International Research Journal of Engineering, IT & Scientific Research
Available online at https://sloap.org/journals/index.php/irjeis/
Vol. 10 No. 2, March 2025, pages: 47-64
ISSN: 2454-2261
https://doi.org/10.21744/irjeis.v11n2.2506

Development of Risk-Based BIM Integrated Material Resource Control Procedures to Improve Time Performance on Public Facility Construction Projects in the Seribu Islands

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Article history:

Submitted: 27 January 2025
Revised: 09 February 2025
Accepted: 18 March 2025

Keywords:

material resource control;
public facilities construction project;
risk-based BIM;
time performance;

Abstract

This study aims to develop a material resource control procedure from a contractor's perspective that is integrated with 4D and 5D Building Information Modeling (BIM) technology, based on dominant risks at each stage, to improve project time performance. The research approach includes the identification and analysis of dominant risks, integration of activities with BIM, and data processing using the Delphi method and statistical analysis with SPSS version 27. The results of the study showed seven improvements to existing activities and the addition of nine new activities at the stages of shipping, receiving, storing, distributing, and using materials. Of all these activities, twelve can be integrated with BIM technology according to the results of risk validation. To ensure the feasibility of implementation, the developed procedure was tested through a case study on the Public Facility Construction (PFU) project in Gusung Klanceng. The results of the case study showed that the integrated BIM risk-based procedure was able to improve the accuracy of material requirement estimates and control project schedule changes, thereby supporting the achievement of time targets more optimally.

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1 Introduction

The development of public facilities is one of the strategies of the DKI Jakarta Provincial Government in improving the welfare of the community in the Seribu Islands region. Through Sub-Department X, various projects have been implemented, such as the construction of environmental roads, toilets, community halls, canopies, gazebos, green open spaces, plazas, gates, and other supporting facilities for settlements. However, the implementation of these projects faces complex geographical challenges because the locations are spread across a cluster of small islands. In addition, the consistent use of low-qualified contractors also becomes an obstacle, especially in terms of material resource management (Yang et al., 2010).

Problems in material control are becoming increasingly apparent because most small-scale contractors do not have standard procedures but instead rely on undocumented field practices (Donyavi & Flanagan, 2009). Analysis of PFU projects in the 2021–2023 budget years shows that more than 30% of projects experienced delays, the majority of which were caused by material-related problems, such as late delivery, non-conformity to specifications, damage, and shortages of materials at the project site. This condition not only reduces implementation efficiency but also has an impact on the contractor's reputation and financial burden.

In response to these problems, the use of technology such as Building Information Modeling (BIM) has proven effective in increasing the efficiency of project control. BIM integration, especially in the 4D (project schedule) and 5D (material quantity and cost) dimensions, allows for dynamic schedule visualization, strengthens coordination between stakeholders, and improves the accuracy of material requirement estimates (Eastman, 2011; Mi & Li, 2024). In addition, BIM also supports a faster decision-making process that is responsive to changes in project conditions (McGraw, 2017), making it a potential solution in overcoming material control problems.

However, the application of BIM in material control on small-scale projects is still very limited, especially because there is no systematic procedure that can be used as a reference in the field (Porwal & Hewage, 2013). Therefore, this study aims to develop a material resource control procedure from the contractor's perspective, which is integrated with 4D and 5D BIM technology, and is compiled based on the identification of dominant risks at each stage of implementation, including the process of sending, receiving, storing, distributing, and using materials. The resulting procedure is expected to be a practical and applicable technical guide in improving the performance of construction projects time, especially in public facility development projects in island areas with accessibility challenges such as the Seribu Islands.

The objectives of this research are as follows: 1) Identifying the form of organizational structure and job description of the implementation of the material resource control process in the PFU project in the Seribu Islands. 2) Identifying business processes and activities that occur in the implementation of the material resource control process on the PFU project in the Seribu Islands at this time. 3) Identifying the completeness required (input) and the output that must be achieved (output) in each activity in the implementation of the material resource control process in the PFU project in the Seribu Islands. 4) Identifying the communication flow in the implementation of the material resource control process in the PFU project in the Seribu Islands. 5) Identifying risk factors in the implementation of the material resource control process in the PFU project in the Seribu Islands. 6) Identifying the causes, preventive actions, impacts, and corrective actions that can be taken to anticipate dominant risks in the implementation of the material resource control process on the PFU project in the Seribu Islands. 7) Identifying the role of BIM that can be applied to the implementation of material resource control processes. 8) Developing SOP for implementing BIM-integrated risk-based material resource control process on PFU project in Seribu Islands. 9) Analyze the relationship model between material resource control processes, risk factors, and the role of BIM on project time performance.

Literature review

Public Facilities Development Project (PFU) in Seribu Islands

The construction of Public Facilities (PFU) in the Seribu Islands is the task of the Sub-dept. X, which is carried out following DKI Jakarta Governor Regulation No. 57 of 2022 and No. 90 of 2018, with a focus on improving the quality of settlements through physical environmental planning. As a project in an archipelago, its implementation faces major challenges, especially in controlling material resources due to limited access and logistics (Ralahalu & Jinca, 2013). This condition requires an effective and structured material control system so that the project can run on time, according to specifications and budget.

Project Time Performance

In PMBOK 6th Edition, time management is an aspect of project management that includes the processes required to ensure that the project is completed on time. PTime performance measurement can be done using the Earned Value Management (EVM) method, which is a method that combines the measurement of work that has been completed with the costs and time spent on the work (Project Management Institute, 2000). EVM involves several key components, namely: *Planned Value* (PV), *Earned Value* (EV), and *Actual Cost* (*AC*)
By using the components above, time performance measurement can be done in two ways, namely:

1) Schedule Variance (SV)
   Measures the difference between the expected value of work completed (EV) and the planned value (PV). The formula is:
   SV = EV – PV
   Information:
   SV = 0 : Project is running on time
   SV < 0 : Projects are running slower
   SV > 0 : Projects are running faster
2) Schedule Performance Index (SPI)
   Measures the time efficiency of work completed (EV) compared to planned (PV). The formula is:
   SPI = EV/PV
   Information:
   SPI = 1 : Project is running on time
   SPI < 1 : Projects are running slower
   SPI > 1 : Projects are running faster

Organizational Structure and Job Description of Contractors on the PFU Project in the Seribu Islands

Based on Presidential Regulation Number 12 of 2021, projects with a value of under IDR 15 billion can only be participated by contractors with small business qualifications. Therefore, the organizational structure of the contractors used is generally simple, including positions with qualification levels that refer to the Indonesian National Work Competency Standards (SKKNI), namely: Project manager, Field manager, Logistics manager, Field implementer, and Foreman.

Business Processes, Activities, Inputs, and Outputs in the Implementation of Material Resource Control Processes

1) Business Process
   Control is a process to achieve a goal consisting of three main steps, namely measurement, evaluation, and correction (Kerzner, 2025). Material management is a management system that functions to plan and control materials and equipment with the appropriate quality and quantity promptly, obtained at a reasonable cost, and available when needed (Bell & Stukhart, 1986). The scope of material management is grouped into several stages, namely, planning, vendor evaluation, purchasing, shipping, receiving, storage, distribution, and use of materials. Referring to the limitations of the study, namely the scope of project implementation, the stages of material resource control in this study are: Material delivery stage; Material acceptance stage; Material storage stage; and the stage of material distribution and material use.
2) Activity
   Activities are a series of actions that occur in each process to achieve certain results (Harrington, 1991). Referring to the explanation of the business process in sub-chapter 4.4.1, the series of activities in the material resource control process at the PFU project implementation stage in the Seribu Islands are as follows:
   a. Material Delivery Stage
      a) Ensure delivery of materials to the port;
      b) Receiving materials at the port;
      c) Conduct conformity checks on materials received; and
      d) Delivering materials from the port to the project site.

b. Material Receipt Stage
   a) Receiving materials at the project site;
   b) Conduct conformity checks on materials received; and
   c) Create material receipt reports.
c. Material Storage Stage
   a) Prepare material storage layout;
   b) Carrying out material transfers to storage areas; and
   c) Conducting material quantity checks after being stored in the storage area.
d. Distribution and Material Use Stage
   a) Mobilizing materials to the work location;
   b) Conduct supervision of material usage;
   c) Create daily material usage reports; And
   d) Create material availability reports (stock take).

3) Input and Output

Input is all the resources needed to start an activity, such as data or information, while output is the final result produced from the activity (Harrington, 1991). In the context of material resource control, PMBOK 6th Edition explains that the input in the control resources process covers: Project management plan; Project documents; Project performance data, Agreement, and Organizational process assets. Whereas Output in the control resources process generally includes: Project performance information, Change requests, Project management plan updates, and Project document updates.

Communication Flow in the Implementation of Material Resource Control Process

Organizational communication is the process of conveying messages related to the work and activities of the organization through official channels, which can flow downward (Downward communication), upward (Upward communication), or horizontally (Lateral communication) (Greenberg & Baron, 2008). The communication flow in the project needs to be structured so that each party understands their role, one of which is by using the RACI Matrix (Project Management Institute, 2000), which consists of four main elements as follows:

1. R : Responsible - The party who carries out the task directly;
2. A : *Accountable*- The party who is fully responsible for the results of the work;
3. C : *Consulted*- Parties involved to provide input or suggestions; and
4. I : *Informed*- Parties who need to know the progress or results of event tasks but are not directly involved

Development of Standard Operating Procedures (SOP)

Standard Operating Procedures (SOP) are written instructions that are standardized to regulate the implementation of organizational activities consistently (Atmoko, 2011; Rahmawati et al., 2024). SOPs are useful in standardizing work, efficiency, effectiveness, accountability, and legal protection. SOPs are classified based on the nature of the activity (technical and administrative) and the scope of the activity (final and partial). The SOP format can be arranged in the form of simple text, sequential stages, graphs, or flow charts, depending on the complexity of the activity. The principles of compiling SOPs include ease, efficiency, alignment, measurability, flexibility, user orientation, and compliance and legal certainty (PANRB, 2012).

Material Resource Control Process Risk Management

Project risk management aims to identify, evaluate, and control risks to minimize negative impacts and optimize the chances of project success (Project Management Institute, 2000). This process includes several stages, starting from planning, risk identification, qualitative and quantitative analysis, response planning and implementation, to overall risk control. In the context of material resource control in the PFU project in the Seribu Islands, various major risks arise at four crucial stages, namely shipping, receiving, storing, and distributing and using materials. These risks include late delivery, material damage, labor shortages, recording errors, and poor coordination between the parties involved. Therefore, the implementation of effective risk management is key to maintaining the smooth flow of material logistics, increasing cost and time efficiency, and preventing disruption to the overall project schedule (Cui et al., 2023; Yıldız et al., 2024).

Building Information Modelling (BIM)

Building Information Modeling (BIM) is an integrated approach in planning, implementing, and managing construction projects based on a comprehensive and collaborative information model (BIM & RAKYAT, 2018). The development of BIM from 3D dimensions (spatial visualization) to 4D (scheduling) and 5D (cost estimation) provides broader benefits in project management. In the 4D dimension, the role of BIM includes: Project stage simulation, *Lean scheduling*, and Visual validation. Meanwhile, in the 5D dimension, the role of BIM includes: real-time modeling, Quantity extraction, Verification of fabrication model, *Value engineering*, and Prefabricated solutions.

2 Materials and Methods

The following are the stages of research compiled by the author in conducting this research. These stages describe the workflow applied to answer the research objectives that have been explained previously.

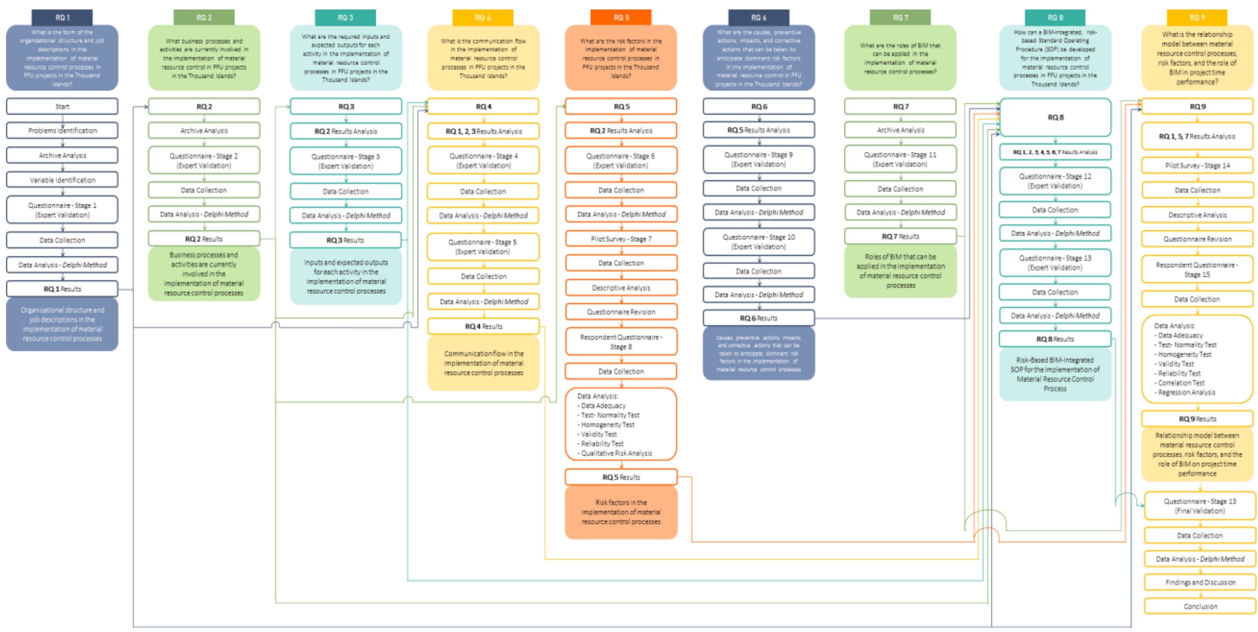

Figure 1. Research Process Flowchart

3 Results and Discussions

A. *Organizational Structure and Job Description of the Implementation of the Material Resource Control Process on the PFU Project in the Seribu Islands*

Based on the results of data analysis, it is known that the organizational structure in the material resource control procedure still needs to be improved, especially through the addition of logistics staff positions. The addition of this role is important to support logistics managers in handling the technical aspects of material distribution, especially in projects in the Seribu Islands which have more complex shipping routes than projects on land. Therefore, the organizational structure in the material control process of the PFU project in the Seribu Islands is adjusted to 6 (six) main positions with their respective duties and responsibilities referring to the

Indonesian National Work Competency Standards (SKKNI) for the main group of building construction, namely: Project manager; Field manager; Logistics manager; Field Executive; Logistics staff; and Foreman.

B. *Business Processes and Activities in the Implementation of Material Resource Control Processes in the PFU Project in the Seribu Islands*

The results of the data analysis show that the material control process in the PFU project in the Seribu Islands consists of five main business processes, namely: Material delivery stage; Material acceptance stage; Material storage stage; Material distribution stage; and Material usage stage.

The distribution and use of materials are separated because each has a different workflow, responsibility, and risk. In addition, the analysis results also identified 12 (twelve) new activities grouped into 5 (five) categories, namely coordination, supervision of physical transfer of materials, preparation and storage of materials, inspection and verification of documents, and planning of material requirements. The addition of these activities aims to clarify and strengthen the implementation of material control, especially in facing logistical challenges in projects in the archipelago. With these additions, the total activities in the material resource control process becomes 26 (twenty-six).

C. Input and Output Documents in Material Resource Control Activities in the PFU Project in the Seribu Islands

Based on the results of data analysis, each activity in material resource control has specific inputs and outputs, with a total of 69 input documents and 32 output documents. The success of material control is highly dependent on proper document and information management at each stage.

D. Communication Flow in the Implementation of the Material Resource Control Process in the PFU Project in the Seribu Islands

The results of the data analysis produced 5 (five) communication flowcharts based on the material control business process, covering the stages of sending, receiving, storing, distributing, and using materials in the PFU project in the Seribu Islands. This flow is arranged using the RACI Matrix to map the role of each position in detail, following the results of RQ 1 related to job descriptions in the implementation of the material resource control process. The following is the communication flow of the 5 (five) stages:

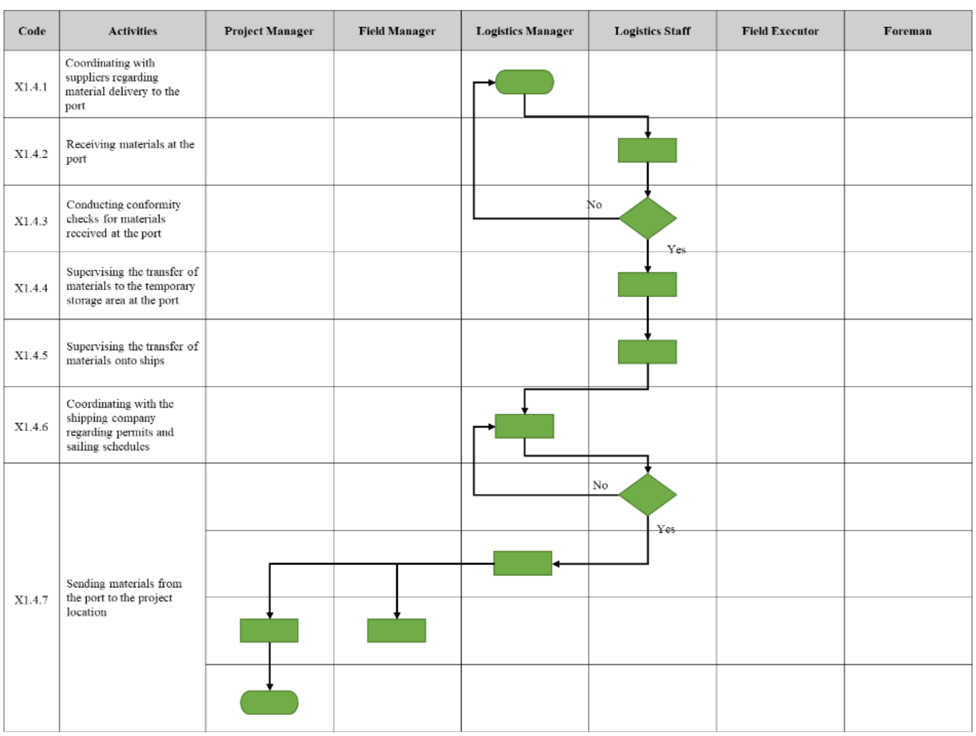

Figure 2. Material Delivery Stage Communication Flow

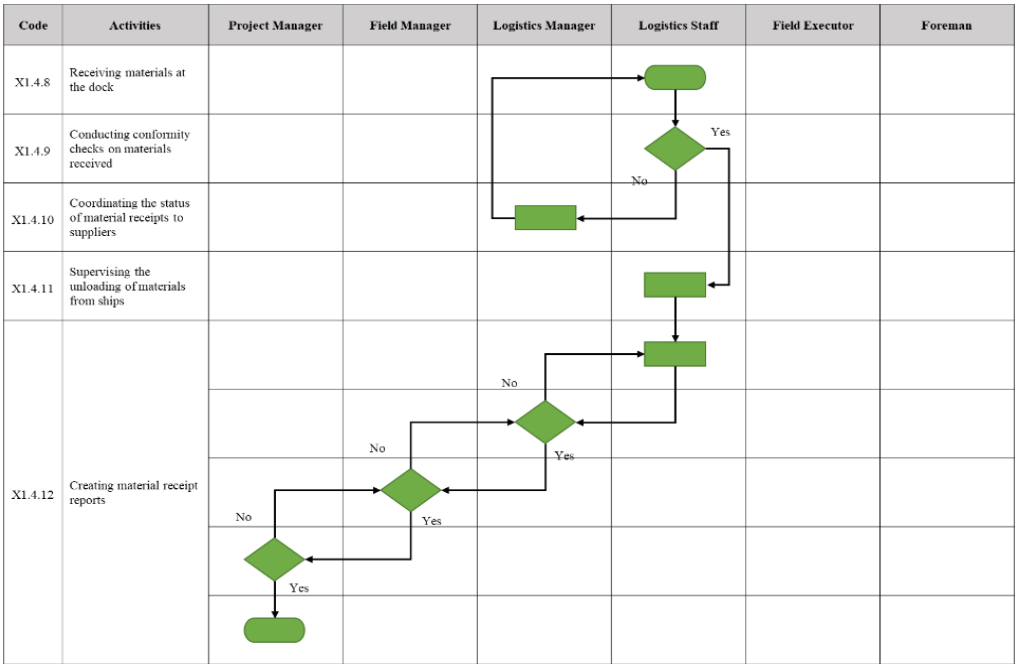

Figure 3. Material Receiving Stage Communication Flow

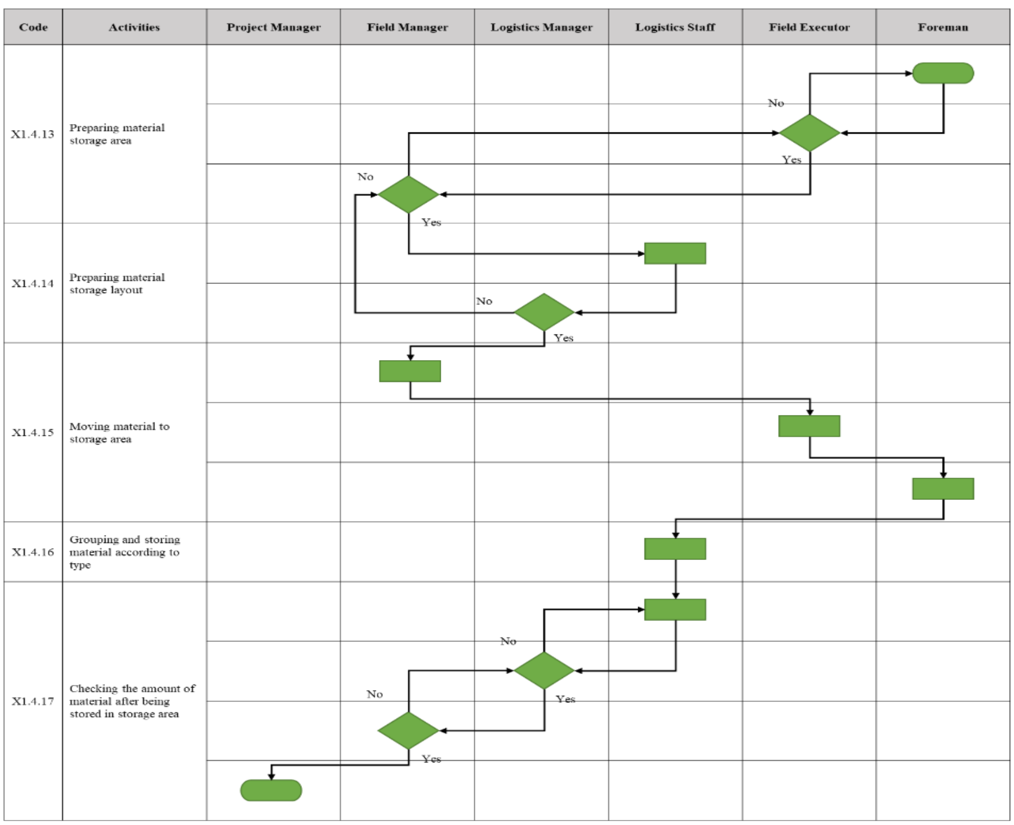

Figure 4. Material Storage Stage Communication Flow

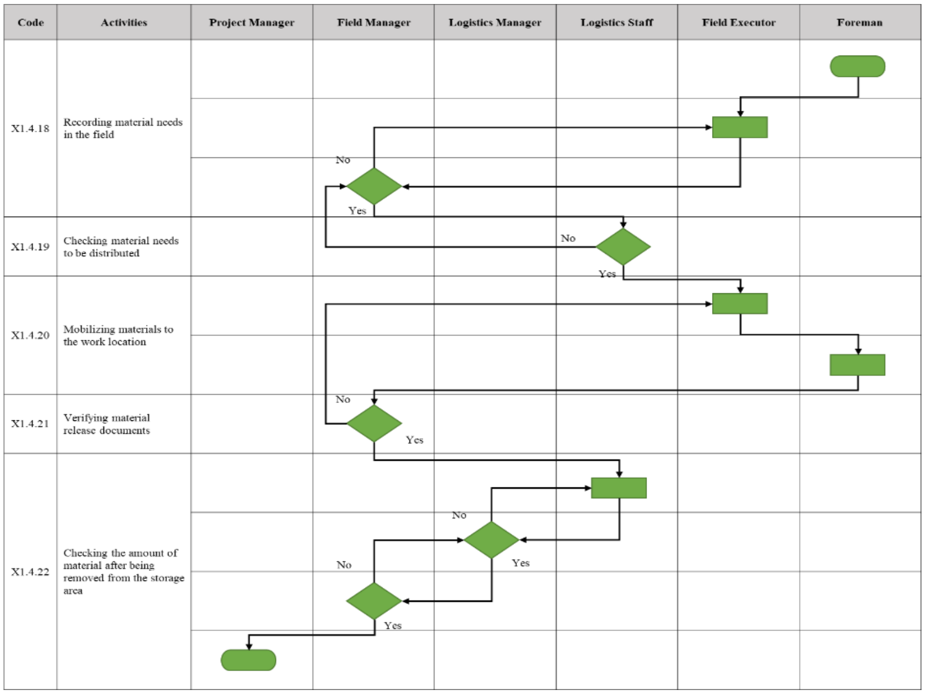

Figure 5. Material Distribution Stage Communication Flow

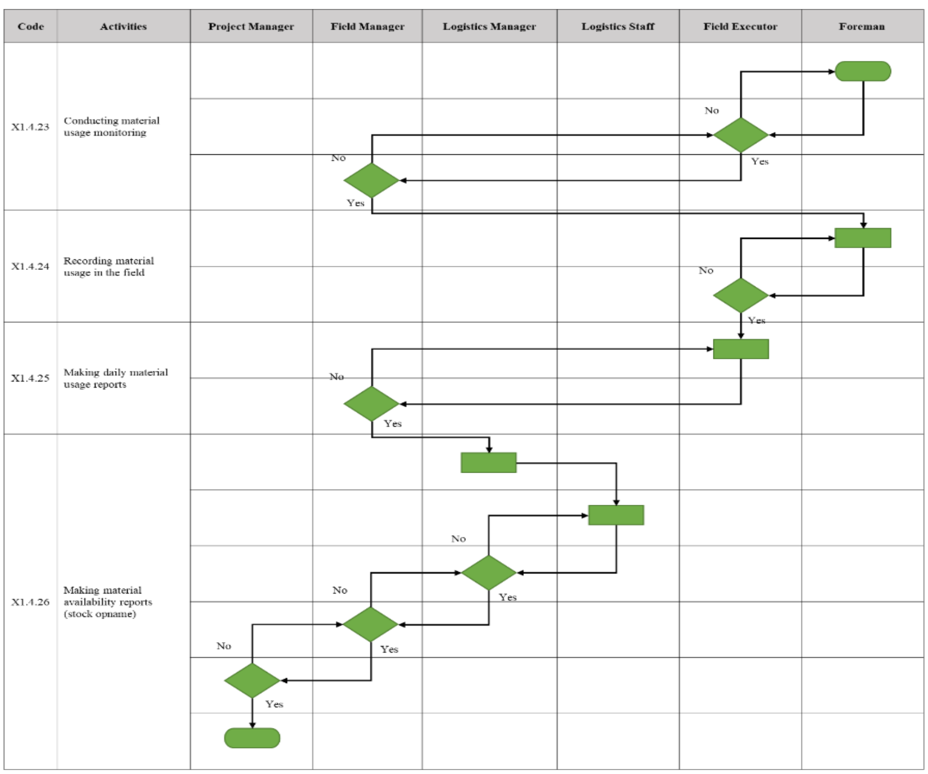

Figure 6. Material Usage Stage Communication Flow

E. Risk Response Actions in the Implementation of Material Resource Control Processes in the PFU Project in the Seribu Islands

Based on the results of the risk analysis, 4 (four) risk factors were obtained with a high category, namely X2.1, X2.7, X2.10, and X2.25 which came from 3 (three) different material resource control processes, namely the material delivery stage, the material receipt stage, and the material distribution and use stage.

Table 1
Risk Category and Value

Process	Code	Risk Potential	Risk Category
Material Delivery Stage	X2.1	Material delivery from supplier location to port is not on schedule	High
	X2.7	Delivery of materials from the port to the dock is not on schedule	High
Material Receipt Stage	X2.10	Materials arrived at the dock later than planned	High
Distribution and Material Use Stage	X2.25	Lack of stock of materials	High

F. Risk Response Actions in the Implementation of Material Resource Control Processes in the PFU Project in the Seribu Islands

The results of data analysis using the Risk Breakdown Structure (RBS) approach and pattern recognition show that to anticipate 4 (four) high category risks in the material resource control process including the stages of sending, receiving, distributing, and using materials, 7 (seven) main causes, 9 (nine) preventive actions, 5 (five) potential impacts, and 6 (six) relevant corrective actions can be identified.

G. The Role of BIM in the Implementation of Material Resource Control Processes in the PFU Project in the Seribu Islands

The results of the research and expert validation show that BIM technology, especially the 4D and 5D dimensions, plays an important role in supporting material resource control in the PFU project in the Seribu Islands. The role of BIM 4D consists of 2 (two) sub-variables, namely lean scheduling and visual validation, with each having 1 (one) indicator that focuses on the punctuality of material arrival and verification of conformity between schedule and implementation in the field. Meanwhile, BIM 5D includes 4 (four) sub-variables, namely real-time modeling, quantity extraction, manufacturing model verification, and value engineering, with a total of 8 (eight) indicators that support the accuracy of cost estimates, automatic quantity calculations, material specification validation, and cost efficiency through design alternatives (Amelia & Latief, 2022).

H. Development of Risk-Based BIM Integrated Material Resource Control Procedures

The development of Standard Operating Procedures (SOP) for material resource control in the PFU project in the Seribu Islands was carried out through a risk-based approach and the integration of Building Information Modeling (BIM) technology into its activities. This development process resulted in 17 (seventeen) development actions consisting of 7 (seven) improvements to existing activities and the addition of 9 (nine) new activities. Of all these activities, 12 (twelve) of them were integrated with risk-based BIM.

To ensure that the integration runs optimally, a case study was conducted on the Gusung Klanceng PFU project in the Seribu Islands. In this study, researchers compiled an algorithm or series of structured procedures that describe how BIM technology is applied in the implementation of material resource control. This BIM application algorithm is classified into 7 (seven) process groups as follows:

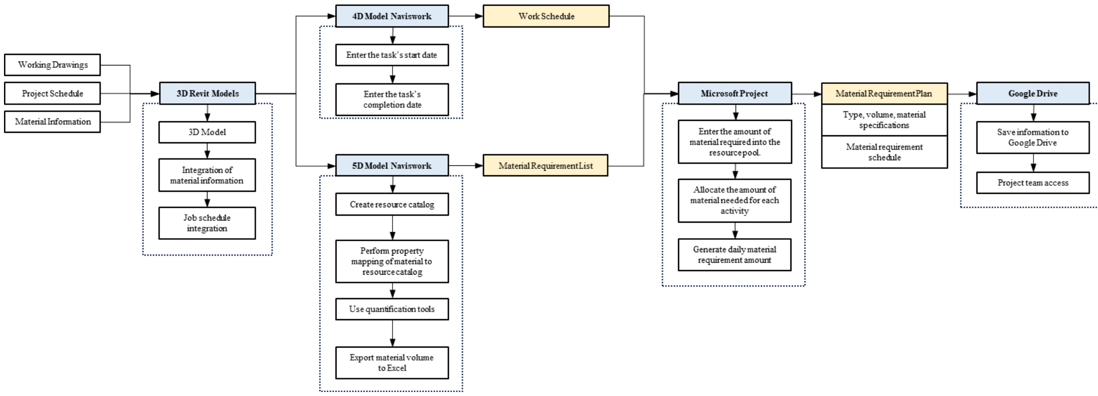

Figure 7. BIM Application Algorithm in Providing Material Requirement Plan Data

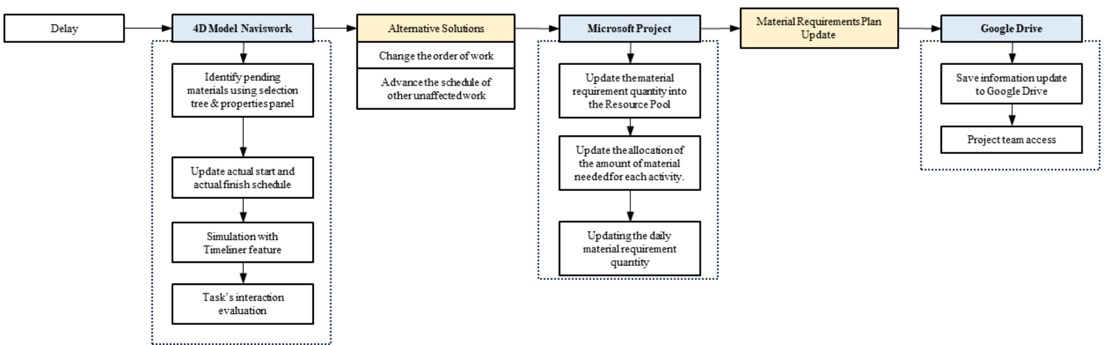

Figure 8. Material Requirements Plan Change Algorithm

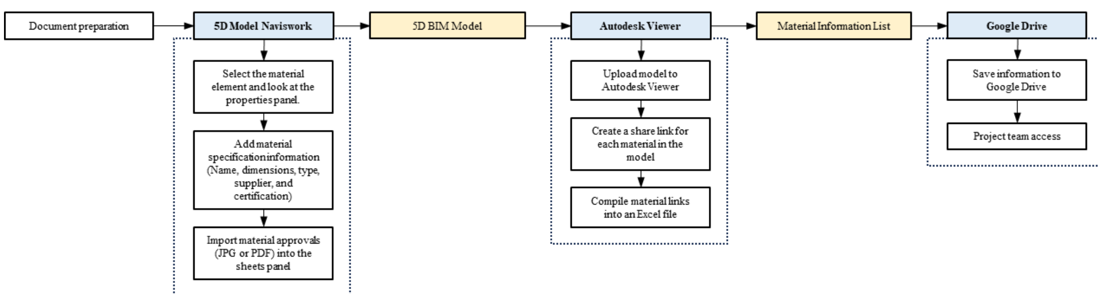

Figure 9. BIM Application Algorithm in Preparation of Reference Documents for Physical Inspection and Material Specification Conformity

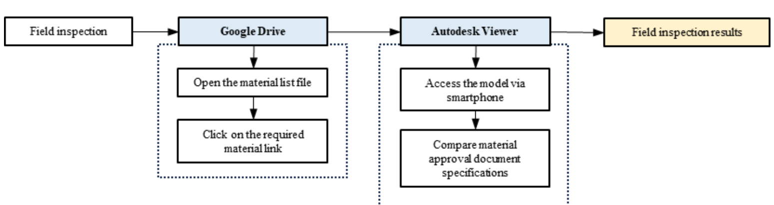

Figure 10. BIM Application Algorithm in Implementing Physical Inspection and Material Specification Conformity

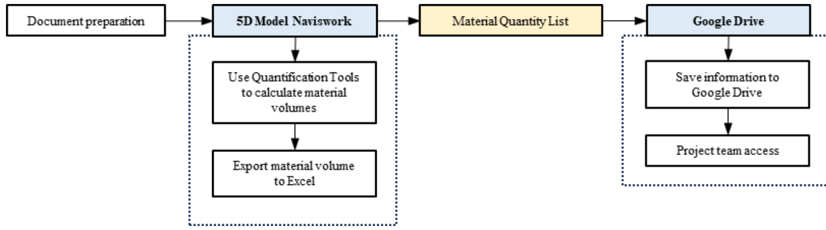

Figure 11. BIM Application Algorithm in Preparation of Reference Document for Material Quantity Conformity Inspection

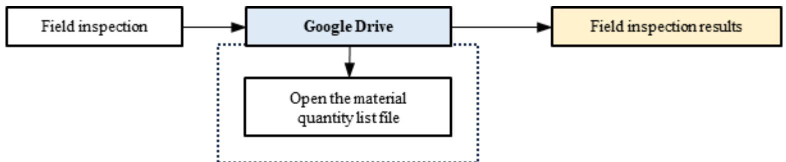

Figure 12. BIM Application Algorithm in Implementing Material Quantity Conformity Inspection

The development of SOP also includes updating the communication flow between stakeholders and adjusting the input and output of each activity. This adjustment is based on research findings, especially activities that utilize BIM technology as a response to high category risks in the implementation of the material resource control process on the PFU project in the Seribu Islands. The following are the results of the development of the BIM-based integrated material resource control SOP on the PFU project in the Seribu Islands:

1. Material Delivery Stage

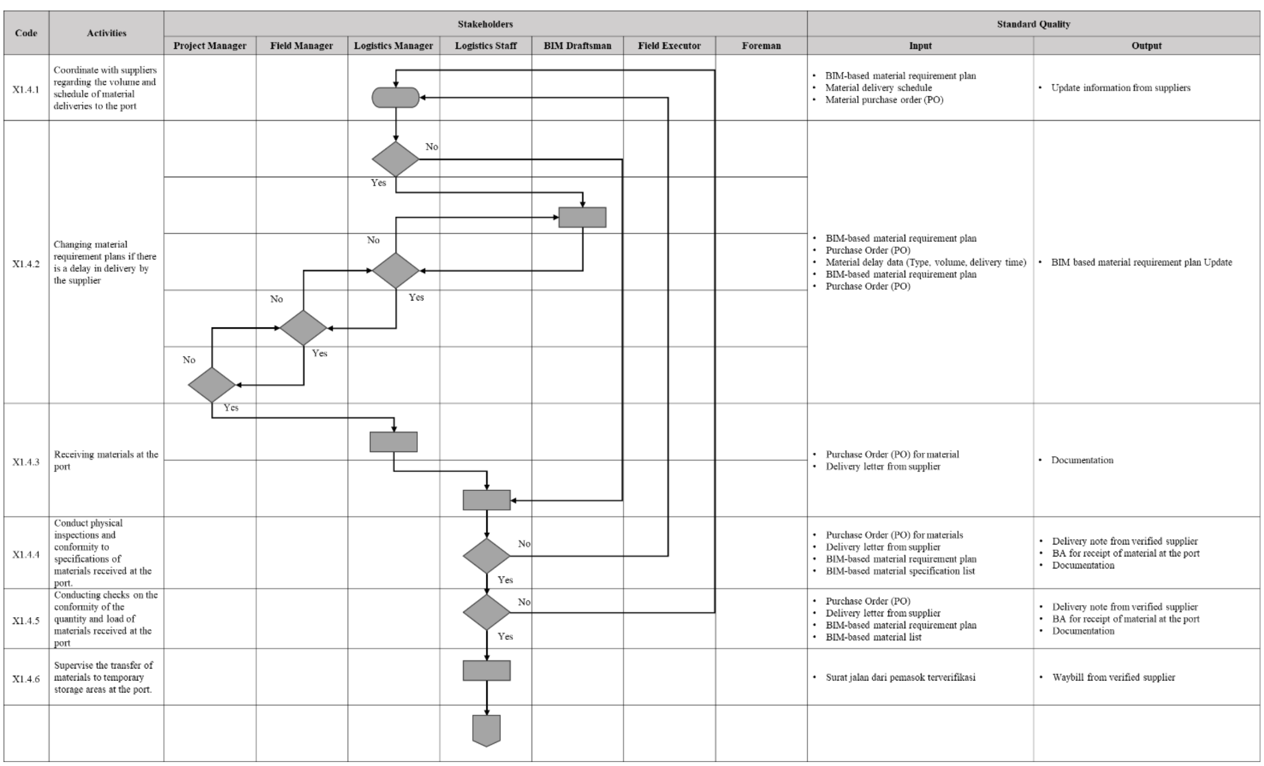

Figure 13. SOP for Material Delivery Stage

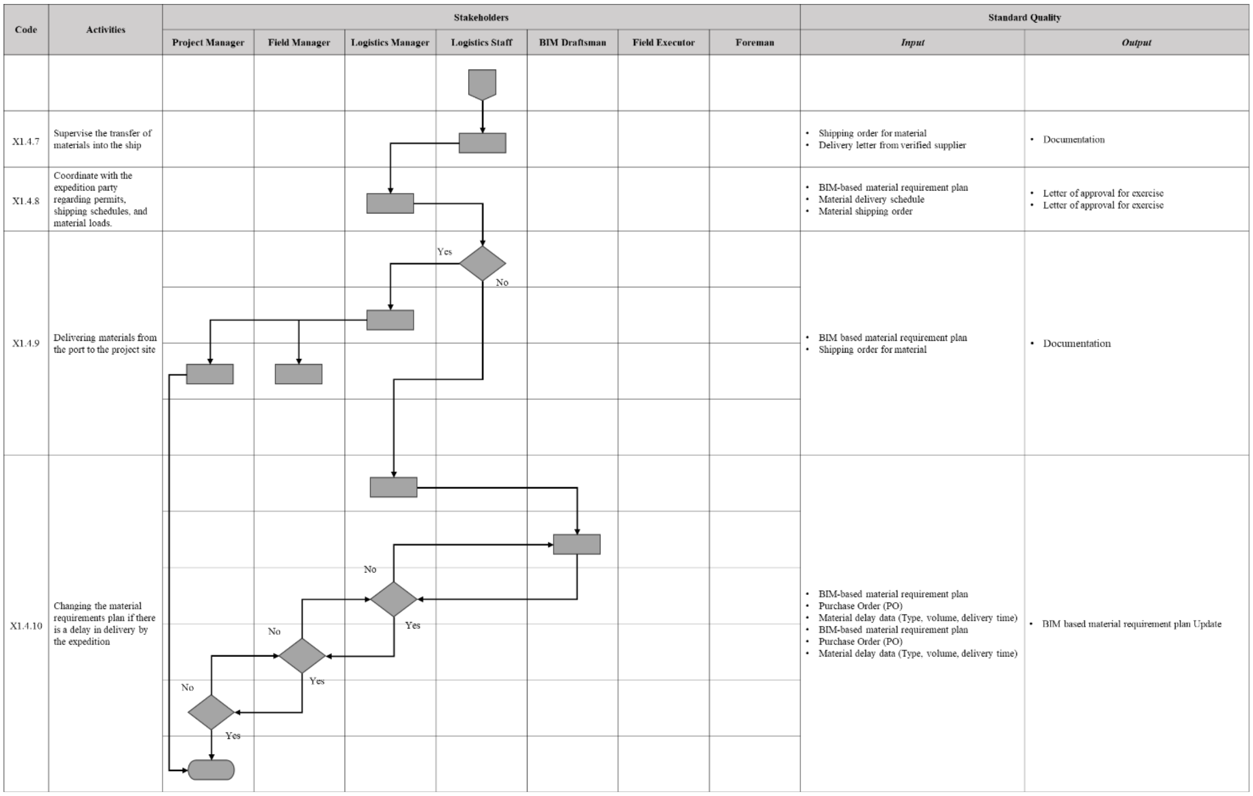

Figure 14. SOP for Material Delivery Stage (Continued)

2. Material Receiving Stage

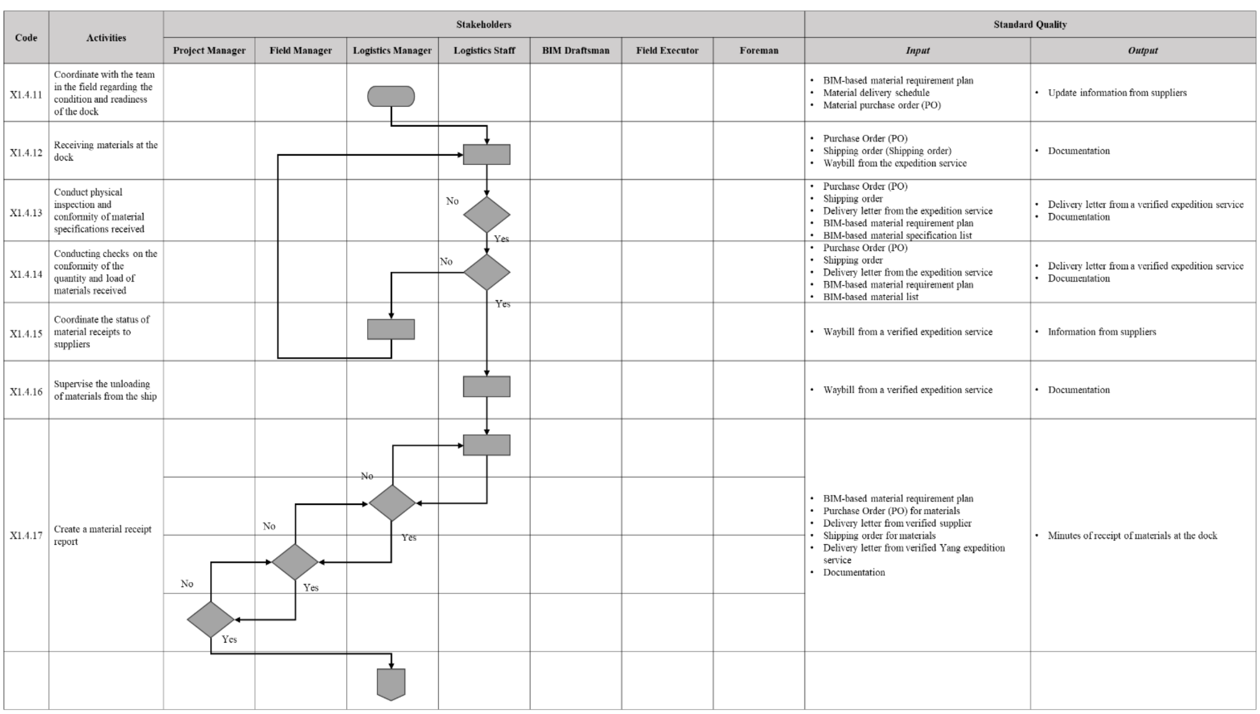

Figure 15. SOP for Material Receiving Stage

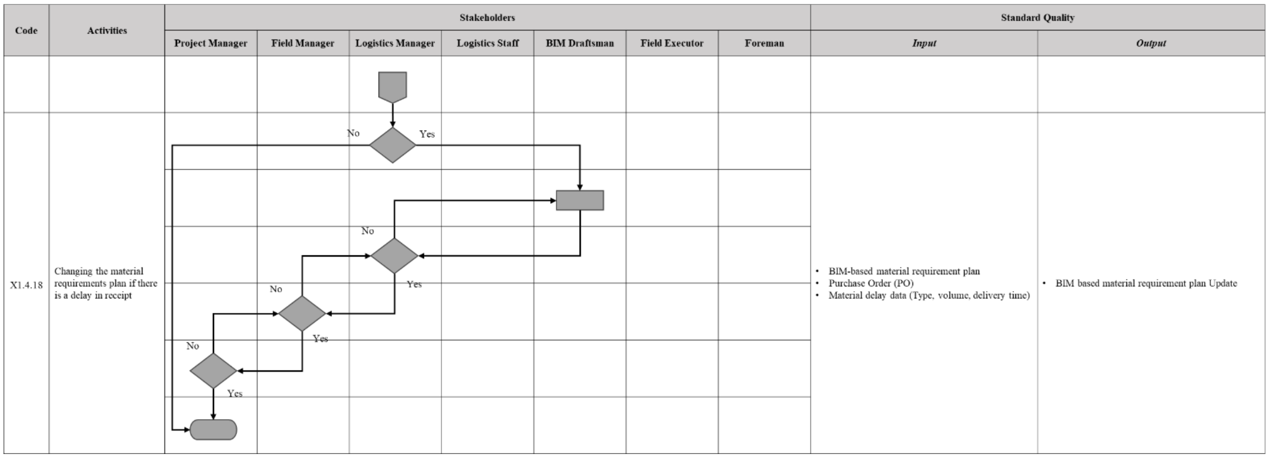

Figure 16. SOP for Material Receiving Stage (Continued)

3. Material Storage Stage

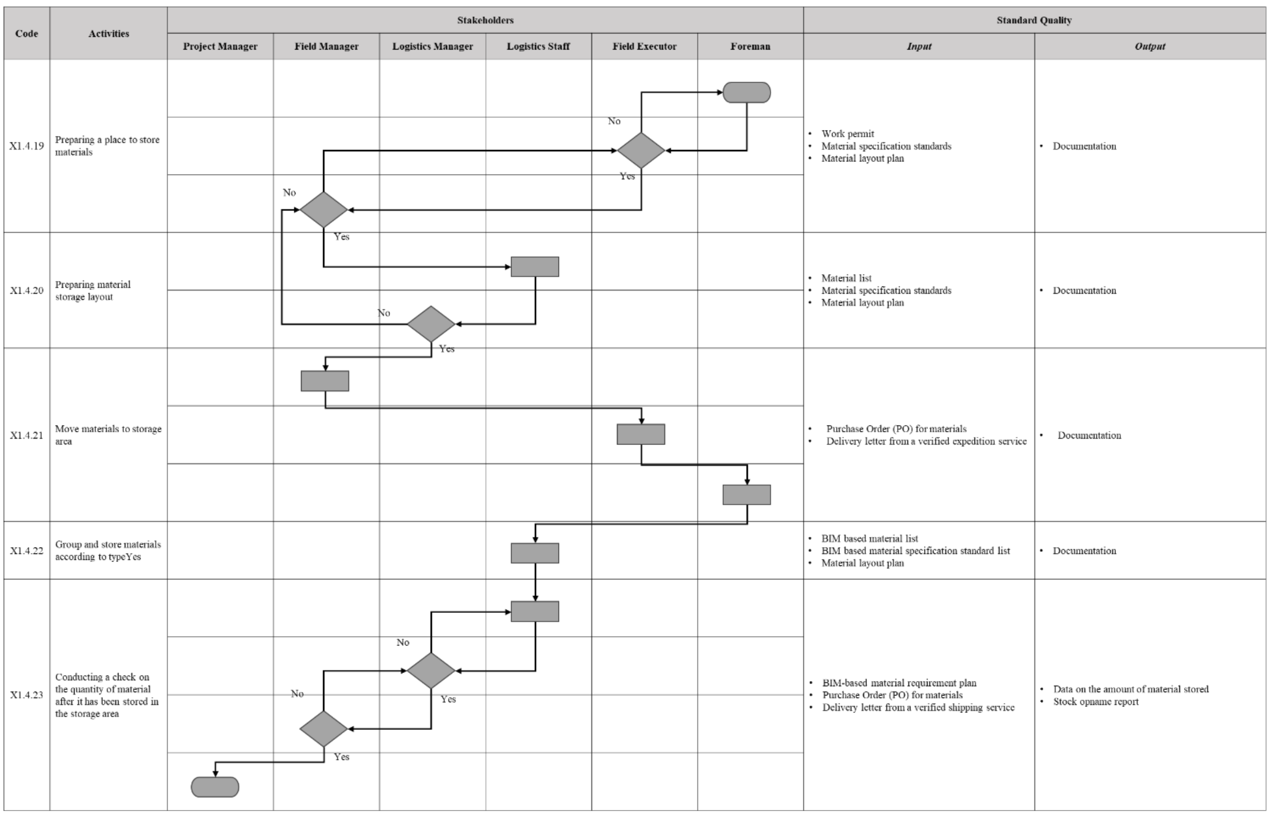

Figure 17. SOP for Material Storage Stage

4. Material Distribution Stage

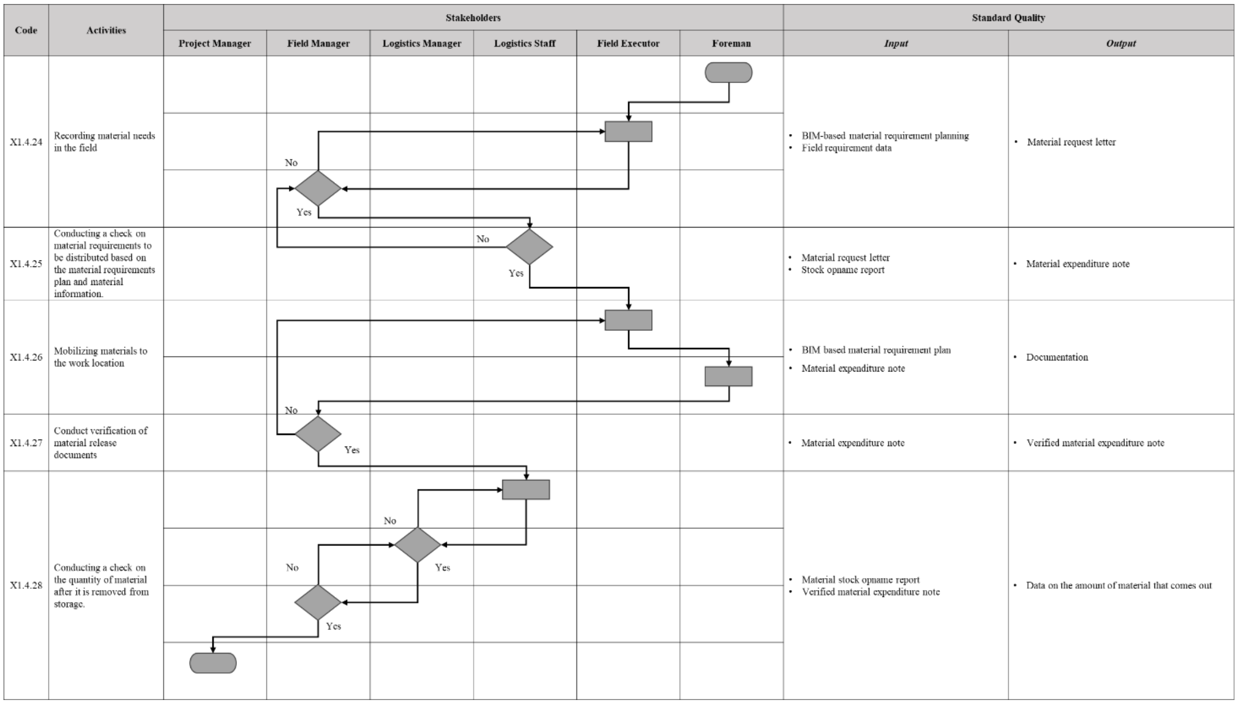

Figure 18. SOP for Material Distribution Stage

5. Material Usage Stage

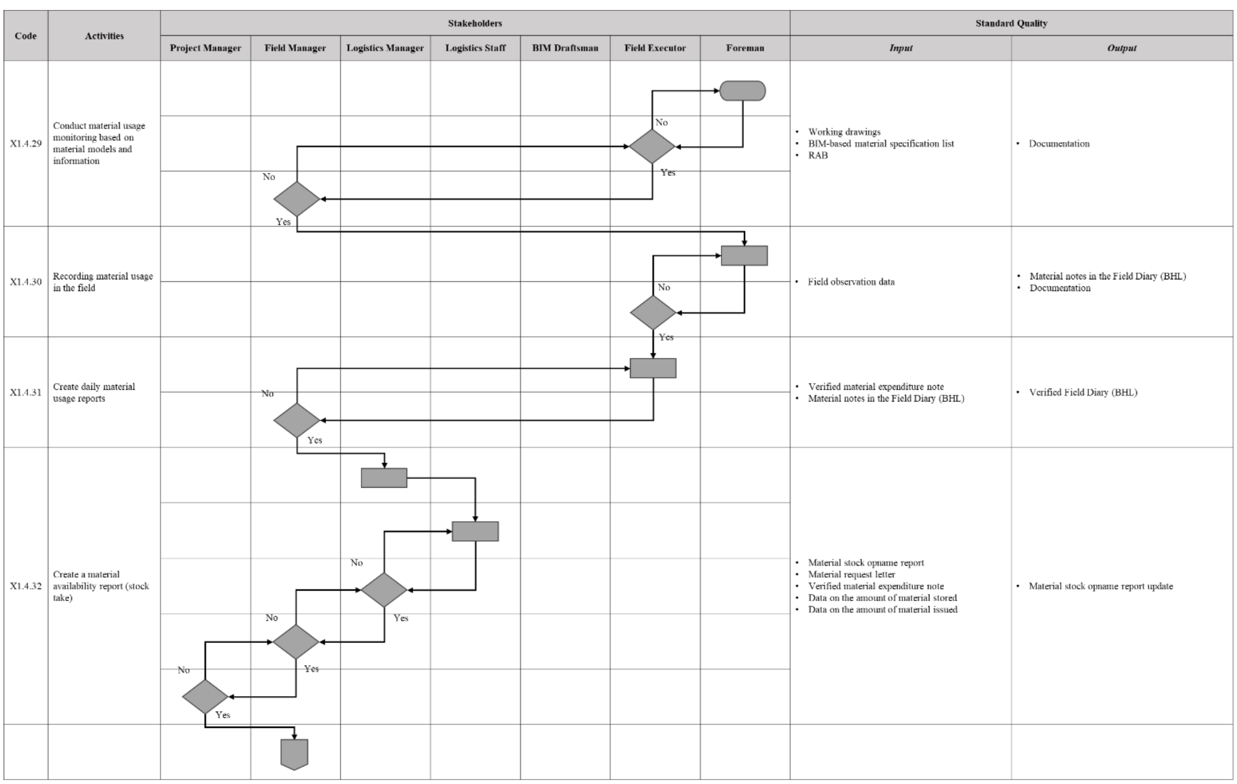

Figure 19. SOP for Material Usage Stage

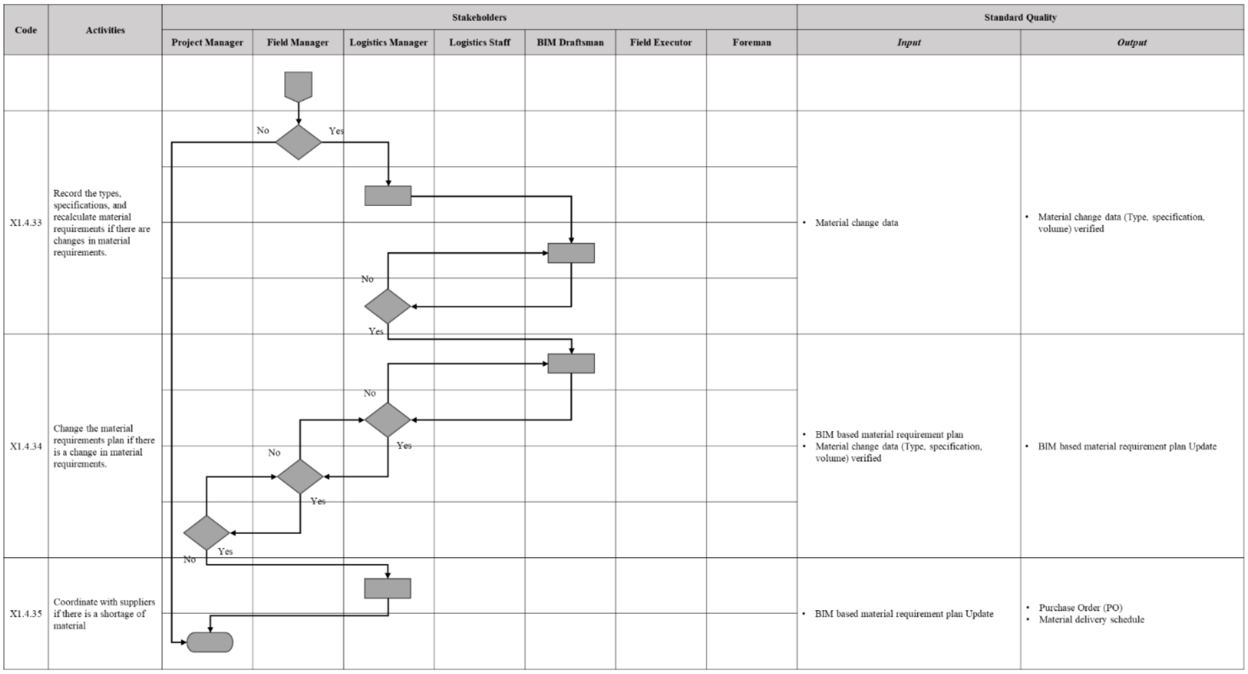

Figure 20. SOP for Material Usage Stage (Continued)Relationship Model between Procedures, Risk Factors, BIM Roles, and Project Time Performance

The results of the factor analysis produced three latent factors that influenced time performance. Each group of factors consists of research variables, namely procedures (X1), risks (X2), and the role of BIM (X3), as follows:

Table 2
Latent Factors and Research Variables

Code	Information
Factor 1	**Suitability and Supervision of Material Use**
X1.4.3	Conduct conformity checks on materials received at the port
X1.4.9	Conduct conformity checks on materials received at the project site
X1.4.23	Conduct supervision of material usage in the field
X2.25	Lack of stock of materials at the project site
X3.5.1	Checking the conformity of specifications and technical requirements set for the material
X3.6.1	Provides automatic material quantity extraction feature
Factor 2	**Material Availability and Project Coordination**
X2.1	Material delivery from supplier location to port is not on schedule
X2.5	The quantity of material does not match the amount ordered
X2.9	Ineffective contractor coordination and management
X2.10	Materials arrived at the dock later than planned
X2.29	The work instructions given during implementation were unclear
Factor 3	**Material Calculation and Schedule Realization**
X3.2.1	Comparing the schedule and implementation of construction work in the field
X3.4.1	Generate material quantity calculations in a short time
X3.4.2	Produce accurate material quantity calculations

Then, after conducting a regression analysis, the relationship between the dependent variable and the independent variable was obtained as follows:

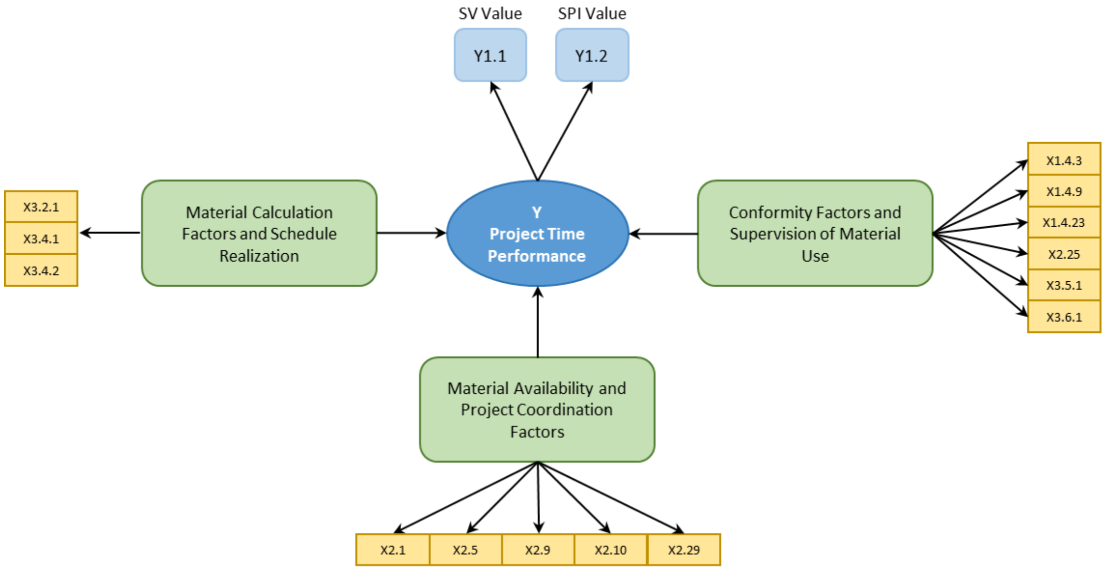

Figure 21. Relationship Between the Dependent Variable and the Independent Variable

The model in the figure shows the relationship between factors in material resource control to project time performance, as measured by schedule conformity and on-time completion. The results of the regression analysis show that the most influential factors are the conformity and supervision of material use, followed by material availability and project coordination, and material calculation and schedule realization. These findings emphasize the importance of material supervision, effective coordination, and technology integration in supporting project time efficiency.

4 Conclusion

The organizational structure of material control consists of project managers, field managers, implementers, logistics managers and staff, foremen, and additional BIM draftsmen to support the integration of risk-based procedures with BIM technology. There are 5 (five) main business processes: shipping, receiving, storing, distributing, and using materials, which consist of a total of 26 (twenty-six) activities resulting from literature studies and expert validation. Each activity was analyzed and produced 68 (sixty-eight) inputs and 32 (thirty-two) outputs. The communication flow is divided into 5 (five) stages according to the business process, arranged based on organizational structure, job description, activities, and input and output. There are 41 (forty-one) risks in the material control process, with 4 (four) main risks being the most dominant, namely: stock shortages, late delivery from supplier to port, from port to dock, and late arrival of materials at the dock. To anticipate these dominant risks, 7 (seven) causes, 9 (nine) preventive actions, 5 (five) impacts, and 6 (six) corrective actions were identified. The role of BIM includes 2 (two) sub variables with 2 (two) indicators in BIM 4D, as well as 4 (four) sub variables with 8 (eight) indicators in BIM 5D, which are applied to all stages of material control. Procedure development is carried out based on 4 (four) dominant risks, followed by the preparation of risk responses, integration of BIM roles, and development of activities, input-output, and overall organizational structure. The developed relationship model shows that the integration of material control procedures with a risk-based approach and BIM technology has a significant effect on improving project time performance, with three main factors: material usage monitoring, material availability and project coordination, and schedule calculation and realization. The development of procedures in this study, which integrates a systematic workflow, a risk-based approach, and the use of BIM technology, has resulted in a material resource control system that is not only administrative but also functions as a managerial and operational tool. The integration of these three aspects directly supports the achievement of the research objectives, namely improving project time performance by ensuring that the material control process runs more efficiently, measurably, and responsively to potential risks. This shows that the implementation of structured and integrated control procedures is very important to address the geographical and logistical challenges in construction projects in island areas such as the Seribu Islands.

As a development, further research is recommended to: expand the scope of the application of the material control process, which in this study is only focused on the stages of sending, receiving, storing, distributing, and using materials, with a case study in the Seribu Islands. Further research can be applied to other construction sectors to see its relevance and effectiveness in different contexts. Develop work instructions for the implementation procedures of the material resource control process that has been prepared in this research. Developing the use of BIM software, which in this study is used to improve time performance, so that it can also be optimized for other aspects of construction projects such as cost, quality, or work safety.

Conflict of interest statement
The authors declared that they have no competing interest.

Statement of authorship
The authors have a responsibility for the conception and design of the study. The authors have approved the final article.

Acknowledgments
We are grateful to two anonymous reviewers for their valuable comments on the earlier version of this paper.

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