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A Comparative Analysis of the Effectiveness of Design Coordination Based on Building Information Modeling (BIM) Using A Value Stream Mapping Approach in Highway Infrastructure Projects

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Building Information Modeling (BIM); Common Data Environment (CDE); Value Stream Mapping (VSM); Design Coordination, Process Cycle Efficiency (PCE)

ABSTRACT
Design coordination in toll road projects involves many stakeholders with high information exchange needs, potentially causing process waste such as waiting time, repeated inspections, design revisions, and information delays, which reduces coordination effectiveness and impacts design completion duration. The application of Building Information Modeling (BIM) through the Common Data Environment (CDE) is expected to enhance information integration and collaboration among stakeholders, thereby increasing design coordination effectiveness. This study aims to analyze the effectiveness of the application of BIM-CDE in the design coordination process in toll road infrastructure projects through waste identification and process performance measurement. The research uses a mixed methods approach with a case study design. Data were obtained through observation, study of project documents, and semi-structured interviews. The analysis was carried out using Value Stream Mapping (VSM) to identify Value Added (VA), Non-Value Added (NVA), and supporting activities, then evaluated using waiting time, lead time, and Process Cycle Efficiency (PCE) indicators. The results of the study identified four types of waste, namely waiting, transportation, defect, and overprocessing. The implementation of BIM-CDE was able to reduce the waiting time from 72 days to 25 days (65.28%), while the total lead time was reduced from 255 days to 134 days (47.45%). In addition, the PCE value increased from 27.45% to 31.34% indicating an improvement in process efficiency. This study was limited to one project case study so generalizations of results are still limited. Further research is suggested to test the application of BIM–CDE on different projects.

INTRODUCTION

The development of transportation infrastructure has an important role in encouraging economic growth through improving regional connectivity, efficiency in the distribution of goods and services, and access to market opportunities. Empirical research shows that good transportation infrastructure improves market accessibility, facilitates trade, and lowers logistics costs, which ultimately drives economic activity and regional growth significantly (Nie et al., 2025) .

In line with the direction of national development policies in the 2020–2024 RPJMN and the 2025–2045 RPJPN, the development of transportation infrastructure, including toll roads, is expected to continue to increase, especially in the Eastern Region of Indonesia such as East Nusa Tenggara Province, the Maluku region, and Papua. This increase aims to strengthen connectivity between regions and open up the isolation of disadvantaged areas. The increasing scale and distribution of projects causes the complexity of design planning and coordination to be even higher, because it involves various disciplines, many stakeholders, and strict technical requirements so that the design planning process becomes complex. This condition makes design coordination a key activity because it greatly affects design changes and rework (Rework) (Permata & Suroso, 2024).

In general practice, design coordination in conventional methods still relies heavily on two-dimensional (2D) drawings, separate document exchanges, and cross-disciplinary review processes conducted through meetings and visual examinations. This condition often leads to delays in the delivery of information and insynchronization between design documents, so that design conflicts are only identified after cross-disciplinary drawings are combined. A study by Hassan et al. (2023) shows that a lack of coordination and communication, as well as errors in design documents, are the main factors that trigger the occurrence of rework in construction projects.

The impact is significant on large-scale civil infrastructure projects, the cost of rework can reportedly be in the range of around 5%–20% of the contract value (Ustymenko, 2024; Eke et al., 2023; Hassan et al., 2023). This figure illustrates that design coordination issues (which trigger revisions, changes, and rework) are not just administrative issues, but project performance issues (Hassan et al., 2023). In addition, the rework factor modeling study emphasizes that improving documentation coordination and design communication is an important step to lower rework (Ayalp, 2025) .

As the need for cross-disciplinary integration increases, Building Information Modeling (BIM) is widely promoted as a solution to strengthen design coordination through integrated three-dimensional (3D) models, data-driven collaboration, and design conflict detection support (Pantiga & Soekiman, 2021; Putin, 2022). Various quantitative studies show that the implementation of BIM is able to reduce project duration and cost, while reducing design errors (Das et al., 2025). Therefore, Building Information Modeling (BIM) is present as an integrated three-dimensional model-based innovation that supports interdisciplinary coordination, so that design conflicts can be identified from the planning stage (Alqodri & Rahmawan, 2025). However, in practice, the use of BIM is often only evaluated in terms of reducing design errors (Defect), while its effectiveness on the overall coordination process and the smooth flow of work (Flow) has not been comprehensively measured (Sampaio et al., 2023).

In this context, Lean Construction becomes relevant because it assesses process performance from the perspective of flow, waste, and value (Hassan et al., 2023; Thoengsal, 2023; Yang et al., 2025). In the design coordination phase, waste can appear in the form of waiting (waiting for review or approval), overprocessing (repeated revision of documents), and defects (missynchronization of information or document format errors). Recent studies show that the application of Value Stream Mapping (VSM) in the design process is effective in identifying bottlenecks, non-value-added activities, as well as opportunities to improve coordination and reduce rework (Cunha et al., 2025). The integration of BIM with the Lean Construction approach allows for a more comprehensive evaluation of the effectiveness of the overall design coordination process (Liu, 2025).

Based on previous research, there are still limited studies that specifically evaluate BIM in the context of the effectiveness of design coordination using the Lean Construction approach and Value Stream Mapping analysis in toll road projects (Gebeyehu et al., 2022; Masmali, 2021; Maulana, 2019). Therefore, this study takes a case study on the Sigli-Banda Aceh Toll Road Project Section 1 which has undergone a transition from a two-dimensional (2D) image-based design coordination method to a BIM-based three-dimensional (3D) model. This shift raises the need to evaluate the effectiveness of the design coordination process using the Lean

Construction approach through Value Stream Mapping (VSM) analysis to measure how efficient a process is by comparing the time that actually adds value to the total process time between conventional and BIM methods. Thus, this study was prepared with the title: "Analysis of the Efficiency of the Design Coordination Process Based on Building Information Modeling (BIM) Using the Value Stream Mapping (VSM) Approach" (Kaur et al., 2025; Pantiga & Soekiman, 2021; Putin, 2022).

The increase in the scale and complexity of toll road projects has consequences for the increasingly complex process of planning and coordinating inter-disciplinary designs (Kermanshahi et al., 2020; Putri et al., 2024; Rakib et al., 2019). This condition has the potential to cause various problems, such as design conflicts, inefficiency of coordination flows, and rework that has an impact on the performance of time and quality of project implementation. Therefore, these problems need to be identified clearly and systematically so that research can be focused on the most relevant aspects and carried out within measurable and directed limits.

Based on the background and literature findings, several research problems are identified: international toll road projects remain vulnerable to delays due to suboptimal planning and design coordination, as evidenced by delays in Indonesia's Trans Sumatra Toll Road including Sigli-Banda Aceh Section 1; BIM implementation on this project occurred during construction, leaving the predominantly conventional design coordination process prone to miscommunication and repetitive revisions that increase rework; the STA 10+250 Bridge case study shows conventional coordination leads to frequent revisions and delayed design approval; Lean Construction analysis reveals high non-value-added activities such as rework, waiting times, and inefficient information flow; and empirical studies evaluating design coordination effectiveness between conventional and BIM-based methods using the Lean-Value Stream framework remain limited. Accordingly, this study addresses three research questions: (1) What types of waste occur in the existing design coordination process based on Value Stream Mapping (VSM)? (2) What is the efficiency level of the design coordination process based on lead time and Process Cycle Efficiency (PCE)? (3) How effective is BIM-based design coordination through Common Data Environment (CDE) in improving design coordination efficiency?

This research aims to analyze BIM-CDE effectiveness in improving toll road design coordination by identifying waste types, measuring process efficiency, and comparing conventional and BIM-based methods through lead time and PCE analysis. Theoretically, this research contributes to construction management knowledge by integrating Lean Construction and BIM concepts via VSM analysis in toll road infrastructure, enriching limited literature on design coordination evaluation using quantitative indicators. Practically, this research offers insights for contractors, consultants, and BUJT in formulating effective coordination strategies, serves as a reference for policymakers in evaluating BIM implementation effectiveness, and guides future researchers exploring similar topics across broader contexts and project types.

RESEARCH METHODS

Design/Type of Research

This research uses a case study approach with mixed methods (quantitative-qualitative comparative) to analyze and compare design coordination effectiveness between conventional and BIM-CDE-based methods in toll road projects. The case study approach enables comprehensive description of design coordination dynamics in complex construction projects, while the object—STA 10+250 Bridge on the Sigli-Banda Aceh Toll Road Section 1—was selected for its 360-meter length, higher complexity, and longer duration compared to other structures. Quantitative analysis measures design coordination efficiency using Value Stream Mapping (VSM) through Cycle Time, Lead Time, VA/NNVA/NVA classification, and Process Cycle Efficiency (PCE), measured on both conventional and BIM systems. Qualitative analysis uses semi-structured interviews with contractors, consultants, and BUJT to validate process flow, identify waste, classify activities, explore waste causes, and obtain improvement input. This mixed-method approach was chosen because evaluating design coordination effectiveness requires both qualitative understanding of workflows and quantitative measurement through Lean-based efficiency indicators like PCE to provide an objective numerical picture of process efficiency..

Research Location

The location of this research was carried out on the Sigli-Banda Aceh Toll Road Project, Section 1 (STA 0+000 – STA 25+000), precisely on the STA 10+250 Bridge located in Aceh Besar Regency, Aceh Province. This location is the initial part of the toll road towards Banda Aceh and has an important role because it involves work on the lower (substructure) and upper (superstructure) which requires strict inter-disciplinary coordination (BPJT, 2022).

Data Types and Sources

Understanding the difference between primary data and secondary data is very important in research because both have different functions in the analysis process. Primary data is obtained directly by researchers through surveys, observations, or experiments so that they are more relevant to the research objectives. Meanwhile, secondary data comes from existing documents or publications and serves as a support and reinforcement of the research context. Proper understanding of these two types of data helps to improve the accuracy of analysis and the quality of research results (Ali Akbar, 2024).

Primary Data

Primary data is data obtained directly from the first source related to the object of research, namely on Bridge 10 + 250 of the Sigli-Banda Aceh Toll Road Project Section 1. The primary data in this study is in the form of:

a) Information related to the stages of the design coordination workflow
b) Parties involved in design coordination
c) Activities that have the potential to become waste
d) Obstacles in the process of exchanging information

Secondary Data

Secondary data is data that has been collected and documented by other parties, then reused to support research analysis. The secondary data in this study include:

a. Scientific journal literature and theses that discuss the implementation of BIM, Lean Construction, and process efficiency.
b. Design Progress Monitoring Document (Conventional)
c. Transmittal Images to identify the number of repairs that occurred.
d. Document History in Common Data Environment (CDE/BIM 360)
e. Project whitepaper

Research Variables and Indicators

This study uses conceptual variables consisting of Lean Construction, Building Information Modeling (BIM), and design coordination process efficiency. These variables are used to analyze waste, evaluate the efficiency of the design coordination process, and examine the application of BIM in improving process efficiency. The variables and research indicators can be seen in Table 1 below:

Table 1. Research Variables and Indicators

Variable	Indicator	Operational Definition	Indicator Reference
Design Coordination Method	Conventional	The design coordination process uses 2D/CAD documents with manual or separate information exchange between parties	(Mounla et al., 2023)

Variable	Indicator	Operational Definition	Indicator Reference
	BIM-CDE	The design coordination process uses BIM and CDE as a medium for integration, storage, and exchange of design information	(Sampaio et al., 2023)
Design Coordination Effectiveness	Lead Time	Total time from document submission to design approval	(Permata & Suroso, 2024)
	Waiting time	Lead time during the design coordination process due to delays in document review, response, or approval	(Permata & Suroso, 2024)
	Value Added Activity (VA)	Activities that provide direct value to the completion of design work	(Nuciferani et al., 2023)
	Non Value Added Activity (NVA)	Activities that don't add value such as wait times and process repetitions	(Berawi et al., 2023)
	Process Cycle Efficiency (PCE)	Value-added activity time to total runtime ratio	(Daniyan et al., 2022)

Source: Researcher's Data Processing, 2026

Data Collection Techniques

To obtain valid and reliable results, the collection of data that
Precise and accurate are essential. The data collection techniques in this study include:

Documentation Studies

Data collection is carried out through the review of project documents monitoring design progress, transmittal images, meeting minutes, and other technical documents relevant to the design coordination process.

Direct Observation

Observations were made to gain an empirical understanding of the implementation of the design coordination process in the research project. Observations were made directly on the stages of activities, information flows, document distribution mechanisms, and interactions between stakeholders involved in design coordination. The observation results were used to verify the suitability of the process flow obtained from the documentation study and to strengthen the preparation of process mapping using the Value Stream Mapping (VSM) approach. In addition, observation serves as a complement to qualitative data and supports validation of the results of the quantitative analysis obtained.

Semi-Structured Interviews

Semi-structured interviews were conducted with several stakeholders involved in the design coordination process, including the document manager (DCC) and the project technical side. Interviews with DCCs are focused on validating document flows and stages of the coordination process, while interviews with technical stakeholders are used to obtain information about obstacles and activities that cause inefficiencies in the design coordination process, identify activities that contribute to the design coordination process and activities that do not provide direct value to the design results, and obtain information on process changes design coordination after the use of BIM-CDE.

Based on the results of the interviews, the identified activities were then analyzed and classified based on the concepts of Value Added (VA), Necessary but Non-Value Added (NNVA), and Non-Value Added (NVA).

Selection of Resource Persons

Interviews were conducted with key informants, namely individuals who have significant experience in the STA 10+250 Bridge project, on the Sigli-Banda Aceh Toll Road project. The criteria for resource persons include:

- Document Control Center (DCC) – Manages, controls, and distributes design documents and monitors the status of design revisions and approvals.
- Contractor (Drafter and Bim Modeler) – Compiles, updates, and coordinates models and design documents as per project requirements.
- Consultant (Geotechnical Engineer and Desaign Engineer) - Conduct technical inspections and provide technical approval for design documents before submitting them to BUJT.
- BUJT (Controller Mananger) - Performs final verification and provides design approval based on conformity with the technical provisions and project contract.

The number of speakers is planned to be 7, where this number is chosen not for generalization, but to get depth of information. This is in accordance with the opinion (Sugiyono, 2022), that in qualitative research, in-depth information takes precedence over a large number of sources

Research Instruments

Research instruments are tools used in the data collection process so that the data obtained can be presented more systematically (Arikunto, 2010). Research instruments are also used to record conditions and activities related to the attributes being studied. Thus, research instruments can be interpreted as tools used to obtain and collect data and information, both qualitative and quantitative, regarding the variables being studied.

The research instruments in this study are in the form of:

Observation guidelines

Observation guidelines are used to identify the actual conditions of the design coordination process in the research object. Observations were made on the flow of activities, the parties involved, as well as the mechanism for exchanging information and design documents. This technique is used to obtain an empirical picture of the implementation of design coordination, both in conventional and BIM-CDE-based methods.

The focus of observation is directed at the following:

- The design coordination flow starts from the process of submission, examination, revision, to approval of design documents.
- Information exchange mechanism and distribution of design documents, both conventionally and through the BIM-CDE system.
- Stakeholders involved in the design coordination process include those who conduct inspections, reviews, verification, and approval of documents.
- Design coordination process activities, such as design inspection, revision, verification, and document approval.
- Process obstacles that occur during design coordination, such as waiting time, repetition of the revision process, and information exchange constraints.
- The duration of each stage of the design coordination activity to find out the lead time of the process.

The results of the observations are used as the basis for the preparation of flowcharts, the process of coordination, design, and identification of activities in Value Stream Mapping.

Semi-Structured Interview Guidelines

The interview guidelines are prepared based on the main indicators in the conceptual framework of the research, so that they have a clear conceptual basis and can be scientifically accounted for. The interview guidelines are used to obtain information from stakeholders regarding the actual conditions of the design coordination process. Some of the question topics include:

- Design coordination flow — the mechanism for document distribution from submission, examination, revision, to design approval.

- Information exchange mechanism — the process of exchanging information and design documents in both conventional and BIM-CDE methods.
- Design coordination bottlenecks — obstacles that lead to process delays, revision repetitions, and waiting times.
- Waste—activities that lead to wasted time, process repetition, and design coordination inefficiencies.
- Effectiveness of BIM-CDE implementation — changes in the design coordination process after BIM-CDE implementation on process efficiency, lead time, and waste reduction.
- Process-critical activity — the longest-time-consuming stage of design coordination and the most influential process lead time.
- Design coordination process stakeholders — parties involved in the process of reviewing, reviewing, verifying, and approving design documents.
- Evaluation of the design coordination process — stakeholder perception of the effectiveness of BIM-CDE-based design coordination methods compared to conventional methods.

Interviews are conducted face-to-face or online (Zoom/Teams) with a duration of between 30 to 60 minutes per source, depending on the availability and depth of information provided. All interviews were recorded (with the consent of the interviewees) Interview transcripts were used as the basis for validating the design coordination process, identifying VA/NVA activities, and triangulating the results of observation and document studies.

Project Data Documentation Sheet

Documentation sheets and process activity measurements are used to record project secondary data and measure the duration of design coordination activities based on observation results, progress monitoring data, transmittal documents, and document history in BIM-CDE.

The data recorded includes:

- the date of submission of the design document;
- the date of inspection and approval;
- document revision history;
- document status on CDE/BIM 360;
- the duration of each stage of the process;
- The time difference between the stages of the design coordination process.

Data Analysis Methods

The data analysis in this study was carried out using the Lean Construction approach through the Value Stream Mapping (VSM) analysis method which is integrated with the application of Building Information Modeling (BIM) based on Common Data Environment (CDE) to evaluate the effectiveness of the design coordination process in the STA 10+250 Bridge infrastructure project of the Sigli-Banda Aceh Toll Road Project Section 1. This approach was chosen because it is able to identify activities that provide added value and activities that cause process inefficiencies, as well as evaluate changes in design coordination performance through a comparison of conditions before and after the implementation of BIM.

Identification and Mapping of Design Coordination Process

The initial stage is carried out by identifying the flow of coordination of existing designs through direct observation, data collection in the form of progress monitoring documents, image transmittals, and semi-structured interviews with related parties. The data is analyzed to find out:

a) The sequence of stages of design coordination;
b) Stakeholders involved in each process;
c) Flow of design document transfers;
d) The duration of each stage of the process.

The identification results are used to compile a flow chart of the design coordination process and determine the activities to be further analyzed.

Preparation of Value Stream Mapping (VSM)

After the design coordination process was identified, mapping was carried out using the Value Stream Mapping (VSM) approach. VSM is used to describe process flows and information in design coordination as well as identify activities that cause process delays. Mapping is carried out by outlining the main stages of design coordination into more detailed activities based on:

a) parties involved;
b) type of activity;
c) document flow;
d) process time and waiting time.

The results of the VSM mapping are used to determine the characteristics of the design coordination process and become the basis for classifying activities.

RESULTS AND DISCUSSION

Data Processing and Analysis Results

The results of data processing and analysis were carried out on the design coordination process on the Sigli-Banda Aceh Toll Road Section 1 project, especially on the STA 10+250 bridge work. The analysis compares conventional and Building Information Modeling (BIM)-based methods using the Value Stream Mapping (VSM) approach.

Process Flow Design Coordination

The design coordination process describes the flow of information exchange, inspection, and design approval involving various parties in the project, namely contractors, consultants, and Toll Road Business Entities (BUJT). This flow mapping aims to provide a comprehensive overview of the stages of the design coordination process that occurs in the field, starting from design submission to final approval. In addition, this mapping is also used as a basis for identifying potential inefficiencies in each stage of the process. This process flow is compiled based on the results of field observations and design progress monitoring documents used in the project.

Explanation of the Flow of the Design Coordination and Endorsement Process:

a) Submission of Design Documents by the Contractor
The process begins with the submission of the design by the contractor through the DCC (Document Control Coordinator) admin to the consultant for technical inspection.

b) Inspection of Design Documents by Consultant
The submitted designs are then examined sequentially by the consultant, which includes the first inspection by the Geometric Engineer (GE), followed by the Design Engineer (DE), and concluded with approval by the Lead Consultant. At this stage, an evaluation of the technical feasibility of the design is carried out. The results of the consultant's examination result in a decision whether the design meets the criteria or not. If the design has not met, it is returned to the contractor for revision and submitted back to the initial stage. If the design has been met, the process is continued to the next stage.

c) Final Design Verification by Toll Road Business Entities (BUJT)
The design that has been approved by the consultant is then carried out final verification by the Controller Mananger from the Toll Road Business Entity (BUJT). This stage aims to ensure the conformity of the design with the technical and contractual provisions. If the design does not meet the requirements, it will be returned to the contractor for revision. However, if the design has met all the conditions, it will proceed to the final approval stage.

d) Decision on the Results of Verification by Toll Road Business Entities (BUJT)

At this stage, the design document that has met all the requirements will receive final approval from the Project Director and declared approved, so that it can be used as a reference in the implementation of construction. This stage marks the end of the design coordination and ratification process.

Subactivities in the Design Coordination Process

The design coordination process shown in Figure 2 consists of several stages of activity. The breakdown of the 6 main stages into 15 process activities in design coordination was carried out based on the results of identifying the coordination flow through project documents, field observations, and semi-structured interviews with parties involved in document management, especially the Document Control Center (DCC). The results of the interview with DCC were used to validate the sequence of activities, the mechanism of document transfer and the parties involved at each stage. Here are the 15 stages of design coordination, namely:

Table 2. Design Coordination Process Subactivity

Process	Code	Activities
Design Document Submission	A1	Distribution of design documents to DCC admins
	A2	Printing and drafting of documents
	A3	Internal verification and approval of the design
Inspection by a Geometric Engineer (GE)	A4	Waiting for the inspection queue
	A5	Verify the suitability of survey data
	A6	Technical coordination and design refinement
Inspection by Design Engineer (DE)	A7	Waiting for the inspection queue
	A8	Verify the suitability of design data
	A9	Technical coordination and design refinement
Consent by Lead Consultant	A10	Waiting for the inspection queue
	A11	Checks and Approvals
Final Design Verification by Controller Manager	A12	Waiting for the inspection queue
	A13	Data conformity check on design documents
Final Approval by Project Director	A14	Waiting for the approval queue
	A15	Verification and approval of design documents

Source: Researcher's Data Processing, 2026

Time of Coordination of Design Per Activity

The process time of coordinating the design per activity can be seen in Table 3 below. The data on the time of the design coordination process per activity is data obtained from the results of document studies, as well as semi-structured interviews with parties involved in document management, especially the Document Control Center (DCC). Document studies were conducted to obtain the overall duration of the document flow, while the results of interviews with DCC were used to determine the division of time in 15 activities that occurred in the design coordination process.

Table 3. Per-activity Design Coordination Process Time

Process	Code	Activities	Time (day)
Design Document Submission	A1	Distribution of design documents to DCC admins	5
	A2	Printing and drafting of documents	5
	A3	Internal verification and approval of the design	5
	A4	Waiting for the inspection queue	15

Inspection by a Geometric Engineer (GE)	A5	Verify the suitability of survey data	25
	A6	Technical coordination and design refinement	35
Inspection by Design Engineer (DE)	A7	Waiting for the inspection queue	10
	A8	Verify the suitability of design data	15
	A9	Technical coordination and design refinement	31
Approval by Lead Consultant	A10	Waiting for the inspection queue	30
	A11	Checks and Approvals	35
Final Design Verification by Controller Manager	A12	Waiting for the inspection queue	15
	A13	Data conformity check on design documents	23
Final Approval by Project Director	A14	Waiting for the approval queue	2
	A15	Verification and approval of design documents	4

Source: Researcher's Data Processing, 2026

Analysis of Activity Duration and Lead Time of Design Coordination Process

Based on Table 4, lead time is the total process time from start to finish, which includes cycle time (completion time of one cycle) and waiting time (waiting time to the next stage). These two values were obtained from the analysis of the duration of the STA 10+250 Bridge design coordination activities in the previous subchapter. Table 4 presents data on the number of workers, cycle time, and waiting time per stage, which is then used to compile Current State Value Stream Mapping (Current State VSM) to describe existing conditions.

Table 4. Cycle Time and Waiting Time in the Design Coordination Process

Yes	Activities	Workforce	Cycle Time (days)	Waiting Time (days)
1	Design submission	1	15	0
2	GE Inspection	1	60	15
3	DE Inspection	2	46	10
4	Approval by Lead Consultant	1	35	30
5	Final Design Verification	2	23	15
6	Final Design Approval	1	4	2
		Total	183	72
		Lead Time	255	

Source: Researcher's Data Processing, 2026

Current State Value Stream Mapping

Current State Value Stream Mapping is a diagram that describes the existing conditions of the design coordination process flow based on the activity duration data that has been identified in Table 4.3. This mapping describes the flow of information and time at each stage of the process, including cycle time, waiting time, and lead time. So that it can provide a comprehensive overview of the current performance of the design coordination process. Through this mapping, it can be identified which activities provide added value and those that do not, as well as the potential for waste that occurs in the process.

Waste Identification in the Design Coordination Process

Classification of activities by added value (VA–NNVA–NVA)

Waste identification is carried out to find out activities that cause inefficiencies in a work process (Anggraini et al., 2022). According to Koskela (1992), every activity in the construction process can be classified into three categories, namely:

1) Value Added (VA): activities that directly contribute to the final product and are willing to receive rewards from customers.

2) Non-Value Added Activities (NVA): activities that do not add value to the final product, either directly or indirectly, and are considered waste that needs to be eliminated.

3) Necessary Non Value Added (NNVA): activities that are necessary to support the implementation of value-added activities (VA) but do not directly contribute to the final product in the waste identification process.

In this study, waste identification was carried out based on the results of semi-structured interviews with six respondents representing three stakeholder groups directly involved in the design coordination process, namely two representatives of the contractor, two representatives of the consultant, and two representatives of the Toll Road Business Entity (BUJT). The interview was conducted to obtain views from each stakeholder on whether the 15 activities that have been identified are included in the activities that cause waste in the design coordination process. The determination of the results of waste identification is carried out based on the most dominant opinion of all stakeholders involved in the design coordination process of the STA 10+250 Bridge.

The results of the interviews that have been conducted show that the activity validation process was carried out by representatives of the three stakeholders involved in the coordination process and examination of design documents on the STA 10+250 bridge work. Thus, conclusions and groupings that have been determined are obtained. VA, NVA and NNVA.

The determination of waste classification in activities is not only based on the respondents' intuition or experience, but uses a systematic framework on the principles of Lean Construction and the Value Stream Mapping (VSM) approach. The two main measures used to classify are:

- The direct linkage of activities to the project's functional output,
- Perception of value from end users or project stream owners (Lee et al., 2021).

Classification and Justification:

- Value Added (VA) Activities

Technical coordination and design refinement activities (A6 and A9) are categorized as Value Added (VA) because these activities directly contribute to the refinement of design documents used in the implementation of construction. Revision activities result in changes to design outputs so as to provide added value for projects and stakeholders. In the Lean Construction approach, activities that directly improve the quality and suitability of the final product are categorized as value-added activities.

In addition, the verification and approval of design documents (A15) activities are also categorized as Value Added (VA) because they produce design documents that have been validated, validated, and can be used as the basis for the implementation of construction work. Without a final verification and approval process, the design document cannot be used in the implementation of the project.

Non-Value Added (NVA) Activities

Waiting for the inspection queue (A4, A7, A10, and A12) and waiting for the approval queue (A14) are categorized as Non-Value Added (NVA) because they do not directly contribute to the design output or improve the quality of project documents.

Waiting activities occur due to the coordination and approval process that is still being carried out in stages and has not been digitally integrated. Wasting time on this activity leads to an increase in the lead time of the design coordination process without generating added value to the project. In the Lean Construction approach, waiting activities are one form of waste that needs to be reduced to improve process efficiency.

Necessary Non-Value Added (NNVA) Activities

Document distribution activities (A1), document printing (A2), internal design approval verification (A3), verification of survey data conformity and design suitability (A5 and A8), checking and approval (A11), and checking the conformity of design documents (A13) are categorized as Necessary Non-Value Added (NNVA). These activities do not directly add value to the final design results, but are still needed to support the administrative process, document control, technical coordination, and quality control of the project.

Document inspection and distribution activities are still needed to ensure design compliance with technical standards and project approval procedures, so these activities cannot be completely eliminated.

Identification of Types of Waste Based on the Seven Waste Concept

In addition to the grouping of activities into the categories of Value Added (VA), Necessary Non-Value Added (NNVA), and Non-Value Added (NVA), this study also identifies the dominant types of waste in the design coordination process. According to Ohno (1988), there are seven types of waste in the Toyota Production System (TPS) that are the basis for the Lean Construction approach, namely overproduction, waiting, transportation, overprocessing, inventory, motion, and defect (Gebeyehu et al., 2022; Guzel & Asiabi, 2022; Masmali, 2021).

Seven Waste identification is carried out on all activities that do not provide non-value added, namely NVA and NNVA activities. NVA activities are waste that is a priority to be eliminated, while NNVA activities are waste that is still necessary (necessary waste) according to current process conditions so that it is more directed to be minimized through process improvement (Nuciferani et al., 2024). VA activities are not included in waste identification because they are activities that directly contribute to value creation in the design coordination process.

Based on the results of the summary of interviews with the three stakeholders, it was analyzed using Lean theory references and four types of waste were found that are dominant in the design coordination process, namely waiting, defect, transportation and overprocessing. These three wastes have a significant impact on increasing lead time, revision of work, and low efficiency of the design coordination process.

Waste Analysis with Process Activity Mapping (PAM)

After identifying waste and grouping activities into the categories of Value Added (VA), Necessary Non-Value Added (NNVA), and Non-Value Added (NVA) based on the results of semi-structured interviews with the three stakeholders, the next stage is to analyze the design coordination process using Process Activity Mapping (PAM).

PAM is used to map activities based on the classification of Operation (O), Transportation (T), Inspection (I), Storage (S), and Delay (D). PAM serves to show changes in process flow before and after repairs, so that it can be proven that activities have been successfully eliminated to improve process efficiency. The PAM results are then used to calculate the Process Cycle Efficiency (PCE), so that the level of efficiency of the design coordination process can be determined under existing conditions.

Based on the results of Process Activity Mapping (PAM), a recapitulation of activities and time duration in each process category was carried out to describe the characteristics of the overall design coordination flow.

Based on the results of Process Activity Mapping (PAM), the distribution of activities was obtained based on the classification of Value Added (VA), Necessary Non Value Added (NNVA), and Non Value Added (NVA).

The results illustrate a comparison based on the number of activities carried out by VA by 20%, NVA by 33% and NNVA by 47%.

The results show a time comparison based on the total duration of the design coordination process on the 10+250 bridge of 255 days. So the proportion of VA is 27.45% with a duration of 70 days, NVA is 28.24% with a duration of 72 days and NNVA is 44.31% with a duration of 113 days.

Process Cycle Efficiency (PCE)

Based on the recapitulation of the results of Process Activity Mapping (PAM) in Table 4.7, a comprehensive picture of the time distribution in each activity in the design coordination process is obtained. To quantitatively determine the level of process efficiency, Process Cycle Efficiency (PCE) is calculated, which is a comparison between the Value Added activity time and the total overall process time (Lead Time). The PCE value is used as an indicator to evaluate the effectiveness of the process in generating added value compared to the total time required during the process. Next, the PCE value is calculated using the following equation:

$$\text{PCE} = \frac{\text{Total Value Added Time}}{\text{Total Production Lead Time}}$$

$$\text{PCE} = \frac{70 \text{ Days}}{255 \text{ Days}}$$

$$= 27.45\%$$

The PCE value of 27.45% shows that the proportion of value-added activity is still relatively low compared to the overall process time (lead time), so the design coordination process under existing conditions still needs improvement to improve workflow efficiency and reduce waste.

Improvement of BIM-Based Design Coordination Process (BIM Implementation in Design Coordination Process)

Based on the results of waste identification in Table 4.5, several activities were found that caused process inefficiencies, namely waiting, defect, transportation and overprocessing, resulting in an increase in non-value-added activities (Non Value Added) in the design coordination process. Therefore, the proposed improvement is focused on these three categories by optimizing Building Information Modeling (BIM) technology. Based on the results of waste identification through Value Stream Mapping, a proposal was prepared to improve the BIM-based design coordination process. The proposal is then validated through interviews with related parties to ensure the suitability of the implementation in the project conditions.

The application of Building Information Modeling (BIM) in the design coordination process is directed to reduce various types of waste that occur during the implementation of coordination between stakeholders. The most dominant types of waste include waiting, transportation, defect, and overprocessing. Each type of waste has different problem characteristics so it requires a repair strategy supported by appropriate BIM features.

In the waiting category, waste occurs in activities A4, A7, A10, A12, and A14. This condition is caused by the design inspection and approval process that is still carried out in stages so that each stage must wait for the completion of the process by previous stakeholders. In addition, the delivery of information and follow-up between parties has not taken place in real-time, thus extending the waiting time in the coordination process. To overcome these problems, the process of document distribution, review, and approval is integrated into one digital platform so that all stakeholders can access information in real-time and provide follow-up without having to wait for manual document distribution. The implementation of these improvements is supported by the use of Common Data Environment (CDE), Digital Review, and Automatic Notification.

In the transportation category, waste was found in activities A1 and A3. The main problem comes from the distribution of documents that are still carried out manually from one stakeholder to another. This increases the risk of delayed distribution, loss or scattering of documents, and uncontrolled use of document versions. Therefore, improvements are made by utilizing the Common Data Environment (CDE) as a centralized document repository so that the entire document distribution process is carried out digitally, documented, and all parties access documents from the same source.

In the defect category, waste occurs in activities A5, A8, and A13. At the verification and inspection stage, there are still discrepancies in survey data, design information, and documents so that the documents must be returned for repair before they can be processed to the next stage. This condition resulted in rework and extended the duration of design coordination. Improvement efforts are carried out by improving inter-disciplinary coordination through an integrated BIM model, validating data from the initial stage, and implementing clash detection to identify potential conflicts before entering the implementation stage. BIM features that support this fix include Common Data Environment (CDE) and Clash Detection using Autodesk Navisworks.

Meanwhile, in the overprocessing category, waste was found in activities A2 and A11. The problem occurs because the coordination process still involves printing documents, manual administration, and approval mechanisms that are carried out conventionally. Each revision of the document requires that the printing and administration process be repeated, adding activities that do not directly add value to the design results. Improvements are made by reducing administrative and printing activities through the implementation of digital documents, electronic approvals, and integrated document management in the Common Data Environment (CDE). The implementation of these improvements is supported by the use of the Common Data Environment (CDE) and the Electronic Approval feature in BIM 360 Docs. Thus, the application of BIM not only improves the efficiency of design coordination, but is also able to minimize non-value-added activities, speed up the flow of information, and reduce the potential for errors during the design coordination process.

Future State Value Stream Mapping

Based on the proposed improvements through the implementation of BIM Common Data Environment (CDE), the following is presented future Process Activity Mapping (PAM) which shows changes in process flows and reductions in activities that are not added value.

Process Activity Mapping (PAM) analysis in this study was used to evaluate changes in activity flows before and after the implementation of BIM Common Data Environment (CDE). The mapping results show that some Transportation (T) category activities, such as Design document distribution (A1) and Design internal verification and approval (A3) activities can be eliminated as they have been replaced by an integrated platform that can be accessed in real-time. Furthermore, a recapitulation of the number of activities and duration in each process category was carried out to describe the characteristics of the design coordination flow in future state conditions.

The results of the Future Process Activity Mapping (PAM) show that the total lead time of the design coordination process has decreased from 255 days to 134 days. The decline mainly occurred in Non Value Added (NVA) activities, especially delay activities that were successfully reduced through the implementation of BIM such as Common Data Environment (CDE), digital review, and integrated model coordination. The percentage of NVA activity decreased from 28.24% to 18.66%, while the percentage of Value Added (VA) activity increased from 27.45% to 31.34%. Although the percentage of Necessary Non Value Added (NNVA) increased from 44.31% to 50.00%, these activities are still required in the design inspection and approval process so as to continue to support the sustainability of the overall design coordination process. Thus, PAM serves as a tool to demonstrate the elimination of non-value-added activities and prove an increase in process efficiency due to the implementation of BIM CDE.

Furthermore, based on the recapitulation of the results of Process Activity Mapping (PAM) after improvements in Table 4.10, it is known that the level of process efficiency quantitatively calculated using the Process Cycle Efficiency (PCE) Table obtained the following PCE values:

$$\text{PCE} = \frac{\text{Total Value Added Time}}{\text{Total Production Lead Time}}$$

$$\text{PCE} = \frac{42 \text{ Days}}{134 \text{ Days}}$$

$$= 31.34\%$$

Based on these results, it can be concluded that the use of BIM has a positive impact on improving the efficiency of the design coordination process. The increase in the value of PCE from 27.45% to 31.34% indicates that the proportion of value-added activities in the process flow has become more dominant than the initial condition. This condition shows that the work process becomes more effective due to the reduction of non-value added activities such as delays in information distribution, repeated revisions, and coordination waiting times. Thus, BIM not only functions as a modeling medium, but also plays a role in improving the quality of information flow and the effectiveness of the project design coordination process.

Based on the results of the improvements in the future PAM, Future State Value Stream Mapping was then prepared as a proposal to improve the design coordination process based on Lean Construction and Building Information Modeling (BIM). The improvement is focused on reducing Non Value Added (NVA) activities by utilizing Common Data Environment (CDE), digital review, clash detection, and automated checking to improve information integration and accelerate the coordination process between stakeholders. Future State Value Stream Mapping can be seen in the following illustration.

The results showed that the implementation of BIM was able to reduce the lead time from 255 days to 134 days (47.45%), so that the process of inspection, coordination, and design approval could be completed faster. In addition, the PCE value increased from 27.45% to 31.34%, which indicates an increase in process efficiency through an increase in the proportion of activities that provide Value Added (VA) value to the overall process flow in design coordination.

The results showed that the implementation of BIM-CDE increased the proportion of VA activity from 27.45% to 31.34% and decreased the NVA from 28.24% to 18.66%. The increase in the proportion of VA occurred due to the reduction of activities that did not provide added value, especially waiting time, as well as the reduction of document transportation activities through the digitization process using BIM. In addition, the use of BIM- Common Data Environment (CDE) also speeds up the process of coordination, examination, and design approval through the provision of information that is integrated in one platform. This condition causes lead time to be significantly reduced so that the proportion of activities that add value to the entire process becomes larger. For NNVA though the percentage shows the proportion of each activity to the total lead time. Although the proportion of NNVA increased from 44.31% to 50.00%, the duration decreased from 113 days to 67 days. The increase in proportion occurred because the total lead time was significantly reduced after the implementation of BIM–CDE.

Based on the Future State Map shown in Figure 4.7, information was obtained that the application of BIM-based design coordination analyzed using the Value Stream Mapping (VSM) approach was able to improve the efficiency of the design coordination process flow. The results of the analysis show that process digitization through BIM can reduce coordination barriers, speed up the information exchange process, and minimize waiting time at the stages of submission, inspection, and design revision. This condition caused the process duration which originally reached 255 days to be reduced to 134 days, resulting in a time saving of 47% from the time before using BIM.

Discussion

Integration of Lean Construction and Building Information Modeling

This study uses the Lean Construction approach through Process Activity Mapping (PAM) and Value Stream Mapping (VSM) as an analysis tool to evaluate the efficiency of the design coordination process in bridge work. This approach is used to identify activities that provide added value and do not provide added value, analyze waste, and measure the performance of the design coordination process. The results of the analysis were then used to evaluate the potential application of Building Information Modeling (BIM) as a solution in improving information integration, coordination between stakeholders, and the effectiveness of the process of examining and approving design documents compared to conventional design coordination methods.

a) The role of Lean Construction in identifying waste design coordination processes

The Lean Construction approach through the identification of seven wastes, Process Activity Mapping (PAM), and Value Stream Mapping (VSM) is used as an analysis tool to systematically evaluate the design coordination process. The analysis was used to identify waste, classify activities into Value Added (VA), Necessary Non-Value Added (NNVA), and Non-Value Added (NVA) categories, and map activities based on Operation, Transportation, Inspection, Storage, and Delay (OTISD) categories. The results of the analysis show that waste that occurs in the design coordination process is waiting, defect, transportation and overprocessing, which contributes to high lead time and low process efficiency. In addition, PAM shows that there are waiting activities, repeated design revisions, and document inspection and approval processes that are still carried out manually and gradually.

b) The role of BIM in supporting the improvement of the design coordination process

Based on the results of waste identification using the Lean Construction approach, the application of Building Information Modeling (BIM) is used as a proposed improvement to improve the efficiency of the design coordination process. BIM implementation is carried out through the use of Common Data Environment (CDE), digital review, clash detection, and cloud collaboration that supports information integration and coordination between project stakeholders.

In the existing conditions, the design coordination process is still dominated by waiting activities, repeated revisions, and manual document distribution and checking. This condition causes high lead times and low efficiency of the design coordination process.

Through the application of BIM, the process of information exchange, coordination, examination, and approval of documents can be carried out in a more integrated manner so that it can reduce waste in the form of waiting, defects, and overprocessing (Kermanshahi et al., 2020; Kaur et al., 2025; Rakib et al., 2019). These improvements have an impact on reducing waiting times, decreasing the need for design revisions, and increasing the smooth coordination between stakeholders. Thus, BIM plays a role as a process improvement solution that supports the improvement of design coordination efficiency compared to conventional methods.

Key Findings

Based on the results of the research, several key findings were obtained as follows:

1. The existing design coordination process still contains waste dominated by waiting, defects, and overprocessing. Identification through Value Stream Mapping (VSM) shows that process activities are still dominated by the Necessary Non-Value Added (NNVA) and Non-Value Added (NVA) categories.
2. The level of efficiency of the design coordination process shows that lead time is still relatively high with a smaller proportion of value-added activities (VA) compared to activities that do not provide added value. The results of measurements using Process Cycle Efficiency (PCE) show that there is still an opportunity to improve process efficiency.
3. The application of BIM-CDE through the Lean Construction approach shows an increase in the efficiency of the design coordination process through the reduction of non-value-added activities, acceleration of information flow, and improvement of process performance indicators compared to conventional design coordination methods.

Comparison with Previous Research

The results of this study are in line with several previous studies that stated that BIM plays a role as lean tools in the design phase through the application of clash detection, model coordination, and digital coordination to reduce waste Aziz et al. (2024). In addition, Cunha et al. (2025) show that the Value Stream Mapping (VSM) approach is effective in identifying waste in the construction design process.

The difference between this research and the previous research lies in the focus of the research which specifically analyzes the process of coordinating the design of bridge work using the Lean Construction approach through PAM and VSM, and integrates it with the proposal for BIM optimization. The study also used the classification of VA, NNVA, and NVA activities as well as Process Cycle Efficiency (PCE) calculations to evaluate the efficiency level of the design coordination process.

Research Limitations

In the implementation of this research, there are several limitations that need to be considered as the limit of interpretation of the research results, namely:

1. This study uses a case study approach on the Sigli-Banda Aceh Toll Road Project Section 1, especially the process of coordinating the design of the STA 10+250 Bridge work, so that the results of the study are not intended to be generalized to all construction projects.
2. Activity identification, VA–NNVA-NVA classification, and waste identification are based on observation results, documentation studies, and semi-structured interviews with the stakeholders involved, so that the results of the study are influenced by the actual conditions and perceptions of respondents at the time of the study.
3. The evaluation of process efficiency in this study is limited to the indicators of lead time, waiting time, proportion of VA–NNVA–NVA activities, and Process Cycle Efficiency (PCE), so it does not include an analysis of cost, design quality, and overall project performance.
4. The analysis of the application of BIM-CDE in this study is focused on aspects of design coordination and information flow, so that it has not evaluated the application of BIM at the construction and operational stages of the project.

CONCLUSION

Based on the results of the research, the design coordination process in toll road infrastructure projects still contains waste in the form of waiting, transportation, overprocessing, and defects that cause an increase in lead time and reduce process efficiency. Analysis using Process Activity Mapping (PAM) shows that the existing condition has a lead time of 255 days with a composition of Value Added (VA) of 27.45%, Non-Value Added (NVA) of 28.24%, and Necessary Non-Value Added (NNVA) of 44.31%, resulting in a Process Cycle Efficiency (PCE) of 27.45% which shows that the process is still inefficient. The application of Building Information Modeling (BIM) through Common Data Environment (CDE), digital review, and clash detection has been proven to be able to improve the efficiency of design coordination by reducing lead time to 134 days (down 47%), increasing PCE to 31.34%, and reducing the proportion of NVA activities to 18.66%. Theoretically, this study strengthens the concept of Lean Construction and BIM integration, where the Value Stream Mapping (VSM) and PAM approaches are effective in identifying waste, while BIM plays a role as a solution to reduce waste, improve the quality of information flow, and accelerate coordination between stakeholders, thereby supporting increased efficiency of the construction process. Based on the research findings, it is recommended that project stakeholders adopt BIM-CDE implementation from the early planning phase and integrate digital review and clash detection to reduce waiting time and design revisions; that policymakers develop guidelines and standards for BIM implementation in toll road projects and encourage Lean Construction adoption; and that future researchers conduct similar studies on different project types, expand analysis to include cost and quality indicators, and develop predictive models for design coordination efficiency based on BIM implementation parameters.

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