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From planning to performance: MRP-driven material optimization for the bored pile construction of the MUI and Safa-Marwa towers in Indonesia

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Abstract

PT. Prima Jaringan is an Indonesian company operating in the property sector. One of its ongoing residential facility development projects is the construction of the MUI Tower and Safa-Marwa Tower in Jakarta. A key issue encountered during the project was the insufficient availability of construction materials when needed, primarily due to inadequate material requirement planning. This problem was particularly evident during the construction of the bored pile foundation for the MUI Tower, where there was a shortfall of 18 m^3 of ready-mix concrete (fc'30) in the 20th week. This shortage led to delays in the project schedule.

The aim of this study is to analyze material inventory planning for the bored pile construction of the Safa Tower. The inventory planning method employed is Material Requirement Planning (MRP). The required data include general project information, the master schedule, material data, lead times, and the bill of materials. The study applies four lot-sizing techniques: Lot for Lot (LFL), Economic Order Quantity (EOQ), Period Order Quantity (POQ), and Part Period Balancing (PPB). Among these, the most optimal lot-sizing technique is identified based on the minimization of order quantity and inventory costs.

The results of the analysis indicate that the Part Period Balancing (PPB) technique yields the lowest cost for multiplex phenolic film and ready-mix concrete fc'30. Meanwhile, the Period Order Quantity (POQ) technique results in the lowest cost for D13, D16, and D19 reinforcement bars.

Keywords: Material Requirement Planning; Lot Sizing; Inventory; Performance; Bored Pile Construction

1. Introduction

The property sector in Indonesia has undergone significant growth in recent years, as evidenced by the increasing number of newly developed housing projects offered at competitive prices. This rapid development is primarily driven by housing, which is one of the fundamental human needs alongside food and clothing. Additionally, property has become a major investment alternative due to its relatively stable value and potential for long-term returns. Within this context, the residential development sector in East Jakarta plays a particularly strategic role, offering considerable potential for property business expansion. This sector is among the key contributors to regional development efforts.

One of the companies operating in the property sector is PT Prima Jaringan. The company engages in the development and marketing of various types of real estate, including land, residential housing, office buildings, and commercial spaces. PT Prima Jaringan can thus be categorized as both a developer and a marketer, managing both large- and small-scale housing projects. One of its ongoing initiatives is the construction of the MUI Tower and Safa-Marwa Towers in Jakarta.

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The MUI Tower is designed to consist of 17 floors, while each of the Safa and Marwa Towers will have 20 floors. Construction began on September 1, 2018, with the project expected to be completed by August 2020. The buildings are supported by bored pile foundations, a type of deep foundation designed in a cylindrical form to transfer structural loads to deeper, more stable soil layers. Such foundations are typically used in situations where the surface soil does not possess adequate bearing capacity to support the entire structure, necessitating additional support from deeper strata.

In any construction project, material inventory planning is one of the most critical aspects, as material resources account for a substantial portion of total project costs. Managing material procurement is a complex task, and in practice, construction projects frequently face challenges related to inventory management. Oversupply of materials leads to risks such as material damage, high storage costs, and excessive capital investment. Conversely, material shortages can disrupt the construction workflow, resulting in delays and increased costs. Therefore, achieving a balance between material availability and project requirements is essential. Effective planning and control of material inventory are key to ensuring that projects proceed smoothly, stay within budget, and are completed on schedule.

One of the material management issues encountered by PT Prima Jaringan was an inadequate supply of materials at critical times, caused by insufficiently detailed material requirement planning. This issue became evident during the construction of the bored pile foundations for the MUI Tower, when the supply of ready-mix concrete fc'30 fell short by 18 m^3 during the 20th week of the project. This shortage led to schedule delays, which in turn increased construction costs.

Given the background described above, it is essential to conduct an analysis of material inventory planning for the construction of the Safa Tower using the Material Requirement Planning (MRP) method. MRP is designed to determine the exact quantity of materials needed, thereby avoiding excessive inventory levels. The method also enables the scheduling of procurement activities to ensure material availability in accordance with project timelines, reducing the risk of delays.

MRP is based on three key principles: (1) determining material needs through accurate order quantities, timing, and component specifications; (2) prioritizing tasks by aligning due dates and maintaining valid schedules; and (3) capacity planning through accurate workload forecasts and appropriate time allocation for future production activities (Orlicky, 1975; Vollmann et al., 2005). In essence, MRP aims to ensure the right material is delivered to the right place at the right time.

The MRP process involves four main stages, one of which is lot sizing, a step designed to determine the optimal order quantity (lot size) that minimizes the total cost of inventory. This study employs four lot sizing techniques:

- Lot-for-Lot (LFL)
- Economic Order Quantity (EOQ)
- Period Order Quantity (POQ)
- Part Period Balancing (PPB)

These methods are analyzed to determine the most effective technique for minimizing inventory-related costs and optimizing material orders for the Safa Tower bored pile foundation project.

2. Method

This study adopts a structured and systematic approach to analyze material inventory planning using the Material Requirement Planning (MRP) method. The research methodology is divided into several key stages as outlined below.

2.1. Preliminary Study

The research begins with a preliminary study, which includes both a literature review and field observations. The literature review serves to establish a theoretical foundation and provide insight into previous studies related to material planning, construction supply chain management, and the application of MRP in similar contexts (Vollmann et al., 2005; Stevenson, 2020). Concurrently, the field study is conducted to gather empirical data from the actual construction site of the Safa-Marwa Tower project developed by PT Prima Jaringan.

2.2. Problem Formulation and Research Objectives

Based on findings from the preliminary study, the problem statement and research objectives are clearly formulated. The primary issue identified is the occurrence of material shortages during critical stages of construction, which can be attributed to ineffective planning. The objective of the study is to apply the MRP method to optimize inventory levels, minimize costs, and prevent future delays.

2.3. Data Collection

The next phase involves the collection of relevant data, which is essential for implementing the MRP framework. The types of data collected include:

- General project information
- The master construction schedule
- Detailed material data
- Lead times for each material
- The Bill of Materials (BOM)

These data serve as the foundation for calculating inventory costs and scheduling procurement activities effectively.

2.4. Inventory Cost Calculation

Following data collection, the inventory costs are calculated. This includes the estimation of holding costs, ordering costs, and potential shortage costs. These calculations help to assess the current state of material inventory management and identify areas for optimization.

2.5. Calculation of Total Material Requirements

This step involves determining the total material requirements based on the master production schedule and BOM. The required quantities are adjusted according to lead times and buffer stocks to ensure supply continuity throughout the construction phases.

2.6. Master Production Schedule (MPS) Development

The Master Production Schedule (MPS) is then developed. The MPS outlines when and how much material is needed at various stages of the project. This schedule is critical for aligning procurement with the project timeline.

2.7. Lot Sizing Techniques

Once material requirements are established, the next step is to determine the optimal order quantity using various lot sizing techniques, including:

- Lot for Lot (LFL)
- Economic Order Quantity (EOQ)
- Period Order Quantity (POQ)
- Part Period Balancing (PPB)

Each technique is evaluated in terms of its ability to minimize total inventory cost while meeting project needs (Orlicky, 1975; Nahmias & Olsen, 2015).

2.8. Offset Calculation (Timing of Orders)

After selecting the appropriate lot sizing technique, the offsetting process is conducted to determine the optimal ordering time. This step ensures that materials are procured and delivered just in time, avoiding both early delivery (which increases storage costs) and late delivery (which causes project delays).

2.9. Total Inventory Cost Analysis

Using the selected lot sizing and offsetting results, the total inventory cost is calculated. This total cost reflects the effectiveness of the material planning strategy in reducing expenses related to ordering, holding, and stockouts.

2.10. Conclusion and Recommendations

Finally, the research concludes with a summary of findings and practical recommendations for PT Prima Jaringan. These recommendations aim to improve inventory control practices, enhance project delivery timelines, and reduce overall construction costs.

3. Results

3.1. Project Overview

The construction project under investigation is the Menara MUI and Safa-Marwa Tower Development, located on Jalan Hankam, Bambu Apus, Jakarta. The project is commissioned by PT Prima Jaringan, a private entity engaged in property development. The design team comprises Codinachs Architectsas the principal architect, supported by ARKONINas the architectural and mechanical, electrical, and plumbing (MEP) consultants. Structural consultancy is provided by Stadin.

The scope of the development includes the construction of Menara MUI, a 17-story building, alongside two high-rise towers—Safa and Marwa—each consisting of 20 floors. The project represents a significant contribution to the urban housing infrastructure in East Jakarta and aligns with the increasing demand for residential and commercial mixed-use buildings in metropolitan areas (Firman, 2004; Nasution & Zahrah, 2012).

3.2. Project Schedule

The construction activities commenced on September 1, 2018, with a planned completion date of August 2020, resulting in a total construction duration of approximately 1 year and 11 months. The foundation work for Safa Tower, specifically the bored pile construction, was scheduled to begin in week 27 of the project timeline and was projected to be completed by week 30. Bored pile foundations are critical for high-rise structures, particularly in regions with low surface soil bearing capacity, and their timely execution is essential to avoid cascading delays in the superstructure phase (Das & Sivakugan, 2013). The Gantt chart for the construction activities related to the Bored Pile for Safa Tower is shown in Fig. 1, which illustrates the timeline and duration of the three main components of the work.

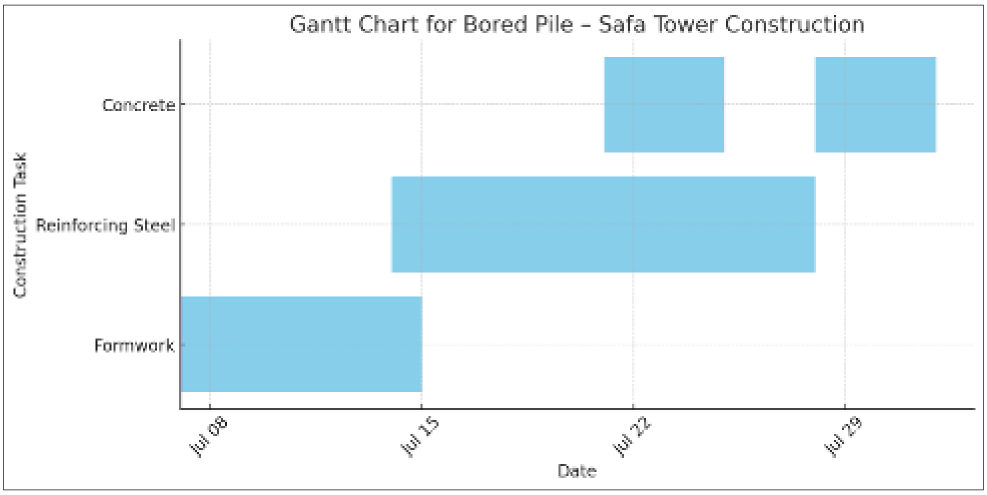

Figure 1 Project schedule

3.3. Bill of Material

The Bill of Materials (BoM) contains detailed information regarding all components and sub-components required to construct or produce the final product of a given task. The product structure for the bored pile structural work is illustrated in Fig. 2.

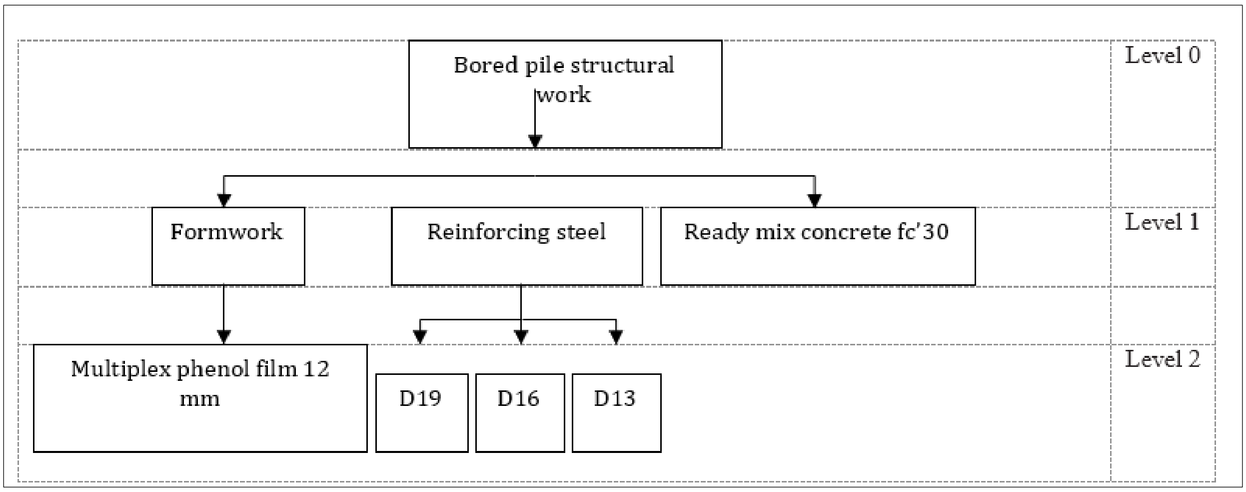

Figure 2 Bill of material of bored pile

3.4. Inventory Costs

Inventory costs refer to all expenditures and losses incurred as a result of holding inventory. These costs typically include purchasing costs, ordering costs, and storage costs. The assumptions applied in this analysis are as follows:

- The ordering cost is fixed for each procurement cycle.
- The lead time is constant for every material order.

3.5. Purchasing Costs

The material purchasing cost represents the expenditure incurred to acquire the materials required for the project. General data on material costs were obtained from the project's material price records, as presented in Table 1.

3.6. Ordering Costs

Ordering costs encompass all expenditures associated with the procurement of materials from external sources beyond the project site. In the context of this study, the ordering costs comprise telecommunication expenses and administrative fees. Specifically, the telecommunication cost is IDR 1,250, while the administrative cost amounts to IDR 1,800. Consequently, the total ordering cost incurred for each material procurement is IDR 3,050.

3.7. Storage Costs

Table 1 Material purchasing, storage costs, and lead time

No	Material	Unit	Unit price (IDR)	Percentage of storage costs (%)	Daily storage costs (IDR)	Lead time
1	Ready-mix concrete fc'30	m^3	783,325	11%	236,071	2
2	Reinforcing steel D13 @ 12.5 kg	bar	93,750	7%	17,979	1
3	Reinforcing steel D16 @ 19 kg	bar	142,500	7%	27,329	1
4	Reinforcing steel D19 @ 26.5 kg	bar	198,750	7%	38,116	1
5	Phenolic film plywood @1 m^2	sheet	185,000	8%	40,548	1

Storge costs in Table 1 refer to all expenses incurred as a result of storing goods or materials. Due to the unavailability of specific data required for calculating storage costs in this study, the following assumptions are applied: the inventory holding cost or capital cost for construction projects is estimated at 6% per annum, based on the Bank Indonesia interest rate for 2019, calculated from the unit price of each material. In addition, depreciation or damage costs associated with material storage are assumed to be 1% of the unit price for steel materials, 2% for timber materials, and 5% for Ready-Mix concrete, as suggested by Wijayanto (2012).

3.8. Master Production Schedule

Once the duration of each work item and the interrelationships among the activities are determined, a Master Production Schedule (MPS) can be developed. The material requirements per period are calculated by dividing the total material requirements by the duration of the corresponding activity. Table 2 presents the Master Production Schedule for the bored pile construction work of Safa Tower.

3.9. Optimal Order Quantity

The analysis of the optimal order quantity includes the calculation of lot sizing and order scheduling (offsetting). The lot sizing process aims to determine the optimal order quantity based on the calculated material requirements per period. The selection of an appropriate lot-sizing technique significantly influences the effectiveness of material requirement planning.

The offsetting process is intended to establish the appropriate timing for placing orders to ensure that materials are available precisely when needed. The scheduling of orders is determined by accounting for the material procurement lead time, which is calculated by subtracting the lead time from the desired availability date of the required material volume.

3.10. Total Inventory Costs

Following the lot-sizing calculations using four distinct techniques, the next step is to determine the total inventory cost. This total is obtained by summing the material purchasing cost, ordering cost, and storage cost. Each lot-sizing technique provides a different approach to determining order quantity and timing, which directly impacts inventory costs.

Table 2 MPS of Safa Tower bored pile construction

No	**WBS**	**Vol**	**Unit**	**Duration (day)**	**Week 27**							**Week 28**						
1	Safa Tower bored pile				1	2	3	4	5	6	7	1	2	3	4	5	6	7
a	Formwork	280.2	m²	8	36	36	36	36	36	36	36	36						
	Phenolic film plywood	280.2	m²		36	36	36	36	36	36	36	36						
b	Reinforcing steel	469.3	sheet	14							34	34	34	34	34	34	34	34
	D13	225.7	sheet								17	17	17	17	17	17	17	17
	D16	142.5	sheet								11	11	11	11	11	11	11	11
	D19	101.1	sheet								8	8	8	8	8	8	8	8
5	Concrete	33.8	m³	4														
No	WBS	Vol	Unit	Duration (day)	Week 29							Week 30						
1	Safa Tower bored pile				1	2	3	4	5	6	7	1	2	3	4	5	6	7
a	Formwork	280.2	m²	8														
	Phenolic film plywood	280.2	m²															
b	Reinforcing steel	469.3	sheet	14	34	34	34	34	34	34								
	D13	225.7	sheet		17	17	17	17	17	17								
	D16	142.5	sheet		11	11	11	11	11	11								

	D19	101.1	sheet		8	8	8	8	8	8								
5	Concrete	33.8	m^3	4														

3.10.1. The four techniques employed in this study are as follows

- Lot-for-Lot (LFL): This technique matches the order quantity precisely with the net material requirement for each period, resulting in no inventory being carried over between periods. While it minimizes holding costs, it may lead to higher ordering costs due to frequent purchases.
- Economic Order Quantity (EOQ): EOQ determines the optimal order quantity that minimizes the total cost of inventory by balancing ordering costs and holding costs. This classical model assumes constant demand and lead time.
- Period Order Quantity (POQ): POQ is a time-based ordering method that groups requirements into fixed time intervals. The goal is to reduce the number of orders while keeping inventory levels manageable.
- Part Period Balancing (PPB): PPB seeks to balance the holding cost and ordering cost by determining the number of periods that should be covered by one order. It does so by accumulating demand until the holding cost equals or just exceeds the ordering cost.

These techniques are used to identify the most cost-efficient approach for material procurement within the context of the project. The total inventory cost calculated from each technique is shown in Table 3, and then compared to determine which method offers the lowest overall cost.

Table 3 Total inventory costs

No	**Level**	**Material**	**Costs for each method (IDR)**			
			LFL	EOQ	POQ	PBB
1	1	Ready-mix concrete fc'30	28,211,900	28,213,316	28,215,497	28,210,049
2		Formwork	53,304,400	57,748,779	53,303,616	53,299,368
3		Reinforcing steel	207,188,100	212,391,239	207,150,494	207,247,669
4	2	Reinforcing steel D13	22,355,200	25,334,492	22,331,124	22,334,187
5		Reinforcing steel D16	21,987,700	24,959,445	21,963,469	21,968,535
6		Reinforcing steel D19	22,302,700	24,865,098	22,278,603	22,281,652
7		Phenolic film plywood	53,304,400	57,748,779	53,303,616	53,299,368

The comparison is then conducted using paired samples t-test to search for lowest total inventory cost. The tests result is pictured in Fig. 3.

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 LFL - EOQ	-2609839,96	1614235,874	721908,2293	-4614178,53	-605501,386	-3,615	4	,022

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
Pair 1	LFL - POQ	76944,42400	147186,6328	65823,86329	-105811,919	259700,7670	1,169	4	,307

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
Pair 1	LFL - PPB	76244,60600	144427,2887	64589,84707	-103085,559	255574,7707	1,180	4	,303

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
Pair 1	EOQ - POQ	2686784,380	1627764,814	727958,5549	665647,4134	4707921,347	3,691	4	,021

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
Pair 1	EOQ - PPB	2686084,562	1626036,271	727185,5270	667093,8649	4705075,259	3,694	4	,021

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper			
Pair 1	POQ - PPB	-699,81800	5148,13375	2302,31541	-7092,07034	5692,43434	-,304	4	,776

Figure 3 Paired samples t-test results

3.10.2. From the paired samples test results above, the compared total inventory costs are:

- Better using Lot-for-Lot, rather than Economic Order Quantity,
- Better using Period Order Quantity, rather than Lot-for-Lot,
- Better using Part Period Balancing, rather than Lot-for-Lot,
- Better using Period Order Quantity, rather than Economic Order Quantity,
- Better using Part Period Balancing, rather than Economic Order Quantity, and
- Better using Period Order Quantity, rather than Part Period Balancing.

3.11. Material Requirement Planning

The subsequent step in this study involved developing a Material Requirement Planning (MRP) schedule for each material using various lot-sizing methods. Table 4 summarizes the calculation outcomes, including ordering frequency, inventory level, total procurement volume, total purchasing cost, total ordering cost, total holding cost, and overall inventory cost.

Table 4 Overall inventory cost comparisons

No	1	2	3	4	5
Material	**Ready-mix concrete fc'30**	**Reinforcing steel D13**	**Reinforcing steel D16**	**Reinforcing steel D19**	**Phenolic film plywood**
Chosen method	PPB	POQ	POQ	POQ	PPB
Ordering frequency	2	3	3	3	3
Inventory level	18	527	341	248	252
Total procurement volume	36	238	154	112	288
Total purchasing cost	28,199,700	22,312,500	21,945,000	22,260,000	53,280,000
Total ordering cost	6,100	9,150	9,150	9,150	9,150
Total holding cost	4,249	9,474	9,319	9,453	10,218
Overall inventory cost	28,210,049	22,331,124	21,963,469	22,278,603	53,299,368

4. Discussion

The calculation of inventory costs across four different lot-sizing techniques aimed to assess the total expenditure associated with material procurement. A lower total procurement quantity corresponds to reduced purchasing costs. However, more frequent ordering results in higher ordering costs, and smaller inventory quantities lead to lower holding costs. Total inventory cost is determined by summing the total purchasing cost, total ordering cost, and total holding cost.

Based on the comparative summary of lot-sizing techniques, the Part Period Balancing (PPB) method yielded the lowest total inventory costs for ready-mix concrete fc'30 and phenolic film plywood. Meanwhile, the Period Order Quantity (POQ) method proved most cost-effective for D13, D16, and D19 reinforcing steel.

Fig. 4 indicates that the POQ method produced the lowest average material inventory cost, amounting to IDR 29,555,435.58. Furthermore, it demonstrates minimal differences in average inventory cost between POQ and Lot-for-Lot (LFL), which differed by only IDR 76,944.42, and PPB, differing by IDR 699.82. However, a significant difference was observed between POQ and the Economic Order Quantity (EOQ) method, amounting to IDR 2,686,784.38. The POQ method is particularly advantageous in inventory control as it aims to minimize total inventory costs by optimizing the ordering frequency in a structured manner.

The POQ approach is derived from the EOQ model, focusing on determining the economic order size and the appropriate time interval for ordering during each period (Septiyana, 2016). One strength of the POQ method is its capacity to reflect ordering costs based on time periods rather than solely on unit quantity. Nevertheless, it overlooks future demand in MRP, potentially affecting planning accuracy (Hartini, 2011). Despite requiring larger storage facilities due to higher volumes ordered at once, POQ is expected to help prevent stockouts, ensuring that projects proceed on schedule without losses due to material shortages.

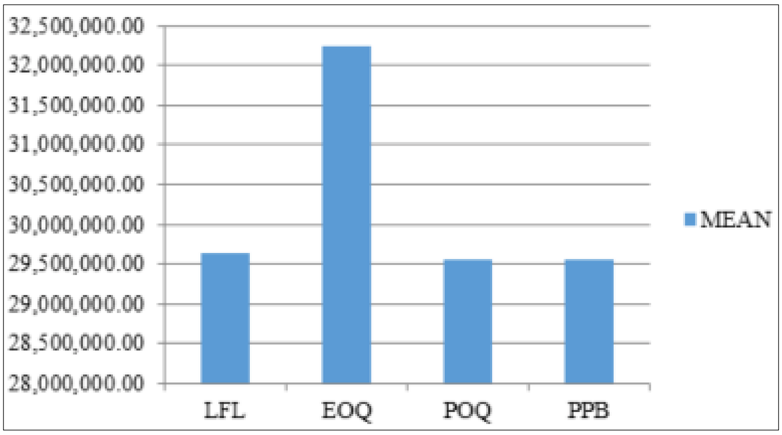

Figure 4 Methods comparison

The next most effective method after POQ in minimizing inventory costs is the Part Period Balancing (PPB) method, with a total cost of IDR 29,556,135.39. As shown in Figure 5.1, the PPB method also demonstrated no significant difference in average inventory cost when compared to LFL (a difference of IDR 76,244.61) and POQ (a difference of IDR 699.82). However, there is a marked difference when compared to EOQ (IDR 2,686,084.56). PPB seeks to balance ordering and holding costs by aggregating demand over several periods until it approaches the economic part period (EPP). This technique is designed to identify the lot size that minimizes inventory costs by covering multiple demand periods effectively (Ristono, 2009). The method uses a "look ahead/look back" strategy, analyzing future and past net material requirements, thus helping to avoid both excessive inventory and under-ordering (Ginting, 2007).

In contrast, the use of the Lot-for-Lot (LFL) and Economic Order Quantity (EOQ) methods is not recommended in this case, as both techniques produced higher inventory costs. The EOQ method does not incorporate future demand projections, often leading to surplus inventory and increased holding costs. The LFL method, while eliminating excess inventory, lacks a buffer against unexpected demand fluctuations, leaving the project vulnerable to delays and inefficiencies (Rizki, 2016).

5. Conclusion

This study has structurally analyzed the Material Requirement Planning (MRP) with four lot-sizing calculations using the Lot-for-Lot (LFL), Economic Order Quantity (EOC), Period Order Quantity (POQ), and Part Period Balancing (PPB) techniques on the MUI Tower and Safa Tower construction projects. Based on the overall analysis, it can be concluded that the lot-sizing technique with optimal order quantity and minimum inventory costs for ready-mix concrete fc'30 and phenolic film plywood is the Part Period Balancing (PPB) technique. However, for D13 reinforcing steel, D16 reinforcing steel, and D19 reinforcing steel are better calculated using the Period Order Quantity (POQ) technique. Furthermore, for the project owner, this study suggests that the MRP makes the raw material supply system easier because it has been well scheduled which can avoid stock out, and over stock so that it will not hinder the production process. This can be considered by the company to apply the MRP method in planning material requirements.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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