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Optimization of Construction Material Inventory Using Material Requirement Planning

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ABSTRAK: *Pengelolaan persediaan material yang efisien sangat penting dalam proyek konstruksi untuk menghindari keterlambatan, pembengkakan biaya, serta kekurangan dan kelebihan material. Penelitian ini menyelidiki optimalisasi pengelolaan persediaan material menggunakan metode Material Requirements Planning (MRP), dengan fokus pada teknik Lot Sizing—Lot for Lot (LFL) dan Part Period Balancing (PPB). Studi kasus dilakukan pada pembangunan Kantor Kementerian Agama di Banda Aceh. Penelitian ini menargetkan material beton bertulang, seperti semen, pasir, dan besi tulangan, yang merupakan bahan penting bagi proyek tersebut. Data primer dikumpulkan melalui observasi lapangan dan wawancara, sementara data sekunder diperoleh dari dokumentasi proyek, termasuk Bill of Materials (BOM), jadwal, dan rincian biaya. Dengan menggunakan MRP, penelitian ini menghitung kebutuhan material, jadwal pengadaan, dan biaya untuk teknik LFL dan PPB. Hasil penelitian menunjukkan bahwa teknik LFL secara signifikan mengurangi biaya dan meningkatkan efisiensi dibandingkan dengan metode PPB. Pada lantai pertama, teknik LFL menghasilkan penghematan biaya sekitar 51,9% dibandingkan dengan metode PPB. Demikian pula, untuk lantai kedua, penghematan biaya sekitar 72,2%. Penelitian ini menyimpulkan bahwa teknik LFL merupakan teknik yang optimal untuk pengelolaan persediaan material dalam proyek konstruksi, memastikan ketersediaan material tepat waktu dan biaya penyimpanan minimal. Temuan ini memberikan kerangka praktis untuk meningkatkan efisiensi pengadaan dan menawarkan wawasan berharga bagi proyek konstruksi di masa depan yang ingin mengurangi biaya dan meningkatkan keandalan penjadwalan.*

Kata kunci: *Material Requirements Planning (MRP), Efisiensi Konstruksi, Pengelolaan Persediaan Material, Lot-for-Lot (LFL), Part-Period Balancing (PPB)*

ABSTRACT: Efficient material inventory management is critical in construction projects to avoid delays, cost overruns, and both shortages and surpluses of materials. This study investigates the optimization of material inventory management using the Material Requirements Planning (MRP) method, focusing on Lot Sizing techniques—Lot for Lot (LFL) and Part Period Balancing (PPB). A case study was conducted on the construction of the Ministry of Religious Affairs Office in Banda Aceh. The research targeted reinforced concrete materials, such as cement, sand, and rebar, which are crucial for the project. Primary data was collected through field observations and interviews, while secondary data was obtained from project documentation, including the Bill of Materials (BOM), schedules, and cost breakdowns. Using MRP, the study calculated material requirements, procurement schedules, and costs for both LFL and PPB techniques. The findings revealed that the LFL technique significantly reduces costs and improves efficiency compared to the PPB method. For the first floor, the LFL technique resulted in a cost saving of approximately 51.9% compared to the PPB method. Similarly, for the second floor, the cost savings were around 72.2%. This study concluded that LFL is the optimal technique for material inventory management in construction projects, ensuring timely availability and minimal storage costs. These findings provided a practical framework for improving procurement efficiency and offered valuable insights for future construction projects seeking to reduce costs and enhance scheduling reliability.

Keywords: Material Requirements Planning (MRP), Construction Efficiency, Material Inventory Management, Lot-for-Lot (LFL), Part-Period Balancing (PPB)

1. INTRODUCTION

The global construction industry is under increasing pressure to enhance operational efficiency, reduce costs, and adopt sustainable practices. Traditional inventory management methods often fail to meet these demands, necessitating the integration of modern tools such as Material Requirements Planning (MRP). MRP optimizes procurement processes by ensuring the timely availability of materials while minimizing holding costs, making it an essential tool in contemporary construction management [1, 2].

Effective material management balances material availability with cost control. Research indicates that inefficient procurement can lead to project delays and financial losses. Structured planning systems like MRP mitigate these risks by improving procurement accuracy and scheduling [3, 4, 5]. Additionally, predictive models and real-time data integration further enhance the reliability of material planning [6, 7].

MRP operates by utilizing three key inputs—the Master Production Schedule (MPS), Bill of Materials (BOM), and inventory records—to determine material requirements and procurement schedules [8, 9, 10]. Lot-sizing techniques such as Lot-for-Lot (LFL) and Part-Period Balancing (PPB) play a crucial role in optimizing material orders. While LFL minimizes holding costs by ordering exactly what is needed, PPB attempts to balance ordering and holding costs by grouping material requirements [9, 10]. However, studies suggest that PPB may lead to increased holding costs in projects with fluctuating demands [7, 11].

This study evaluates the application of LFL and PPB in optimizing material procurement for a construction project in Banda Aceh, Indonesia. The research focuses on reinforced concrete materials, including cement, sand, and rebar, sourced from local suppliers. By analyzing these techniques, the study aims to determine the most effective material planning strategy that balances cost efficiency and operational reliability. Additionally, it contributes to the advancement of knowledge in MRP applications by exploring modern advancements such as AI-driven inventory optimization and blockchain-based supply chain transparency. These innovations enhance material management reliability, making them valuable for future construction projects.

2. MATERIALS AND METHODS

2.1. Research Location

The research was conducted at the Ministry of Religious Affairs Office project in Banda Aceh, located at Jl. Mohd. Jam No. 29, Kampung Baru, Baiturrahman, as illustrated in Figure 1.

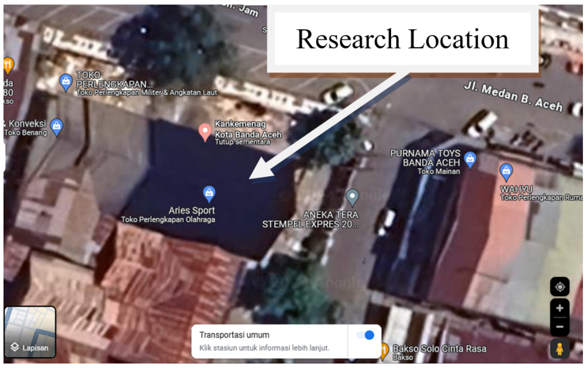

Figure 1. Research Location

This project involved the rehabilitation of a government office building with a total construction budget of IDR 1,176,931,000. The implementation period spanned from July 11, 2023, to November 7, 2023. This case study was selected to apply Material Requirements Planning (MRP) for optimizing material procurement, aligning with recent advancements in construction project management.

2.2. Materials Analyzed

Figure 2 illustrates the key materials used in the construction project, including cement, sand, and rebar. These materials play a critical role in ensuring structural integrity, durability, and overall project stability. Cement serves as the primary binding agent in concrete, while sand provides the necessary aggregate to strengthen the mixture. Steel reinforcement bars (Ø14, Ø10, and D16) are essential for enhancing the tensile strength of concrete structures [12]. The selection and timely procurement of these materials are crucial for preventing delays and managing costs effectively.

Figure 2. Materials Used in Construction

Recent studies emphasize the importance of efficient material tracking systems to optimize inventory levels and minimize waste [13]. This study focused on reinforced concrete materials, including cement, sand, and rebar, which are essential for structural integrity. Cement was procured locally, while sand and steel reinforcement bars (Ø14, Ø10, and D16) were obtained from regional suppliers. Ensuring the timely availability of these materials is crucial for preventing construction delays and cost overruns [6, 14]. Recent research highlights the benefits of integrating IoT-based tracking for real-time inventory monitoring, reducing material waste, and improving efficiency [13].

2.3. Data Collection

Primary data collection included field observations and interviews with project stakeholders, such as project managers, procurement officers, and site engineers. The study utilized the Bill of Materials (BOM) and construction schedules to determine material needs. Secondary data was obtained from previous research and project documentation. Additionally, simulation tools were utilized to validate procurement schedules against supply chain fluctuations [7, 15].

2.4. Methodology

The study employed the Material Requirements Planning (MRP) method, which integrates three key inputs: the Master Production Schedule (MPS), the Bill of Materials (BOM), and inventory status records. MRP is widely recognized as an effective tool for managing complex supply chains, particularly when enhanced by predictive analytics [8]. Dynamic demand forecasting models have demonstrated the ability to optimize construction material inventory by improving procurement accuracy and reducing waste [16].

The research focused on two lot-sizing techniques. The first technique, Lot-for-Lot (LFL), matches procurement quantities to exact material requirements for each period, minimizing inventory holding costs [9]. The second technique, Part-Period Balancing (PPB), balances ordering and holding costs by grouping material requirements over a specified time horizon [17]. Previous studies suggest that LFL is preferable in projects with variable demand, while PPB may be more effective for stable requirements [18, 19].

Table 1 provides a concise summary of the analytical steps undertaken in this study, emphasizing the role of Material Requirements Planning (MRP) in optimizing material procurement. These steps align with findings from previous studies [21], demonstrating their effectiveness in reducing material waste and ensuring project efficiency.

Table 1. Analytical Framework for MRP Implementation

Analytical Step	Description
Data analysis	Material requirements were calculated based on the Bill of Materials (BOM) and the construction schedule. Advanced tools, such as Microsoft Excel, were used to process the data [4, 10].
MRP implementation	Input data, including the Master Production Schedule (MPS), BOM, and inventory status records, were used to generate procurement schedules [20].
Cost comparison	The total costs associated with the Lot-for-Lot (LFL) and Part-Period Balancing (PPB) techniques were compared, incorporating ordering, holding, and procurement costs [11, 19].

2.5. Analytical Framework

Figure 3 illustrates the research flowchart, outlining the systematic methodology adopted in this study. The process begins with problem identification, focusing on challenges in material inventory management. This is followed by a literature review and secondary data collection, gathering insights from previous studies and project documentation. Primary data are then gathered through field observations and stakeholder interviews to capture real-world procurement challenges.

The collected data undergo analyses using the Material Requirements Planning (MRP) method, incorporating Lot-for-Lot (LFL) and Part-Period Balancing (PPB) techniques. This step calculates material requirements, schedules procurement, and determines cost efficiency. The results were analyzed to identify the most effective inventory management strategy. Finally, conclusions and recommendations were developed to improve procurement efficiency and minimize costs in future construction projects.

This structured approach ensures that research objectives are systematically addressed, leading to actionable insights. The research followed three primary steps: (1) Data analysis based on the Bill of Materials (BOM) and project schedule, (2) Material Requirements Planning (MRP) implementation to generate procurement schedules, and (3) Cost comparison of the Lot-for-Lot (LFL) and Part-Period Balancing (PPB) techniques. This structured approach aligns with established methodologies in construction management and ensures procurement optimization by minimizing costs and improving resource allocation [21, 22].

Figure 3. Research Flowchart

2.6. Tools and Software

Microsoft Excel was used for data analysis, procurement scheduling, and cost estimation. Additionally, findings from previous studies on simulation tools and AI-driven forecasting were incorporated to validate material planning strategies. The integration of real-time data analytics was considered was explored to enhance procurement accuracy and mitigate potential supply chain disruptions [8, 23, 24].

3. RESULTS AND DISCUSSION

3.1. Results

The analysis of material requirements for the construction project demonstrated significant cost differences between the Lot-for-Lot (LFL) and Part-Period Balancing (PPB) techniques. As shown in Table 2, the LFL technique resulted in lower total inventory costs compared to the PPB method for both floors. The cost reduction highlights the efficiency of the LFL approach in minimizing inventory holding costs while ensuring timely material availability.

The findings in Table 2 indicate that the Lot-for-Lot (LFL) method significantly reduces costs, particularly by lowering inventory holding expenses. On the first floor, the LFL approach achieved substantial cost savings by minimizing excess material storage. Similarly, on the second floor, the LFL method further optimized inventory efficiency by preventing unnecessary material accumulation, thereby reducing financial overhead.

Table 2. Comparison of Total Inventory Costs (IDR)

Floor	LFL	PPB	Cost Difference
First Floor	224,200,464	466,169,440	241,968,975
Second Floor	88,577,398	318,381,280	229,803,881

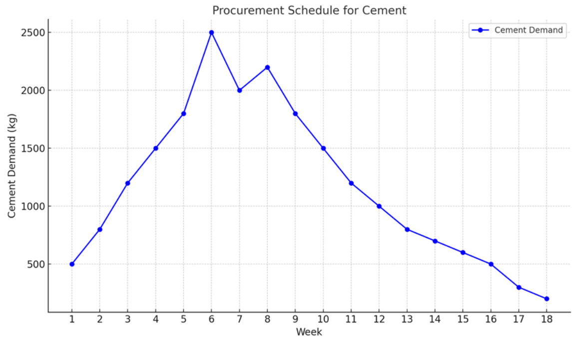

Figure 4. Procurement Schedule for Cement

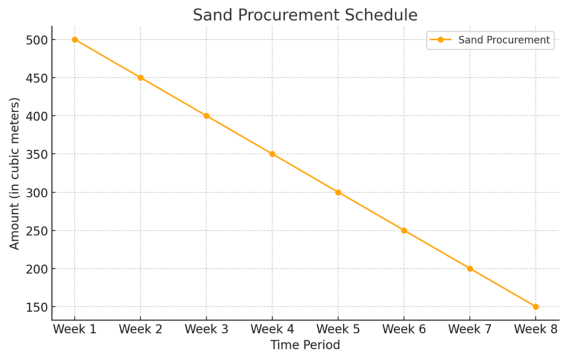

Figure 5. Procurement Schedule for Sand

Figure 4 illustrates the procurement schedule for cement, highlighting demand variations over an 18-week construction period. Demand is initially low during the first two weeks, reflecting preparatory construction activities. A sharp increase occurs in Weeks 6 and 8, corresponding to major structural work that requires large cement volumes. Following these peaks, demand gradually declines, signaling the completion of critical construction phases. This procurement schedule ensures cement availability aligns with project requirements, mitigating the risks of shortages and excessive stockpiling.

Figure 5 presents the procurement schedule for sand, which follows a similar fluctuating pattern. The highest demand occurs in Week 6, coinciding with peak construction activities such as masonry work. After this peak, demand stabilizes during the middle phase and gradually declines toward project completion. Effective scheduling, as depicted in Figure 2, is crucial for balancing material availability with cost efficiency.

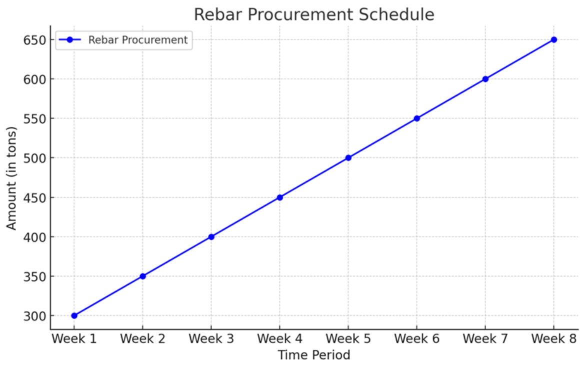

Figure 6. Procurement Schedule for Rebar

Figure 6 displays the procurement schedule for rebar, highlighting variations in weekly material requirements. The demand for rebar peaks in Week 8, aligning with the intensive structural work phase. Subsequently, demand stabilizes before gradually decreasing as the project nears completion. The procurement strategy, illustrated in Figure 3, ensures that rebar is ordered in alignment with construction progress, minimizing excess inventory and associated costs.

Table 3. Breakdown of Ordering and Holding Costs (IDR)

Floor	Technique	Ordering Costs	Holding Costs	Total Costs
First Floor	LFL	45,000,000	179,200,464	224,200,464
	PPB	30,000,000	436,169,440	466,169,440
Second Floor	LFL	22,000,000	66,577,398	88,577,398
	PPB	18,000,000	300,381,280	318,381,280

These results confirm that adopting the LFL technique enhances cost efficiency by reducing excess inventory storage while maintaining a reliable supply of materials. This approach is particularly beneficial for construction projects where precise scheduling and budget optimization are critical to success.

3.2. Discussion

The findings align with previous studies that have demonstrated the effectiveness of the Lot-for-Lot technique in reducing holding costs. For example, [18] found that Lot-for-Lot is particularly suitable for projects with consistent and predictable material requirements. This study extends these findings by showing that even in projects with fluctuating demands, such as the Banda Aceh case, Lot-for-Lot remains a superior choice due to its ability to align procurement schedules with actual material usage [5, 25]. Furthermore, recent research suggests that integrating Lot-for-Lot with predictive tools, such as machine learning algorithms, can further enhance its effectiveness by dynamically adjusting procurement schedules based on real-time data [1, 24]. This capability ensures that projects can respond more flexibly to unexpected changes in material demand or supply chain disruptions, thereby minimizing risks and delays.

Similar conclusions were drawn by [6], who highlighted the robustness of Lot-for-Lot in mitigating stockouts while reducing surplus inventory, particularly in projects with tight schedules. The results also highlight the limitations of the Part-Period Balancing technique, which, despite its ability to reduce ordering costs, often leads to higher holding costs due to bulk procurement strategies. Similar conclusions were reached by [11], who emphasized the need to balance ordering and holding costs to achieve overall cost optimization. This is consistent with findings by [26], which indicate that balancing the cost trade-offs between ordering, holding, and procurement is crucial for improving overall supply chain performance.

Furthermore, the study underscores the importance of integrating advanced planning tools, such as MRP, into construction management practices. Recent advancements in machine learning and predictive analytics, as highlighted by [8], can further enhance the accuracy of procurement schedules and reduce the risks associated with material shortages or surpluses. Additionally, the incorporation of real-time data, as discussed by [7], allows for dynamic adjustments in procurement strategies, providing more flexibility and reducing the risk of material shortages in fast-moving construction projects.

Sustainability-driven material procurement models, as emphasized by [2], also play a pivotal role in aligning material management strategies with environmental and economic goals, ensuring that resources are utilized efficiently. Additionally, the adoption of blockchain-based MRP systems has gained traction in recent years due to their ability to enhance transparency and accountability in material supply chains [4]. Blockchain technology ensures real-time tracking of materials, reducing risks associated with procurement fraud and inefficiencies. Combined with IoT-enabled sensors, these innovations allow for seamless integration of material tracking and procurement planning, enabling construction projects to operate more efficiently while maintaining sustainability goals [13, 27].

By providing a detailed cost comparison and linking the results to existing literature, this study contributes to the growing body of knowledge on inventory management in construction projects. It highlights the practical benefits of adopting Lot-for-Lot for similar projects and provides a framework for future research aimed at integrating advanced technologies into MRP systems [13].

4. CONCLUSION

This study demonstrates the effectiveness of Material Requirements Planning (MRP) in optimizing material inventory management for construction projects. By comparing the Lot-for-Lot (LFL) and Part-Period Balancing (PPB) techniques, the findings reveal that LFL is the more cost-efficient approach, significantly reducing inventory holding costs while ensuring timely material availability.

The results indicate that LFL resulted in a 51.9% cost reduction on the first floor and a 72.2% cost reduction on the second floor compared to the PPB method. These findings confirm that LFL is particularly suitable for construction projects with fluctuating material demands, as it prevents excess inventory accumulation while maintaining operational efficiency.

This research contributes to the field of construction management by providing empirical evidence of the benefits of LFL in real-world scenarios. Future studies should explore the integration of predictive analytics and machine learning into MRP systems to further enhance procurement efficiency and adaptability.

Study Limitations: This study is limited to a single construction project in Banda Aceh, which may impact the generalizability of the findings. Additionally, external factors such as supplier reliability and market price fluctuations were not analyzed in detail. Future research should incorporate these variables and apply the methodology to a broader range of construction projects to further validate the findings.

5. ACKNOWLEDGMENT

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