventory system*, Load Scanner integration with BIM dashboards, and periodic logistics audits. Risks include technological dependency, internet bandwidth needs, and the digital literacy

of project personnel.

Overall, the T-test results show that most relationships between variables in the model are statistically significant. The application of BIM and Load Scanners, along with strengthening the aspects of monitoring, planning, and material procurement, has been proven to contribute significantly to more effective waste material management. These findings underscore that *technology-based aggregate waste control strategies* can be an effective approach to enhancing cost efficiency and project sustainability, especially in large infrastructure projects like the Trans-Sumatra Toll Road.

To address the critical issue of aggregate waste in large-scale infrastructure projects, a comprehensive strategic framework is proposed. This strategy emphasizes the integration of advanced technologies—namely Building Information Modeling (BIM) and Load Scanner systems—to enhance accuracy in planning, construction, and monitoring of aggregate materials. The approach focuses on time and cost savings, improved coordination among key actors, and risk mitigation, while ensuring replicability in similar project environments. The following table outlines the strategic plan components, implementation phases, and key success indicators necessary for effective Construction.

Table 3. Strategic Framework for Enhancing Aggregate Waste Efficiency through BIM and Load Scanner Integration

Strategic Subsection	Detailed Description	Success Indicators	Tangible Outputs
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Strategic Subsection	Detailed Description	Success Indicators	Tangible Outputs
1. Strategic Objective	Enhance the efficiency of aggregate utilization, reduce waste, and accelerate construction timelines by integrating Building Information Modeling (BIM) for planning and Load Scanner technology for on-site volume validation.	-Aggregate waste reduced - Construction time improved	- Policy and implementation guideline - Project-specific strategy module
2. Implementation Modeling (Time & Cost Saving)	a. Time Saving: BIM streamlines technical design, minimizing field revisions and accelerating aggregate estimation. b. Cost Saving: Load Scanner prevents over-ordering and financial loss from excess material.	-Fewer design revisions -Cost efficiency in aggregate	- Comparison charts: estimated vs actual usage -Pre- and post-implementation cost table

Strategic Subsection	Detailed Description	Success Indicators	Tangible Outputs
3. Implementation Roadmap	Phase 1 – Preparation: Staff training, equipment procurement, and system setup. Phase 2 – BIM Design: Digital modeling and volume estimation. Phase 3 – Load Scanner Monitoring: Validate incoming material volumes. Phase 4 – Review & Optimization: Analyze data and refine SOPs.	-Digital system fully installed -Applied to at least one active project	-Standard Operating Procedures (SOP) - Postimplementation evaluation report
4. Key Actors & Roles	-Project Manager: Oversees policy and budget allocation. -BIM Engineer: Develops digital design and material models. -Load Scanner Operator: Performs on-site volume validation. -IT Team: Integrates data into central project system.	-All roles engaged from planning to execution - Coordination meetings follow planned schedule	-Role assignment chart - Coordination logbook

Strategic Subsection	Detailed Description	Success Indicators	Tangible Outputs
5. Implementation Prerequisites	-Availability of BIM software and Load Scanner tools. -Competent personnel trained in technology usage. -Reliable communication and data infrastructure.	-Staff certified and trained -System operational of project time	-Training certificate - Equipment readiness checklist
6. Implementation Risk Assessment	-Cost Risks: High initial investment in tools and licenses. - Human Resources Risks: Lack of skilled BIM/Scanner operators. -Technology Risks: Integration failure between field data and central system.	-Technical issues rate is low -System integration success rate is high	-Risk register and mitigation plan - Troubleshooting report
7. Replication Scenario in Other Projects	This strategy can be replicated in other large-scale infrastructure projects such as ports, airports, and industrial zones where aggregate control is critical. Adjustments may be made according to project terrain, material type, and scale.	- Successfully implemented in at least one other project -Minimal adjustments required for adaptation	- Adaptation template for new projects -Case study report on replication outcome

Source: Author's Data Processing (2025)

Table 3 presents a strategic framework designed to improve the efficiency of aggregate utilization through the integration of Building Information Modeling (BIM) and Load Scanner technologies. The primary objective is to reduce aggregate waste and accelerate construction timelines. This is achieved by leveraging BIM for streamlined digital design and volume estimation, while Load Scanner technology ensures on-site volume validation to prevent over-ordering. Key success indicators include reduced design revisions and cost efficiency, with tangible outputs such as policy guidelines, strategy modules, comparison charts, and cost evaluation tables.

The strategy includes a four-phase implementation roadmap: preparation (training, equipment, setup), BIM-based design, on-site volume validation using Load Scanner, and final review and SOP optimization. Key actors involved are the Project Manager, BIM Engineer, Load Scanner Operator, and IT Team, each responsible for ensuring coordinated execution. Implementation prerequisites include software availability, trained personnel, and reliable data infrastructure. Potential risks—such as high initial investment, lack of skilled operators, and system integration challenges—are addressed through risk mitigation plans. This strategy is also scalable and replicable across other infrastructure projects like ports and airports, with minimal adjustments required, supported by adaptation templates and case study documentation.

V. CONCLUSION

Based on the T-test results, most of the relationships between variables in the model are statistically significant, indicating a tangible contribution to material management efficiency and waste reduction. Three key hypotheses showing significant effects include: BIM on planning and design ($t = 20.910$; $p = 0.000$), Load Scanner on construction and material procurement ($t = 7.577$; $p = 0.000$), and material monitoring on waste management ($t = 4.137$; $p = 0.000$). These findings confirm that integrating technologies such as BIM and Load Scanners can not only reduce potential waste but also accelerate construction processes and lower project costs. On the other hand, relationships such as BIM on material monitoring (t

$= 1.010$; $p = 0.313$) and planning on procurement ($t = 1.840$; $p = 0.066$) remain statistically insignificant, highlighting the need for better system integration and team coordination.

The proposed waste control strategy—based on the integration of BIM and Load Scanners—demonstrates that this technology-driven approach can significantly improve aggregate utilization and reduce waste, while also increasing project execution speed. The strategy is structured through clear implementation phases, including staff training, equipment use, and post-project evaluation. The involvement of key actors such as project managers, BIM engineers, Load Scanner operators, and IT teams is crucial to ensuring successful execution. Moreover, this strategy is replicable and adaptable to other large-scale infrastructure projects, such as ports, airports, and industrial zones, with minor adjustments based on project characteristics. Therefore, this approach can serve as a model for effective, adaptive, and sustainable material management in future projects.

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