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# Optimization of material requirements to support the accuracy of delivery materials based on the quantity of cubicost analysis results

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***Abstract***
*Construction projects heavily rely on labor, materials, and equipment to ensure timely completion, with materials being a significant cost component. This study addresses discrepancies between rebar inventory and material demand, which can disrupt production and delay project completion. This study aims to determine the rebar volume using Cubicost TRB and optimize the lowest requirement cost by applying the Silver-Meal and Wagner-Whitin algorithms. Detailed engineering data supports the application, ensuring rebar bends meet technical standards at beam, column, and slab intersections. Material planning incorporates project schedules, inventory records, and rebar volume data from Cubicost. This planning aims to minimize ordering and storage costs. The results showed that the volume of rebar calculated using the Cubicost application was more accurate than the project's bill of quantities data. The use of the Cubicost application proved to be more advantageous, resulting in a 1% reduction compared to the project data. The Silver Meal algorithm resulted in total costs that were 21% lower than those of the Wagner-Whitin method in minimizing overall inventory costs, particularly for high-demand rebar types such as D13 and D19. These findings highlight the importance of accurate inventory scheduling and selecting appropriate lot-sizing techniques to minimize costs and prevent delays. Future research can compare Cubicost TRB's accuracy with other software and extend the Silver-Meal and Wagner-Whitin algorithms to other materials.*



***Keywords:***
*Cubicost;*
*Material Requirement Planning;*
*Rebar;*
*Silver-Meal Algorithm;*
*Wagner-Whitin Algorithm;*

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## INTRODUCTION

Construction projects heavily rely on labor, materials, and equipment to meet their completion targets [1, 2, 3]. However, during implementation, it often faces delays at different stages [4, 5, 6], leading to penalties if the project fails to follow the planned schedule [7]. One major cause of project delays is inadequate material procurement planning. While contractors prioritize labor and execution methods, poor material inventory planning can disrupt project timelines [8].

Materials contribute significantly to total project costs [9], making accurate quantity estimation essential to prevent demand miscalculations. However, conventional estimation methods that rely on detailed reviews of construction drawings are time-consuming and prone to overestimation, which can lead to further increases in project costs [10]. The accuracy of material requirement calculations is a crucial aspect of material planning and management, which plays a vital role in construction projects. This process encompasses planning, procurement, delivery, and utilisation to ensure timely and cost-effective material availability [4]. Therefore, proper material inventory planning is necessary to prevent surplus or shortage of materials [11], ensuring that production activities proceed according to schedule [12]. In this study, the focus is on reinforced bar (rebar), where shortages can significantly disrupt the structural phase of a construction project. As shown in Figure 1, discrepancies between demand and stock in July 2024 affected production efficiency, potentially delaying the project and incurring penalties for contractors [4].

Based on field conditions, accurate calculations of material requirements and optimal inventory management are essential to ensure timely and cost-efficient material delivery. Consequently, adopting advanced technology becomes crucial to optimize the estimation process [13]. Implementing 5D Building Information Modeling (BIM) enhances material quantity estimation accuracy, reduces human errors [14] and material volume inaccuracies [15][16]. Automated 3D BIM models can speed up measurements by up to 80% compared to conventional methods [10]. Additionally, BIM ensures consistent data updates [17] and supports automated rebar arrangement according to project requirements [13]. However, the precision of the 3D model significantly affects the accuracy of calculations, requiring detailed definitions of elements and materials [15][18].

BIM 5D is implemented through various software, such as Autodesk Revit, Navisworks, Tekla Structures, and Cubicost, with Autodesk Revit known for enhancing estimation accuracy by minimizing manual calculation errors [14]. However, differences in Quantity Takeoff (QTO) accuracy exist among BIM software due to variations in modeling capabilities, quantity calculation approaches, and limitations in standard implementation [19][20].

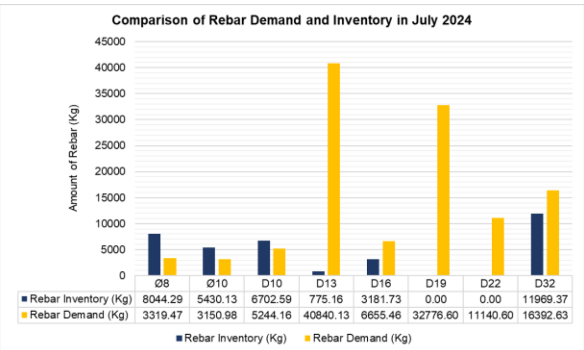

Figure 1. Comparison of Rebar Demand and Inventory in July 2024

Therefore, further analysis using the Cubicost application is essential to assess its effectiveness in enhancing calculation accuracy. Cubicost software offers four core functions: Takeoff for Architecture and Structure (TAS), Takeoff for Rebar (TRB), Takeoff for Mechanical and Electrical (TME), and Tender Series for Bill of Quantity (TBQ). Specifically, the TRB function significantly improves the accuracy of rebar volume estimation [15].

Accuracy in determining material quantities must be accompanied by precise planning for material delivery. Issues related to procurement and delivery planning have also been explored in several previous studies. In a study conducted by Awati and Putra [21] on rebar, formwork, and ready-mix concrete for high-rise buildings, supporting data were obtained from the bill of quantities for rebar (project data). To account for material waste, the quantities were adjusted by multiplying them by a factor of 1.05. Material Requirement Planning (MRP) was conducted for rebar, formwork, and ready-mix concrete using various lot-sizing techniques, including Lot-for-Lot (LFL), Economic Order Quantity (EOQ), and Period Order Quantity (POQ). The results indicated that the LFL and POQ techniques provided optimal order quantities. Similarly, in a study by Cahyani and Putra [22] on rebar, formwork, and ready-mix concrete for upper structure work, project data were also used as the basis for material quantity calculations. The Economic Part Period (EPP) and Least Unit Cost (LUC) techniques were applied, with the study concluding that EPP was more cost-effective for determining optimal order quantities.

Furthermore, inventory cost optimization has been examined in several studies. Asmal et al. [23] found that the Wagner-Whitin Algorithm resulted in higher inventory costs than the Silver-Meal Algorithm, making Silver-Meal more effective for long-term cost reduction. Ikasari et al. [24] demonstrated that implementing the Silver-Meal Algorithm in the shrimp processing industry resulted in a 15% reduction in ordering frequency and inventory costs. Additionally, Ernawati et al. [25] demonstrated that combining the Wagner-Whitin and Silver-Meal algorithms optimised inventory costs, resulting in a 1.8% reduction in the motorcycle manufacturing industry.

To ensure that the project runs according to schedule and is completed on time, the management of rebar inventory must be optimized. This optimization aims to align ordered material quantities with actual needs and ensure timely deliveries to support smooth construction processes. Based on previous studies, no research has applied the Cubicost TRB application to determine rebar quantities. Additionally, the Silver-Meal and Wagner-Whitin lot-sizing algorithms have not yet been implemented in the construction sector, particularly for rebar procurement in high-rise building projects.

This study aims to determine the rebar volume using Cubicost TRB and optimize the lowest requirement cost by applying the Silver-Meal and Wagner-Whitin algorithms. These methods utilize lot-sizing techniques to determine order quantities and offsetting techniques to establish order timing. Furthermore, an analysis is conducted to evaluate the effectiveness of these algorithms in determining optimal order quantities, reducing storage costs, and minimizing the risks of material shortages or surpluses. This study integrates 5D BIM with the MRP method to optimize the planning and procurement of rebar, an area that has not been extensively explored in previous research.

This research is expected to enhance the accuracy of material quantity calculations by applying Cubicost TRB, thereby reducing estimation errors. The integration of the MRP method in inventory management aims to improve efficiency in determining order quantities and timing, ensuring that materials are available on time to meet project requirements. Overall, this study seeks to develop an optimization model that assists contractors in planning and procuring materials using 5D BIM technology, thereby enhancing material delivery accuracy and preventing project delays caused by inventory issues. The findings of this study will be analyzed with reference to previous research to determine whether the results are consistent, contradictory, or provide new insights that contribute to existing studies.

## METHOD

### Material

This research focuses on rebar materials used in structural work for high-rise buildings from the 7$^{th}$ to the 13$^{th}$ floors. The data analyzed in this study includes rebar volume, rebar inventory records, the project schedule, the 2021 Surabaya Unit Price List (HSPK), rebar material ordering costs, stockyard storage costs, and lead time. The rebar volume was determined using the Cubicost application. The building structure was initially modeled in Cubicost based on the Detail Engineering Design (DED).

### Methods

This study adopts a quantitative approach to optimize rebar procurement, aiming to prevent production delays and minimize cost overruns due to inventory shortages or surpluses. The Cubicost TRB application is utilized to ensure precise material estimation based on predefined rebar types and templates. Following this, the MRP method is applied to guarantee material availability as per project needs [26][27]. The MRP method calculates the optimal order quantity (lotting) and order timing (offsetting) while minimizing ordering and holding costs to reduce overall expenditures [28].

MRP integrates various lot-sizing techniques. In this study, the procurement calculation for rebar utilizes two methods: the Silver-Meal Algorithm and the Wagner-Whitin Algorithm. Among these two methods, the one that yields the most economical procurement cost is identified by determining the optimal order quantity and timing to minimize the total costs associated with rebar procurement and storage.

The Silver-Meal method begins by identifying rebar demand for each period, along with ordering and storage costs. The initial order is placed to meet the demand for one period, and the total cost, consisting of ordering and storage costs, is calculated. The ordering cost is determined based on the quantity of rebar to be ordered, while the storage cost is calculated based on the duration for which the rebar must be stored. Subsequently, the demand for the next period is gradually added to the order, and the average cost per period is recalculated. If adding a period results in the same or a lower average cost, the process continues with the inclusion of the next period. However, if the average cost increases, the ordering process is stopped at the previous period with the lowest average cost. This process is repeated until all periods in the planning horizon are covered, ensuring an efficient and cost-effective ordering schedule.

Unlike the Silver-Meal method, the Wagner-Whitin method applies a dynamic programming approach to find an optimal solution. The calculation begins by determining all possible ordering times and quantities. Each scenario is then examined to compute the total cost, including ordering and storage costs. Every decision is thoroughly evaluated to identify the order combination that results in the lowest total cost across the entire planning period.

In this study, the Silver-Meal and Wagner-Whitin methods will be compared fairly by ensuring that both methods are analyzed using the same rebar demand data, ordering and storage costs, planning periods, and decision-making criteria. This approach enables an objective comparison to determine the most efficient method for minimizing total ordering and storage costs.

## Research Stages

The steps of this research are explained in Figure 2. This study begins with the Detail Engineering Design (DED) phase, where key structural elements such as columns, beams, slabs, and shear walls are defined. Structural data from 2D CAD drawings (DWG format) is imported into Cubicost TAS to generate a 3D model, which is then transferred to Cubicost TRB for rebar detailing. The TRB module automatically assigns rebar placement based on predefined rules, including bar diameter, spacing, lap splices, and development lengths, following Indonesian National Standard (SNI) and DED specifications. Cubicost TRB generates the Bar Bending Schedule (BBS) to ensure accurate material volume calculations. BBS efficiency depends on compliance with building codes related to lap splices, development lengths, hook lengths, bar spacing, and concrete cover thickness [13]. The final 3D rebar model is validated by cross-checking it with structural drawings before proceeding to the quantity takeoff process, which calculates rebar requirements based on the completed structural model. After determining material requirements, an activity schedule is created to align procurement with project needs. A Bill of Materials (BoM) is prepared, detailing the required materials for each structural component to prevent overstocking or shortages [26][29]. BoM for columns, beams, slabs, and shear walls is presented in Table 1. Meanwhile, Table 2 outlines the rebar inventory for July 2024, calculated based on stockyard availability after deducting the used rebar.

Table 1. Bill of Materials

| Job | Rebar Type | Unit |
|---|---|---|
| Beam Work | Ø10 Rebar | Kg |
| | D13 Rebar | Kg |
| | D16 Rebar | Kg |
| | D19 Rebar | Kg |
| | D22 Rebar | Kg |
| Slab Work | Ø8 Rebar | Kg |
| | Ø10 Rebar | Kg |
| | D10 Rebar | Kg |
| Column Work | D10 Rebar | Kg |
| | D13 Rebar | Kg |
| | D19 Rebar | Kg |
| | D32 Rebar | Kg |
| Shear Wall Work | D10 Rebar | Kg |
| | D13 Rebar | Kg |
| | D19 Rebar | Kg |

Table 2. Rebar Inventory in July 2024

| Rebar Type | Material Inventory Quantity | Unit |
|---|---|---|
| Ø8 Rebar | 8,044.29 | Kg |
| Ø10 Rebar | 5,430.13 | Kg |
| D10 Rebar | 6,702.59 | Kg |
| D13 Rebar | 775.16 | Kg |
| D16 Rebar | 3,181.73 | Kg |
| D19 Rebar | 0 | Kg |
| D22 Rebar | 0 | Kg |
| D32 Rebar | 11,969.37 | Kg |

This data serves as the foundation for the next period's material planning, so that project needs can be met on time and within budget.

Using rebar volume data and the project schedule, a Master Production Schedule (MPS) is developed, specifying the material quantities required for each task per period [11][29]. Based on the MPS, a material schedule was created detailing the quantities required for each type of material in each period.

The Material Requirement Planning (MRP) method is then applied, utilizing the Silver-Meal and Wagner-Whitin lot-sizing algorithms to optimize procurement. The lotting process considers three key indicators: Gross Requirement (GR), which represents planned material needs; On-Hand Inventory, which indicates stock availability; and Net Requirement (NR), which is the difference between GR and available stock. Order Release and Order Receipt define procurement timing, taking into account lead time and expected arrival dates.

The Silver-Meal Algorithm, developed by Edward Silver and Harlan Meal, is a heuristic method for determining lot sizes based on period cost minimization [30]. It functions similarly to the Economic Order Quantity (EOQ) approach but focuses on optimizing purchase periods rather than total demand [31, 32, 33, 34]. This algorithm aims to determine the most efficient lot size to reduce total costs for each period. This lot size is calculated by summing the material requirements of several consecutive periods as an initial estimate. The formula for the Silver-Meal technique is explained in (1) [23]:

$$K(m)=\frac{A+hD_2+2hD_3+\ldots+nhD_m}{m} \quad (1)$$

where: is K is order quantity in a certain period, m is a period to, A is order cost, h is holding cost, D is total demand and n is m – 1.

The quantity and timing of rebar orders are determined based on material requirements, available stock in the warehouse, and lead time, which refers to the time needed from placing the order to when the material is ready for use.

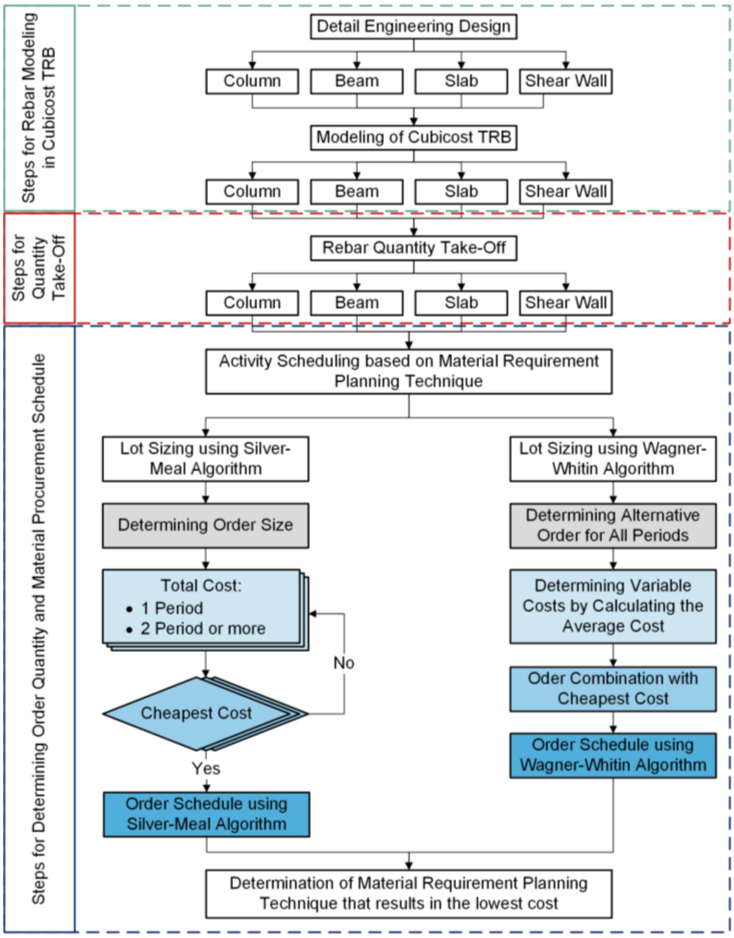


Figure 2. Research Process

In this study, (1) is adjusted to fit the material procurement process in construction projects. Ordering costs are calculated based on the ordered quantity, while storage costs account for the reduced efficiency of the storage area. Therefore, adjustments are necessary in implementing (2).

$$K(m)=\frac{\left((A\times D_n)+\left((m_1-1)h+\ldots+(m_n-1)h\right)\right)}{m_n} \tag{2}$$

Meanwhile, the Wagner-Whitin Algorithm developed by Wagner and Whitin in 1958 [30], aims to minimize total procurement and storage costs over a given period. Unlike period-by-period approaches, this algorithm evaluates all possible ordering combinations to identify the most cost-efficient solution. Equations (3), (4), and (5) describe this method [23][25].

$$Q_{ce}=\sum_{k=c}^{e} D_k \tag{3}$$

$$Z_{ce}=C+h\sum_{i=c}^{e}(Q_{ce}-Q_{ci}) \text{ for } 1\leq c\leq e\leq N \tag{4}$$

$$f_e = \min\,(Z_{ce}+f_c-1) \text{ for } c=1,2\ldots e \tag{5}$$

where:

$Q_{ce}$ : alternative order
$D_k$ : demand in the $k^{th}$ period
$Z_{ce}$ : variable cost
$C$ : ordering cost per order placement
$h$ : storage cost per unit per period
$Q_{ci}$ : demand in period i
$N$ : total number of periods
$f_e$ : order combination with minimum costs
$f_c$ : order combination with the lowest cost

Equation (3) calculates the alternative order from the start to the end of a specific period. Meanwhile, (4) is utilized to determine the total variable costs for all possible ordering options across N periods. The total variable costs from period c to period e, including ordering and holding costs, are denoted as Z. Lastly, (5) selects the optimal order combination. These calculations, like those in the Silver Meal Algorithm, are adjusted to align with construction material procurement.

Order timing is determined by offsetting the required material availability date with the lead time, which in this study is set at one week. Lead time depends on factors such as item availability and supplier distance. To accommodate potential delays, a safety stock is maintained [23]. Finally, total costs from both techniques are analyzed using the MRP method. The lot-sizing technique that yields the lowest total cost is selected for implementation.

## RESULTS AND DISCUSSION

### Data Analysis

#### *1. Validation of Rebar Volume*

Accurate rebar quantity estimation is essential for efficient construction planning and execution. The Bar Bending Schedule (BBS) serves as a reference, determining rebar requirements and providing shaping guidelines [13]. In the Cubicost TRB application, BBS is generated based on DED and includes reinforcement specifications for beams, slabs, columns, and shear walls, covering support and field reinforcements, overlapping lengths, and distribution lengths, as shown in Figure 3. To ensure accuracy, precise modeling settings, coding standards, and template adjustments are necessary. The Cubicost TRB application reduces volume errors through automated quantity takeoff and built-in features such as the deduct function, automated rebar depiction, and 3D geometric integration, significantly enhancing rebar estimation accuracy [15].

Rebar work in this project was divided into two zones, with volume calculations performed separately for each zone and floor. Rebar requirements were determined by multiplying the work volume by the relevant material coefficient, based on the 2021 Surabaya Unit Price List (HSPK). An example of material requirement calculations for the 11th-floor zone 2 beam work is provided below.

Material Type : Ø10 Rebar
Material Volume : 492.23 kg
Coefficient : 1.05
Requirement for Ø10 Rebar
= Material Volume x Coefficient
= 492.23 x 1.05
= 516.84 kg

#### *2. Master Production Schedule (MPS)*

The master production schedule refers to the project master schedule, which determines the type of work and its supporting materials. In this research, the master production schedule is oriented towards rebar material, referring to the project master schedule for reinforced concrete work on columns, beams, and floor slabs. It serves as the primary reference for determining the timing of material procurement and distribution, ensuring synchronization between material availability and on-site requirements. Additionally, the master production schedule outlines the quantity of materials needed for each task, ensuring their availability during the designated period. Below is an example of the material requirement calculation for the beam work on the 11th-floor Zone 2 in Week 47.

Amount of Rebar : 4,669.65 kg
Total Duration : 3 days
The number of days in week 47 : 1 day

$$\text{Material requirement} = \frac{\text{Amount of Materials}}{\text{Number of Days}} = \frac{4,669.65}{3} = 1,556.55 \text{ kg}$$

The overall MPS for rebar works is detailed in Table 3.

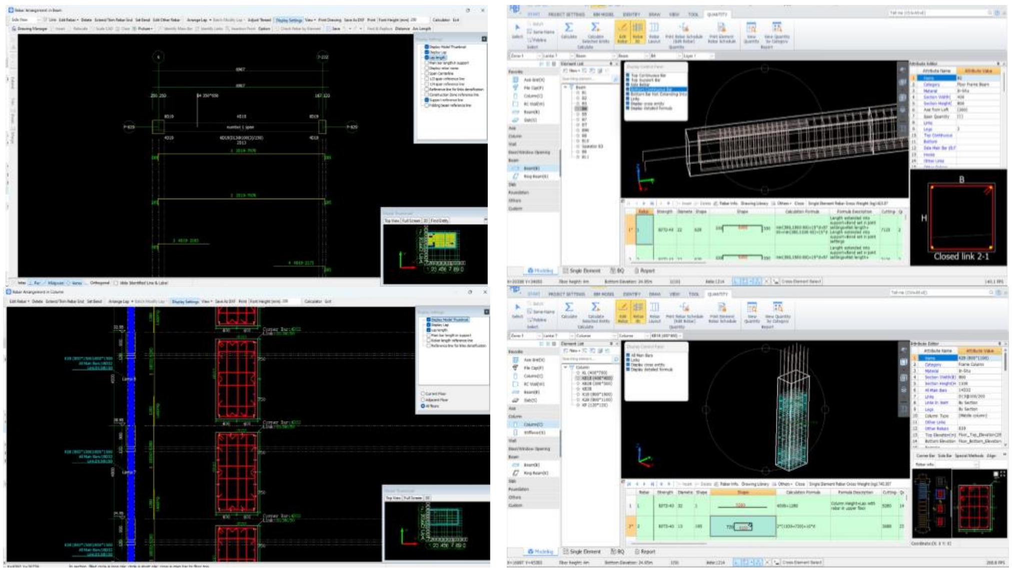

Figure 3. Rebar Work Details from TRB Cubicost

Table 3. Master Production Schedule

| No | Job Description | Unit | 39 | July 40 | 41 | 42 | 43 | August 44 | 45 | 46 | 47 | September 48 | 49 | 50 | October 51 | 52 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 8 - 14 | 15 - 21 | 22 - 28 | 29 - 04 | 05 - 11 | 12 - 18 | 19 - 25 | 26 - 01 | 02 - 08 | 09 - 15 | 16 - 22 | 23 - 29 | 30 - 06 | 07 - 13 |
| 1 | 7th Floor | | | | | | | | | | | | | | | |
| a | Beam | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | 18,453.21 | | | | | | | | | | | | | |
| - | Rebar Zone 2 | Kg | | 4,655.60 | | | | | | | | | | | | |
| b | Slab | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | 3,353.84 | | | | | | | | | | | | | |
| - | Rebar Zone 2 | Kg | | 1,177.06 | | | | | | | | | | | | |
| c | Column | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | 15,535.07 | | | | | | | | | | | | | |
| - | Rebar Zone 2 | Kg | | 8,424.99 | | | | | | | | | | | | |
| d | Shearwall | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | 3,269.55 | | | | | | | | | | | | | |
| - | Rebar Zone 2 | Kg | | 3,268.09 | | | | | | | | | | | | |
| 2 | 8th Floor | | | | | | | | | | | | | | | |
| a | Beam | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | 18,453.21 | | | | | | | | | | | |
| - | Rebar Zone 2 | Kg | | | | 4,655.60 | | | | | | | | | | |
| b | Slab | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | 3,353.84 | | | | | | | | | | | |
| - | Rebar Zone 2 | Kg | | | | 1,177.06 | | | | | | | | | | |
| c | Column | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | 15,535.07 | | | | | | | | | | | |
| - | Rebar Zone 2 | Kg | | | | 8,424.99 | | | | | | | | | | |
| d | Shearwall | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | 3,269.55 | | | | | | | | | | | |
| - | Rebar Zone 2 | Kg | | | | 3,268.09 | | | | | | | | | | |
| 3 | 9th Floor | | | | | | | | | | | | | | | |
| a | Beam | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | 15,315.93 | | | | | | | | | |
| - | Rebar Zone 2 | Kg | | | | | | 4,669.64 | | | | | | | | |
| b | Slab | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | 3,442.13 | | | | | | | | | |
| - | Rebar Zone 2 | Kg | | | | | | 1,257.07 | | | | | | | | |
| c | Column | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | 15,049.48 | | | | | | | | | |
| - | Rebar Zone 2 | Kg | | | | | | 7,983.86 | | | | | | | | |
| d | Shearwall | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | 3,307.14 | | | | | | | | | |
| - | Rebar Zone 2 | Kg | | | | | | 3,268.09 | | | | | | | | |
| 4 | 9th Floor | | | | | | | | | | | | | | | |
| a | Beam | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | 15,315.93 | | | | | | | |
| - | Rebar Zone 2 | Kg | | | | | | | | 4,669.64 | | | | | | |
| b | Slab | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | 3,442.13 | | | | | | | |
| - | Rebar Zone 2 | Kg | | | | | | | | 1,257.07 | | | | | | |
| c | Column | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | 15,049.48 | | | | | | | |
| - | Rebar Zone 2 | Kg | | | | | | | | 7,983.86 | | | | | | |
| d | Shearwall | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | 3,307.14 | | | | | | | |
| - | Rebar Zone 2 | Kg | | | | | | | | 3,268.09 | | | | | | |
| 5 | 11th Floor | | | | | | | | | | | | | | | |
| a | Beam | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | | | 15,315.93 | | | | | |
| - | Rebar Zone 2 | Kg | | | | | | | | | 1,556.55 | 3,113.09 | | | | |
| b | Slab | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | | | - | | | | | |
| - | Rebar Zone 2 | Kg | | | | | | | | | 419.02 | 838.04 | | | | |
| c | Column | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | | | 15,049.48 | | | | | |
| - | Rebar Zone 2 | Kg | | | | | | | | | | 7,983.86 | | | | |
| d | Shearwall | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | | | 3,307.14 | | | | | |
| - | Rebar Zone 2 | Kg | | | | | | | | | | 3,268.09 | | | | |
| 6 | 12th Floor | | | | | | | | | | | | | | | |
| a | Beam | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | | | | | 18,474.33 | | | |
| - | Rebar Zone 2 | Kg | | | | | | | | | | | 1,556.55 | 3,113.09 | | |
| b | Slab | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | | | | | 3,419.78 | | | |
| - | Rebar Zone 2 | Kg | | | | | | | | | | | 419.70 | 839.41 | | |
| c | Column | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | | | | | 18,320.66 | | | |
| - | Rebar Zone 2 | Kg | | | | | | | | | | | | 7,980.60 | | |
| d | Shearwall | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | | | | | 3,269.55 | | | |
| - | Rebar Zone 2 | Kg | | | | | | | | | | | | 3,262.24 | | |
| 7 | 13th Floor | | | | | | | | | | | | | | | |
| a | Beam | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | | | | | | | 19,182.88 | |
| - | Rebar Zone 2 | Kg | | | | | | | | | | | | | 1,298.72 | 2,597.44 |
| b | Slab | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | | | | | | | 1,183.25 | |
| - | Rebar Zone 2 | Kg | | | | | | | | | | | | | 394.42 | 788.84 |
| c | Column | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | | | | | | | 14,118.77 | |
| - | Rebar Zone 2 | Kg | | | | | | | | | | | | | | 7,704.95 |
| d | Shearwall | | | | | | | | | | | | | | | |
| - | Rebar Zone 1 | Kg | | | | | | | | | | | | | 3,268.08 | |
| - | Rebar Zone 2 | Kg | | | | | | | | | | | | | | 3,262.78 |

### 3. Material Schedule

The material schedule defines the required quantity of each material type within a specific period, ensuring availability for construction activities. It is based on the Master Production Schedule (MPS) to align material procurement with project timelines. In this study, the focus is on rebar scheduling, considering construction sequences, procurement lead times, and storage capacity. An accurate material schedule helps prevent shortages and excess inventory, optimizing procurement efficiency. Furthermore, integrating the material schedule with inventory management systems enhances tracking and control, supporting a more structured and efficient construction process. The detailed material schedule for rebar is presented in Table 4.

Table 4. Material Schedule

| No | Rebar Type | Unit | 39 | July 40 | 41 | 42 | 43 | August 44 | 45 | 46 | 47 | September 48 | 49 | 50 | October 51 | 52 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 8 - 14 | 15 - 21 | 22 - 28 | 29 - 04 | 05 - 11 | 12 - 18 | 19 - 25 | 26 - 01 | 02 - 08 | 09 - 15 | 16 - 22 | 23 - 29 | 30 - 06 | 07 - 13 |
| 1 | Ø8 | Kg | 1343.11 | 316.63 | 1343.11 | 316.63 | 1256.90 | 316.63 | 1256.90 | 316.63 | 1362.44 | 211.08 | 1355.07 | 211.08 | 437.06 | 218.53 |
| 2 | Ø10 | Kg | 965.35 | 610.14 | 965.35 | 610.14 | 841.68 | 608.52 | 841.68 | 608.52 | 1044.52 | 405.68 | 1141.67 | 405.68 | 960.43 | 349.02 |
| 3 | D10 | Kg | 1838.89 | 783.18 | 1838.89 | 783.18 | 2258.15 | 1111.52 | 2258.15 | 1111.52 | 2541.07 | 828.60 | 2541.21 | 829.96 | 1386.95 | 824.85 |
| 4 | D13 | Kg | 14204.74 | 6215.32 | 14204.74 | 6215.32 | 12188.90 | 5528.10 | 12188.90 | 5528.10 | 12669.69 | 5047.31 | 15308.36 | 5038.20 | 14151.73 | 4836.41 |
| 5 | D16 | Kg | 2130.82 | 1196.91 | 2130.82 | 1196.91 | 2015.78 | 1196.91 | 2015.78 | 1196.91 | 2414.75 | 797.94 | 2530.44 | 797.94 | 2525.67 | 790.55 |
| 6 | D19 | Kg | 9173.68 | 5591.99 | 12418.93 | 5591.99 | 8154.84 | 5605.42 | 8154.84 | 5605.42 | 8375.99 | 5384.26 | 11308.86 | 5384.26 | 9666.93 | 5076.80 |
| 7 | D22 | Kg | 4720.26 | 850.04 | 4720.26 | 850.04 | 4163.62 | 850.04 | 4163.62 | 850.04 | 4446.96 | 566.69 | 5009.60 | 566.69 | 5009.59 | 566.68 |
| 8 | D32 | Kg | 6234.80 | 1961.51 | 6234.80 | 1961.51 | 6234.80 | 1961.51 | 6234.80 | 1961.51 | 6234.80 | 1961.51 | 6234.80 | 1961.51 | 5307.76 | 1691.15 |

### *4. Cost Data*

The storage cost was calculated based on the rebar stockyard area shown in Figure 4. Based on interviews with the logistics team on this project, rebar is shipped from Cilegon to Surabaya, costing IDR 400 per kilogram. This cost is considered as the material ordering cost. The purchase cost depends on the prevailing unit price. In this study, the unit price for rebar refers to the 2021 Surabaya Unit Price List (HSPK), which is IDR 9,500 for all types of rebar.

The storage cost is calculated based on the depreciation of the stockyard area due to the presence of rebar. This cost is determined by dividing the stockyard area used for rebar by the total duration of the reinforcement work. According to the site management layout in Figure 4, the rebar stockyard area is 628.82 m², equivalent to 7.64% of the total project area. Consequently, the total storage cost resulting from the stockyard depreciation due to rebar is IDR 12,749,526. Since the reinforcement work spans 35 weeks, the storage cost per period for rebar is IDR 27,843.

## Results of Rebar Inventory Planning using Silver Meal Algorithm

To determine the order quantity and timing for rebar using the Silver Meal Algorithm method, the first step is to conduct forecasting or iterations. Table 5 explains the iteration process to obtain the optimal order quantity and timing for D13 rebar. This iteration begins by calculating the net requirements by subtracting the gross rebar requirements from the material inventory in the stockyard. Then, the total ordering cost (A), holding cost (h), and purchase cost for the total trial periods are calculated.

The following is an example calculation for forecasting the order size and timing for the D13 rebar.


Figure 4. Site Layout Management

Period = 39
Net Requirements = gross requirements – on hand inventory
= 14,204.74 – 775.16
= 13,429.58 kg

Next, the total ordering cost (A), holding cost (h), and purchasing cost for the entire test period are calculated.

**Iteration I (1 Period; Period 39)**

Total Ordering Cost (A×D)

A×D = ordering cost per unit × cumulative demand
= IDR 400 × 13,429.58 kg
= IDR 5,371,833

Total Holding Cost (h)

Total h = holding cost per period × holding frequency
= IDR 27,843 × (1-1) period
= IDR 0

Total Inventory Cost (K)

$$K = \frac{(A \times D) + \text{Total h}}{m}$$

$$= \frac{\text{IDR } 5{,}371{,}833 + \text{IDR } 0}{1}$$

= IDR 5,371,833

Alternatively, the iteration can be calculated using (2) as follows:

$$K = \frac{\left((A \times D_1) + ((m_1 - 1)h)\right)}{m_1}$$

$$= \frac{(\text{IDR } 400 \times 13.429{,}58 \text{ kg}) + ((1-1)\text{IDR } 27.843)}{1}$$

= IDR 5,371,833

The total cost for ordering, which covers the demand for one period, is IDR 5,371,833.

**Iteration II (2 Period; Period 39 and 40)**

Rebar demand in period 39 = 13,429.58 kg
Rebar demand in period 40 = 6,215.32 kg
Total periods (m) = 2
Total Inventory Cost (K)

$$= \frac{\left((A \times D_2) + ((m_1 - 1)h + (m_2 - 1)h)\right)}{m_2}$$

$$= \frac{(\text{IDR } 400 \times 19{,}644.90 \text{ kg}) + ((1-1)\text{IDR } 27{,}843 + (2-1)\text{IDR } 27{,}843)}{2}$$

= IDR 3,942,902

The total cost for ordering, covering the demand for two periods, is IDR 3,942,902. Since the result of iteration II is lower than iteration I, the calculation proceeds to iteration III.

**Iteration III (3 Period; Period 39, 40, and 41)**

Rebar demand in period 39 = 13,429.58 kg
Rebar demand in period 40 = 6,215.32 kg
Rebar demand in period 41 = 14,204.74 kg
Total periods (m) = 3

Total Inventory Cost (K)

$$= \frac{\left((A \times D_3) + \left((m_1-1)h + (m_2-1)h + (m_3-1)h\right)\right)}{m_3}$$

$$= \frac{(\text{IDR } 400 \times 33{,}849.65 \text{ kg}) + \left(\begin{array}{c}(0)\text{IDR } 27{,}843 + (1)\text{IDR } 27{,}843 + \\ (2)\text{IDR } 27{,}843\end{array}\right)}{3}$$

= IDR 4,531,848

The total ordering cost for three periods is IDR 4,531,848. Since the result of iteration III is higher than iteration II, the calculation is stopped.

Since iteration II resulted in the lowest cost, the optimal order quantity is 19,644.90 kg, with the order scheduled for week 38 (one week prior to the rebaris use). Subsequently, the iteration is recalculated starting from period 41, as shown in Table 5. After that, the ordering schedule for each type of rebar can be arranged, as presented in Table 6.

After determining the optimal quantity and timing for ordering rebar, the next step is to calculate the material purchasing cost by multiplying the required amount of rebar by the unit price listed in the 2021 HSPK.

Purchasing Cost = unit price x required quantity of rebar
= IDR 9,500 x 19,644.90 kg
= IDR 186,626,585

## Results of Rebar Inventory Planning using Wagner Whitin Algorithm

Determining the order quantity and timing using the Wagner-Whitin Algorithm begins by calculating the alternative order ($Q_{ce}$) as shown in Table 7. This alternative order is obtained by summing the demand from previous periods with the demand for the current period, resulting in a final alternative order that represents the total demand across all periods.

Table 5. Demand Forecasting using Silver Meal Algorithm of D13 Rebar Type

| Period | Requirement | Cumulative Requirement | Total Period [m] | Ordering Cost [A] (IDR) | Storage Cost [H] (IDR) | Total Cost/Period [K] (IDR) | Purchasing Cost (IDR) |
|---|---|---|---|---|---|---|---|
| 39 | 13429.58 | 13429.58 | 1 | 5,371,833 | - | 5,371,833 | |
| **39;40** | **6215.32** | **19644.90** | **2** | **7,857,961** | **27,843** | **3,942,902** | **186,626,585** |
| 39;40;41 | 14204.74 | 33849.65 | 3 | 13,539,859 | 55,685 | 4,531,848 | |
| 41 | 14204.74 | 14204.74 | 1 | 5,681,898 | - | 5,681,898 | |
| **41;42** | **6215.32** | **20420.07** | **2** | **8,168,026** | **27,843** | **4,097,934** | **193,990,628** |
| 41;42;43 | 12188.90 | 32608.97 | 3 | 13,043,587 | 83,528 | 4,375,705 | |
| 43 | 12188.90 | 12188.90 | 1 | 4,875,560 | - | 4,875,560 | |
| **43;44** | **5528.10** | **17717.00** | **2** | **7,086,802** | **27,843** | **3,557,322** | **168,311,537** |
| 43;44;45 | 12188.90 | 29905.90 | 3 | 11,962,362 | 83,528 | 4,015,296 | |
| 45 | 12188.90 | 12188.90 | 1 | 4,875,560 | - | 4,875,560 | |
| **45;46** | **5528.10** | **17717.00** | **2** | **7,086,802** | **27,843** | **3,557,322** | **168,311,537** |
| 45;46;47 | 12669.70 | 30386.70 | 3 | 12,154,680 | 83,528 | 4,079,403 | |
| 47 | 12669.70 | 12669.70 | 1 | 5,067,879 | - | 5,067,879 | |
| **47;48** | **5047.31** | **17717.00** | **2** | **7,086,802** | **27,843** | **3,557,322** | **168,311,537** |
| 47;48;49 | 15308.37 | 33025.37 | 3 | 13,210,148 | 83,528 | 4,431,225 | |
| 49 | 15308.37 | 15308.37 | 1 | 6,123,346 | - | 6,123,346 | |
| **49;50** | **5038.20** | **20346.57** | **2** | **8,138,626** | **27,843** | **4,083,234** | **193,292,378** |
| 49;50;51 | 14151.73 | 34498.30 | 3 | 13,799,319 | 83,528 | 4,627,616 | |
| 51 | 14151.73 | 14151.73 | 1 | 5,660,693 | - | 5,660,693 | |
| **51;52** | **4836.41** | **18988.15** | **2** | **7,595,259** | **27,843** | **3,811,551** | **180,387,391** |

Table 6. Rebar Ordering Schedule with Silver Meal-Algorithm Technique

| No | Material | Unit | Indicator | | | July | | | | August | | | | September | | | | October | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 38<br>01 - 07 | 39<br>8 - 14 | 40<br>15 - 21 | 41<br>22 - 28 | 42<br>29 - 04 | 43<br>05 - 11 | 44<br>12 - 18 | 45<br>19 - 25 | 46<br>26 - 01 | 47<br>02 - 08 | 48<br>09 - 15 | 49<br>16 - 22 | 50<br>23 - 29 | 51<br>30 - 06 | 52<br>07 - 13 |
| 1 | Ø8 Rebar | Kg | Gross Requirement | | 1,279.15 | 1,084.59 | 1,279.15 | 1,084.59 | 1,197.05 | 1,095.70 | 1,197.05 | 1,095.70 | 1,562.28 | 730.47 | 1,290.54 | 201.03 | 416.25 | 208.13 |
| | | | On Hand Inventory | 8,044.29 | 6,765.14 | 5,680.55 | 4,401.40 | 3,316.81 | 2,119.76 | 1,024.06 | - | - | 730.47 | - | 825.41 | 624.38 | 208.13 | - |
| | | | Net Requirement | | | | | | | | 172.99 | | | | | | | |
| | | | Order Receipt | | | | | | | | 172.99 | 1,095.70 | 2,292.75 | | 2,115.95 | | | |
| | | | Order Release | | | | | | | 172.99 | 1,095.70 | 2,292.75 | | 2,115.95 | | | | |
| 2 | Ø10 Rebar | Kg | Gross Requirement | | 956.40 | 638.71 | 956.40 | 638.71 | 832.64 | 637.17 | 832.64 | 637.17 | 1,045.03 | 424.78 | 1,132.55 | 402.77 | 959.65 | 348.63 |
| | | | On Hand Inventory | 5,430.13 | 4,473.73 | 3,835.02 | 2,878.62 | 2,239.91 | 1,407.27 | 770.10 | 637.17 | - | 424.78 | - | 402.77 | - | 348.63 | - |
| | | | Net Requirement | | | | | | | | 62.55 | | | | | | | |
| | | | Order Receipt | | | | | | | | 699.72 | | 1,469.81 | | 1,535.33 | | 1,308.28 | |
| | | | Order Release | | | | | | | 699.72 | | 1,469.81 | | 1,535.33 | | 1,308.28 | | |
| 3 | D10 Rebar | Kg | Gross Requirement | | 1,752.09 | 907.01 | 1,752.09 | 907.01 | 2,163.13 | 1,297.05 | 2,163.13 | 1,297.05 | 2,507.90 | 952.28 | 2,433.48 | 802.95 | 1,333.42 | 798.09 |
| | | | On Hand Inventory | 6,702.59 | 4,950.50 | 4,043.49 | 2,291.40 | 1,384.39 | - | - | 1,297.05 | - | 952.28 | - | 2,934.45 | 2,131.50 | 798.09 | - |
| | | | Net Requirement | | | | | | 778.74 | | | | | | | | | |
| | | | Order Receipt | | | | | | 778.74 | 1,297.05 | 3,460.18 | | 3,460.18 | | 5,367.93 | | | |
| | | | Order Release | | | | | 778.74 | 1,297.05 | 3,460.18 | | 3,460.18 | | 5,367.93 | | | | |
| 4 | D13 Rebar | Kg | Gross Requirement | | 14,204.74 | 6,215.32 | 14,204.74 | 6,215.32 | 12,188.90 | 5,528.10 | 12,188.90 | 5,528.10 | 12,669.70 | 5,047.31 | 15,308.37 | 5,038.20 | 14,151.73 | 4,836.41 |
| | | | On Hand Inventory | 775.16 | 6,215.32 | - | 6,215.32 | - | 5,528.10 | - | 5,528.10 | - | 5,047.31 | - | 5,038.20 | - | 4,836.41 | - |
| | | | Net Requirement | | 13,429.58 | | | | | | | | | | | | | |
| | | | Order Receipt | | 19,644.90 | | 20,420.07 | | 17,717.00 | | 17,717.00 | | 17,717.00 | | 20,346.57 | | 18,988.15 | |
| | | | Order Release | 19,644.90 | | 20,420.07 | | 17,717.00 | | 17,717.00 | | 17,717.00 | | 20,346.57 | | 18,988.15 | | |
| 5 | D16 Rebar | Kg | Gross Requirement | | 2,130.82 | 1,196.91 | 2,130.82 | 1,196.91 | 2,015.78 | 1,196.91 | 2,015.78 | 1,196.91 | 2,414.75 | 797.94 | 2,530.44 | 797.94 | 2,525.67 | 790.55 |
| | | | On Hand Inventory | 3,181.73 | 1,050.91 | 2,130.82 | - | - | 1,196.91 | - | 1,196.91 | - | 797.94 | - | 797.94 | - | 790.55 | - |
| | | | Net Requirement | | | 146.00 | | | | | | | | | | | | |
| | | | Order Receipt | | | 2,276.82 | | 1,196.91 | 3,212.69 | | 3,212.69 | | 3,212.69 | | 3,328.38 | | 3,316.22 | |
| | | | Order Release | | 2,276.82 | | 1,196.91 | 3,212.69 | | 3,212.69 | | 3,212.69 | | 3,328.38 | | 3,316.22 | | |
| 6 | D19 Rebar | Kg | Gross Requirement | | 9,173.68 | 5,591.99 | 12,418.93 | 5,591.99 | 8,154.84 | 5,605.42 | 8,154.84 | 5,605.42 | 8,375.99 | 5,384.26 | 11,308.86 | 5,384.26 | 9,666.93 | 5,076.80 |
| | | | On Hand Inventory | - | 5,591.99 | - | 19,352.25 | 13,760.26 | 5,605.42 | - | 5,605.42 | - | 5,384.26 | - | 5,384.26 | - | 5,076.80 | - |
| | | | Net Requirement | | 9,173.68 | | | | | | | | | | | | | |
| | | | Order Receipt | | 14,765.68 | | 31,771.18 | | - | | 13,760.26 | | 13,760.26 | | 16,693.12 | | 14,743.73 | |
| | | | Order Release | 14,765.68 | | 31,771.18 | | | | 13,760.26 | | 13,760.26 | | 16,693.12 | | 14,743.73 | | |
| 7 | D22 Rebar | Kg | Gross Requirement | | 4,720.26 | 850.04 | 4,720.26 | 850.04 | 4,163.62 | 850.04 | 4,163.62 | 850.04 | 4,446.96 | 566.69 | 5,009.60 | 566.69 | 5,009.59 | 566.68 |
| | | | On Hand Inventory | - | 850.04 | - | 850.04 | - | 850.04 | - | 850.04 | - | 566.69 | - | 566.69 | - | 566.68 | - |
| | | | Net Requirement | | 4,720.26 | | | | | | | | | | | | | |
| | | | Order Receipt | | 5,570.30 | | 5,570.30 | | 5,013.66 | | 5,013.66 | | 5,013.66 | | 5,576.29 | | 5,576.27 | |
| | | | Order Release | 5,570.30 | | 5,570.30 | | 5,013.66 | | 5,013.66 | | 5,013.66 | | 5,576.29 | | 5,576.27 | | |
| 8 | D32 Rebar | Kg | Gross Requirement | | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 5,307.76 | 1,691.15 |
| | | | On Hand Inventory | 11,969.37 | 5,734.57 | 3,773.06 | 1,961.51 | - | 1,961.51 | - | 1,961.51 | - | 1,961.51 | - | 1,961.51 | - | 1,691.15 | - |
| | | | Net Requirement | | | | 2,461.75 | | | | | | | | | | | |
| | | | Order Receipt | | | | 4,423.26 | | 8,196.32 | | 8,196.32 | | 8,196.32 | | 8,196.32 | | 6,998.91 | |
| | | | Order Release | | | 4,423.26 | | 8,196.32 | | 8,196.32 | | 8,196.32 | | 8,196.32 | | 6,998.91 | | |

Below is an example calculation for alternative order for the D13 rebar.

Rebar demand in period 39 = 13,429.58 kg
Rebar demand in period 40 = 6,215.32 kg
Rebar demand in period 41 = 14,204.74 kg

$Q_{39,39}$ = 13,429.58 kg
$Q_{39,40}$ = 13,429.58 + 6,215.32 kg
= 19,644.90 kg
$Q_{39,41}$ = 13,429.58 + 6,215.32 kg +14,204.74 kg
= 33,849.65 kg

Furthermore, the variable cost ($Z_{ce}$) in Table 8 is calculated by determining the ordering cost and storage cost for each alternative order quantity.

$Z_{39,39}$ = $C \times Q_{ce} + h(N_1 - N_1)$
= IDR 400 × 13,429.58 kg + IDR 27,843(39-39)
= IDR 5,371,833

$Z_{39,40}$ = $C \times Q_{ce} + h(N_2 - N_1)$
= IDR 400 × 19,644.90 kg + IDR 27,843(40-39)
= IDR 7,885,804

$Z_{39,41}$ = $C \times Q_{ce} + h(N_3 - N_1)$
= IDR 400 × 33,849.65 kg + IDR 27,843(41-39)
= IDR 13,595,544

From the variable costs, the order combination with the minimum price ($f_e$) is selected, as shown in Table 9. This process yields the most optimal order quantity and timing.

$f_{39}$ = min ($Z_{39,39}+f_0$)
= min (IDR 5,371,833+0)
= IDR 5,371,833

The most optimal ordering and storage cost for D13 rebar in period 39 is IDR 5,371,833.

$f_{40}$ = min ($Z_{39,40}+f_0$;$Z_{40,40}+f_{39}$)
= min (IDR 7,885,804+0;IDR 2,486,129+ IDR 5,371,833)
= IDR 7,857,961

The most optimal ordering and storage cost for D13 rebar in period 40 is IDR 7,857,961.

$f_{41}$ = min ($Z_{39,41}+f_0$;$Z_{40,41}+f_{39}$;$Z_{41,41}+f_{40}$)
= min (IDR 13,595,544+0;IDR 8,195,869 +IDR 5,371,833;IDR 5,681,898+ IDR 7,857,961)
= IDR 13,539,859

The most optimal ordering and storage cost for D13 rebar in period 41 is IDR 13,539,859.

From the results of the procurement costs to supply the demand from period c to period e in Table 9, it was found that rebar material ordering is carried out per period or once a week. The cost of purchasing the rebar is calculated based on the order quantity, with the ordering and storage costs minimized in each period. Subsequently, the ordering schedule for each rebar type using the Wagner-Whitin technique is established, as presented in Table 10.

Table 7. Alternative Order ($Q_{ce}$) of D10 Rebar Type

| Period | | | July | | | | August | | | | September | | | October |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| c \ e | **39** | **40** | **41** | **42** | **43** | **44** | **45** | **46** | **47** | **48** | **49** | **50** | **51** | **52** |
| **GR** | **13429.58** | **6215.32** | **14204.74** | **6215.32** | **12188.90** | **5528.10** | **12188.90** | **5528.10** | **12669.70** | **5047.31** | **15308.37** | **5038.20** | **14151.73** | **4836.41** |
| 39 | 13429.58 | 19644.90 | 33849.65 | 40064.97 | 52253.87 | 57781.97 | 69970.87 | 75498.98 | 88168.67 | 93215.98 | 108524.35 | 113562.55 | 127714.28 | 132550.69 |
| 40 | | 6215.32 | 20420.07 | 26635.39 | 38824.29 | 44352.39 | 56541.29 | 62069.40 | 74739.09 | 79786.40 | 95094.76 | 100132.97 | 114284.70 | 119121.11 |
| 41 | | | 14204.74 | 20420.07 | 32608.97 | 38137.07 | 50325.97 | 55854.07 | 68523.77 | 73571.08 | 88879.44 | 93917.64 | 108069.38 | 112905.79 |
| 42 | | | | 6215.32 | 18404.22 | 23932.33 | 36121.23 | 41649.33 | 54319.03 | 59366.33 | 74674.70 | 79712.90 | 93864.63 | 98701.05 |
| 43 | | | | | 12188.90 | 17717.00 | 29905.90 | 35434.01 | 48103.70 | 53151.01 | 68459.38 | 73497.58 | 87649.31 | 92485.72 |
| 44 | | | | | | 5528.10 | 17717.00 | 23245.11 | 35914.80 | 40962.11 | 56270.48 | 61308.68 | 75460.41 | 80296.82 |
| 45 | | | | | | | 12188.90 | 17717.00 | 30386.70 | 35434.01 | 50742.37 | 55780.57 | 69932.31 | 74768.72 |
| 46 | | | | | | | | 5528.10 | 18197.80 | 23245.11 | 38553.47 | 43591.67 | 57743.41 | 62579.82 |
| 47 | | | | | | | | | 12669.70 | 17717.00 | 33025.37 | 38063.57 | 52215.30 | 57051.72 |
| 48 | | | | | | | | | | 5047.31 | 20355.67 | 25393.87 | 39545.61 | 44382.02 |
| 49 | | | | | | | | | | | 15308.37 | 20346.57 | 34498.30 | 39334.71 |
| 50 | | | | | | | | | | | | 5038.20 | 19189.93 | 24026.35 |
| 51 | | | | | | | | | | | | | 14151.73 | 18988.15 |
| 52 | | | | | | | | | | | | | | 4836.41 |

Table 8. Procurement Costs to Supply from Period C to Period E ($Z_{ce}$) (IDR) of D10 Rebar Type

| Period | | | July | | | | August | | | | September | | | October |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| c \ e | **39** | **40** | **41** | **42** | **43** | **44** | **45** | **46** | **47** | **48** | **49** | **50** | **51** | **52** |
| 39 | 5,371,833 | 7,885,804 | 13,595,544 | 16,109,515 | 21,012,918 | 23,252,002 | 28,155,405 | 30,394,489 | 35,490,210 | 37,536,975 | 43,688,164 | 45,731,287 | 51,419,822 | 53,382,230 |
| 40 | | 2,486,129 | 8,195,869 | 10,709,840 | 15,613,243 | 17,852,327 | 22,755,730 | 24,994,813 | 30,090,535 | 32,137,300 | 38,288,488 | 40,331,611 | 46,020,147 | 47,982,555 |
| 41 | | | 5,681,898 | 8,195,869 | 13,099,272 | 15,338,356 | 20,241,758 | 22,480,842 | 27,576,563 | 29,623,329 | 35,774,517 | 37,817,640 | 43,506,176 | 45,468,584 |
| 42 | | | | 2,486,129 | 7,389,532 | 9,628,615 | 14,532,018 | 16,771,102 | 21,866,823 | 23,913,588 | 30,064,777 | 32,107,900 | 37,796,435 | 39,758,843 |
| 43 | | | | | 4,875,560 | 7,114,644 | 12,018,047 | 14,257,131 | 19,352,852 | 21,399,617 | 27,550,806 | 29,593,929 | 35,282,464 | 37,244,872 |
| 44 | | | | | | 2,211,241 | 7,114,644 | 9,353,728 | 14,449,449 | 16,496,214 | 22,647,403 | 24,690,526 | 30,379,061 | 32,341,469 |
| 45 | | | | | | | 4,875,560 | 7,114,644 | 12,210,365 | 14,257,131 | 20,408,319 | 22,451,442 | 28,139,978 | 30,102,386 |
| 46 | | | | | | | | 2,211,241 | 7,306,963 | 9,353,728 | 15,504,916 | 17,548,039 | 23,236,575 | 25,198,983 |
| 47 | | | | | | | | | 5,067,879 | 7,114,644 | 13,265,833 | 15,308,956 | 20,997,491 | 22,959,899 |
| 48 | | | | | | | | | | 2,018,923 | 8,170,111 | 10,213,234 | 15,901,770 | 17,864,178 |
| 49 | | | | | | | | | | | 6,123,346 | 8,166,469 | 13,855,004 | 15,817,413 |
| 50 | | | | | | | | | | | | 2,015,280 | 7,703,816 | 9,666,224 |
| 51 | | | | | | | | | | | | | 5,660,693 | 7,623,101 |
| 52 | | | | | | | | | | | | | | 1,934,566 |

Table 9. Order Combination with Minimum Costs ($f_e$) (IDR) of D10 Rebar Type

| Period | | | July | | | | August | | | | September | | | October |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| c \ e | **39** | **40** | **41** | **42** | **43** | **44** | **45** | **46** | **47** | **48** | **49** | **50** | **51** | **52** |
| 39 | 5,371,833 | 7,885,804 | 13,595,544 | 16,109,515 | 21,012,918 | 23,252,002 | 28,155,405 | 30,394,489 | 35,490,210 | 37,536,975 | 43,688,164 | 45,731,287 | 51,419,822 | 53,382,230 |
| 40 | | 7,857,961 | 13,567,702 | 16,081,673 | 20,985,076 | 23,224,159 | 28,127,562 | 30,366,646 | 35,462,367 | 37,509,133 | 43,660,321 | 45,703,444 | 51,391,980 | 53,354,388 |
| 41 | | | 13,539,859 | 16,053,830 | 20,957,233 | 23,196,317 | 28,099,720 | 30,338,804 | 35,434,525 | 37,481,290 | 43,632,479 | 45,675,602 | 51,364,137 | 53,326,545 |
| 42 | | | | 16,025,988 | 20,929,391 | 23,168,474 | 28,071,877 | 30,310,961 | 35,406,682 | 37,453,448 | 43,604,636 | 45,647,759 | 51,336,295 | 53,298,703 |
| 43 | | | | | 20,901,548 | 23,140,632 | 28,044,035 | 30,283,119 | 35,378,840 | 37,425,605 | 43,576,794 | 45,619,917 | 51,308,452 | 53,270,860 |
| 44 | | | | | | 23,112,789 | 28,016,192 | 30,255,276 | 35,350,997 | 37,397,763 | 43,548,951 | 45,592,074 | 51,280,609 | 53,243,018 |
| 45 | | | | | | | 27,988,350 | 30,227,433 | 35,323,155 | 37,369,920 | 43,521,109 | 45,564,232 | 51,252,767 | 53,215,175 |
| 46 | | | | | | | | 30,199,591 | 35,295,312 | 37,342,078 | 43,493,266 | 45,536,389 | 51,224,924 | 53,187,333 |
| 47 | | | | | | | | | 35,267,470 | 37,314,235 | 43,465,424 | 45,508,547 | 51,197,082 | 53,159,490 |
| 48 | | | | | | | | | | 37,286,393 | 43,437,581 | 45,480,704 | 51,169,239 | 53,131,648 |
| 49 | | | | | | | | | | | 43,409,739 | 45,452,861 | 51,141,397 | 53,103,805 |
| 50 | | | | | | | | | | | | 45,425,019 | 51,113,554 | 53,075,963 |
| 51 | | | | | | | | | | | | | 51,085,712 | 53,048,120 |
| 52 | | | | | | | | | | | | | | 53,020,278 |

Table 10. Rebar Ordering Schedule with Wagner-Whitin Algorithm Technique

| No | Material | Unit | Indicator | 38 | 39 | July 40 | 41 | 42 | 43 | August 44 | 45 | 46 | 47 | September 48 | 49 | 50 | October 51 | 52 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 01 - 07 | 8 - 14 | 15 - 21 | 22 - 28 | 29 - 04 | 05 - 11 | 12 - 18 | 19 - 25 | 26 - 01 | 02 - 08 | 09 - 15 | 16 - 22 | 23 - 29 | 30 - 06 | 07 - 13 |
| 1 | Ø8 Rebar | Kg | Gross Requirement | | 1,279.15 | 1,084.59 | 1,279.15 | 1,084.59 | 1,197.05 | 1,095.70 | 1,197.05 | 1,095.70 | 1,562.28 | 730.47 | 1,290.54 | 201.03 | 416.25 | 208.13 |
| | | | On Hand Inventory | 8,044.29 | 6,765.14 | 5,680.55 | 4,401.40 | 3,316.81 | 2,119.76 | 1,024.06 | - | - | - | - | - | - | - | - |
| | | | Net Requirement | | | | | | | | 172.99 | | | | | | | |
| | | | Order Receipt | | | | | | | | 172.99 | 1,095.70 | 1,562.28 | 730.47 | 1,290.54 | 201.03 | 416.25 | 208.13 |
| | | | Order Release | | | | | | | 172.99 | 1,095.70 | 1,562.28 | 730.47 | 1,290.54 | 201.03 | 416.25 | 208.13 | |
| 2 | Ø10 Rebar | Kg | Gross Requirement | | 956.40 | 638.71 | 956.40 | 638.71 | 832.64 | 637.17 | 832.64 | 637.17 | 1,045.03 | 424.78 | 1,132.55 | 402.77 | 959.65 | 348.63 |
| | | | On Hand Inventory | 5,430.13 | 4,473.73 | 3,835.02 | 2,878.62 | 2,239.91 | 1,407.27 | 770.10 | - | - | - | - | - | - | - | - |
| | | | Net Requirement | | | | | | | | 62.55 | | | | | | | |
| | | | Order Receipt | | | | | | | | 62.55 | 637.17 | 1,045.03 | 424.78 | 1,132.55 | 402.77 | 959.65 | 348.63 |
| | | | Order Release | | | | | | | 62.55 | 637.17 | 1,045.03 | 424.78 | 1,132.55 | 402.77 | 959.65 | 348.63 | |
| 3 | D10 Rebar | Kg | Gross Requirement | | 1,752.09 | 907.01 | 1,752.09 | 907.01 | 2,163.13 | 1,297.05 | 2,163.13 | 1,297.05 | 2,507.90 | 952.28 | 2,433.48 | 802.95 | 1,333.42 | 798.09 |
| | | | On Hand Inventory | 6,702.59 | 4,950.50 | 4,043.49 | 2,291.40 | 1,384.39 | - | - | - | - | - | - | - | - | - | - |
| | | | Net Requirement | | | | | | 778.74 | | | | | | | | | |
| | | | Order Receipt | | | | | | 778.74 | 1,297.05 | 2,163.13 | 1,297.05 | 2,507.90 | 952.28 | 2,433.48 | 802.95 | 1,333.42 | 798.09 |
| | | | Order Release | | | - | | 778.74 | 1,297.05 | 2,163.13 | 1,297.05 | 2,507.90 | 952.28 | 2,433.48 | 802.95 | 1,333.42 | 798.09 | |
| 4 | D13 Rebar | Kg | Gross Requirement | | 14,204.74 | 6,215.32 | 14,204.74 | 6,215.32 | 12,188.90 | 5,528.10 | 12,188.90 | 5,528.10 | 12,669.70 | 5,047.31 | 15,308.37 | 5,038.20 | 14,151.73 | 4,836.41 |
| | | | On Hand Inventory | 775.16 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | | Net Requirement | | 13,429.58 | | | | | | | | | | | | | |
| | | | Order Receipt | | 13,429.58 | 6,215.32 | 14,204.74 | 6,215.32 | 12,188.90 | 5,528.10 | 12,188.90 | 5,528.10 | 12,669.70 | 5,047.31 | 15,308.37 | 5,038.20 | 14,151.73 | 4,836.41 |
| | | | Order Release | 13,429.58 | 6,215.32 | 14,204.74 | 6,215.32 | 12,188.90 | 5,528.10 | 12,188.90 | 5,528.10 | 12,669.70 | 5,047.31 | 15,308.37 | 5,038.20 | 14,151.73 | 4,836.41 | |
| 5 | D16 Rebar | Kg | Gross Requirement | | 2,130.82 | 1,196.91 | 2,130.82 | 1,196.91 | 2,015.78 | 1,196.91 | 2,015.78 | 1,196.91 | 2,414.75 | 797.94 | 2,530.44 | 797.94 | 2,525.67 | 790.55 |
| | | | On Hand Inventory | 3,181.73 | 1,050.91 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | | Net Requirement | | | 146.00 | | | | | | | | | | | | |
| | | | Order Receipt | | | 146.00 | 2,130.82 | 1,196.91 | 2,015.78 | 1,196.91 | 2,015.78 | 1,196.91 | 2,414.75 | 797.94 | 2,530.44 | 797.94 | 2,525.67 | 790.55 |
| | | | Order Release | | 146.00 | 2,130.82 | 1,196.91 | 2,015.78 | 1,196.91 | 2,015.78 | 1,196.91 | 2,414.75 | 797.94 | 2,530.44 | 797.94 | 2,525.67 | 790.55 | |
| 6 | D19 Rebar | Kg | Gross Requirement | | 9,173.68 | 5,591.99 | 12,418.93 | 5,591.99 | 8,154.84 | 5,605.42 | 8,154.84 | 5,605.42 | 8,375.99 | 5,384.26 | 11,308.86 | 5,384.26 | 9,666.93 | 5,076.80 |
| | | | On Hand Inventory | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | | Net Requirement | | 9,173.68 | | | | | | | | | | | | | |
| | | | Order Receipt | | 9,173.68 | 5,591.99 | 12,418.93 | 5,591.99 | 8,154.84 | 5,605.42 | 8,154.84 | 5,605.42 | 8,375.99 | 5,384.26 | 11,308.86 | 5,384.26 | 9,666.93 | 5,076.80 |
| | | | Order Release | 9,173.68 | 5,591.99 | 12,418.93 | 5,591.99 | 8,154.84 | 5,605.42 | 8,154.84 | 5,605.42 | 8,375.99 | 5,384.26 | 11,308.86 | 5,384.26 | 9,666.93 | 5,076.80 | |
| 7 | D22 Rebar | Kg | Gross Requirement | | 4,720.26 | 850.04 | 4,720.26 | 850.04 | 4,163.62 | 850.04 | 4,163.62 | 850.04 | 4,446.96 | 566.69 | 5,009.60 | 566.69 | 5,009.59 | 566.68 |
| | | | On Hand Inventory | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | | | Net Requirement | | 4,720.26 | | | | | | | | | | | | | |
| | | | Order Receipt | | 4,720.26 | 850.04 | 4,720.26 | 850.04 | 4,163.62 | 850.04 | 4,163.62 | 850.04 | 4,446.96 | 566.69 | 5,009.60 | 566.69 | 5,009.59 | 566.68 |
| | | | Order Release | 4,720.26 | 850.04 | 4,720.26 | 850.04 | 4,163.62 | 850.04 | 4,163.62 | 850.04 | 4,446.96 | 566.69 | 5,009.60 | 566.69 | 5,009.59 | 566.68 | |
| 8 | D32 Rebar | Kg | Gross Requirement | | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 5,307.76 | 1,691.15 |
| | | | On Hand Inventory | 11,969.37 | 5,734.57 | 3,773.06 | - | - | - | - | - | - | - | - | - | - | - | - |
| | | | Net Requirement | | | | 2,461.75 | | | | | | | | | | | |
| | | | Order Receipt | | | | 2,461.75 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 5,307.76 | 1,691.15 |
| | | | Order Release | | | 2,461.75 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 6,234.80 | 1,961.51 | 5,307.76 | 1,691.15 | |

## Comparison of Total Inventory Costs

Subsequently, the procurement costs for all types of rebar are calculated using both lot-sizing techniques, as shown in Table 11 and Table 12. These procurement costs are then compared to identify with the technique that results in the lowest procurement cost as shown in Table 13 and Figure 5. Among the two lot-sizing techniques, the Silver Meal Algorithm achieved the lowest procurement cost. This is consistent with the findings of studies conducted by Asmal et al., [23], Ikasari et al., [24], and Ernawati et al., [25]. The Silver Meal Algorithm is generally more effective for most materials, particularly those with high-volume demands and fluctuating demand patterns.

Table 11. Total Inventory Cost using Silver-Meal Algorithm

| No | Rebar Type | Purchasing Costs | Ordering Costs | Storage Costs | Total Inventory Costs |
|---|---|---|---|---|---|
| 1 | Ø8 | IDR 20,101,563 | IDR 846,382 | IDR 167,055 | IDR 21,115,000 |
| 2 | Ø10 | IDR 47,624,776 | IDR 2,005,254 | IDR 111,370 | IDR 49,741,400 |
| 3 | D10 | IDR 136,458,786 | IDR 5,745,633 | IDR 222,740 | IDR 142,427,159 |
| 4 | D13 | IDR 1,259,231,592 | IDR 53,020,278 | IDR 194,898 | IDR 1,312,446,767 |
| 5 | D16 | IDR 154,685,487 | IDR 7,902,565 | IDR 167,055 | IDR 162,755,107 |
| 6 | D19 | IDR 1,002,195,163 | IDR 42,197,691 | IDR 306,268 | IDR 1,044,699,121 |
| 7 | D22 | IDR 354,674,272 | IDR 14,933,654 | IDR 194,898 | IDR 369,802,823 |
| 8 | D32 | IDR 419,970,612 | IDR 17,682,973 | IDR 167,055 | IDR 437,820,640 |

Table 12. Total Inventory Cost using Wagner-Whitin Algorithm

| No | Rebar Type | Purchasing Costs | Ordering and Storage Costs | Total Inventory Costs |
|---|---|---|---|---|
| 1 | Ø8 | IDR 20,101,563 | IDR 8,420,654 | IDR 28,522,217 |
| 2 | Ø10 | IDR 47,624,776 | IDR 8,544,449 | IDR 56,169,225 |
| 3 | D10 | IDR 136,458,786 | IDR 32,504,695 | IDR 168,963,481 |
| 4 | D13 | IDR 1,259,231,592 | IDR 410,492,529 | IDR 1,669,724,121 |
| 5 | D16 | IDR 180,175,707 | IDR 53,161,683 | IDR 233,337,390 |
| 6 | D19 | IDR 1,002,195,163 | IDR 324,446,618 | IDR 1,326,641,781 |
| 7 | D22 | IDR 354,674,272 | IDR 117,405,229 | IDR 472,079,501 |
| 8 | D32 | IDR 419,970,612 | IDR 114,030,026 | IDR 534,000,637 |

Table 13. Comparison of Total MRP Costs

| No | Rebar Type | Total Cost Material Inventory | |
|---|---|---|---|
| | | Silver Meal Algorithm | Wagner Whitin Algorithm |
| 1 | Ø8 | IDR 21,115,000 | IDR 28,522,217 |
| 2 | Ø10 | IDR 49,741,400 | IDR 56,169,225 |
| 3 | D10 | IDR 142,427,159 | IDR 168,963,481 |
| 4 | D13 | IDR 1,312,446,767 | IDR 1,669,724,121 |
| 5 | D16 | IDR 162,755,107 | IDR 233,337,390 |
| 6 | D19 | IDR 1,044,699,121 | IDR 1,326,641,781 |
| 7 | D22 | IDR 369,802,823 | IDR 472,079,501 |
| 8 | D32 | IDR 437,820,640 | IDR 534,000,637 |
| **Total Material Inventory Costs** | | **IDR 3,540,808,017** | **IDR 4,489,438,354** |

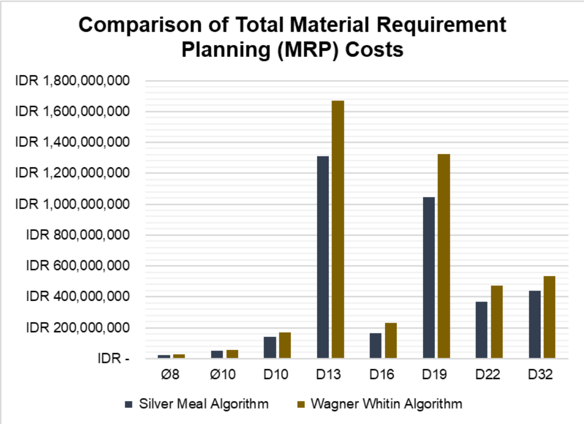


Figure 5. Graphic Comparison of Total Costs Material Requirement Planning (MRP)

In contrast, the Wagner-Whitin Algorithm is better suited for materials with stable demand patterns and relatively small order volumes.

In previous studies by Awati and Putra [21] as well as Cahyani and Putra [22], supporting data were obtained from the bill of quantity for rebar (project data), which was then multiplied by 1.05 to account for leftover materials. In this study, rebar requirement data were based on the detailed engineering design input into the TRB Cubicost application, followed by an analysis to obtain the rebar quantity. Based on the resulting rebar quantity, it was multiplied by 1.05 to account for material waste.

## CONCLUSION

Based on the analysis above, The calculation using the Cubicost TRB application estimated a total rebar requirement of 395,984.76 kg, while project data indicated 399,648.92 kg. This finding demonstrates that using the Cubicost TRB application is more advantageous, reducing the rebar requirement by 3,664.17 kg, or 1%, equivalent to a cost saving of IDR 34,809,591. Additionally, the Silver-Meal Algorithm resulted in a lower total procurement cost (IDR 3,540,808,017) compared to the Wagner-Whitin Algorithm (IDR 4,489,438,354). These results indicate that the Silver-Meal Algorithm is 21% more cost-effective in minimizing the total inventory cost of rebar compared to the Wagner-Whitin method. Although in this study the Silver-Meal Algorithm resulted in lower costs compared to the Wagner-Whitin Algorithm, this outcome does not always apply in all conditions. The effectiveness of each method depends on the demand pattern. The Wagner-Whitin Algorithm is more suitable for stable demand conditions that require a structured solution, while the Silver-Meal Algorithm is more practical for cases with varying demand. This cost-effectiveness comparison varies by rebar type, with D13 and D19 showing the most significant differences, while Ø8 and Ø10 exhibited minimal variation. For Ø8 rebar, the total cost using the Silver-Meal Algorithm was slightly higher than that of the Wagner-Whitin Algorithm.

The findings of this study provide recommendations for contractors to adopt the Cubicost TRB application for more accurate material estimation. To ensure the accuracy of data generated by the Cubicost application, it is crucial to design rebar details with high precision that reflects actual site conditions. This ensures that rebar requirements are calculated accurately. However, the Cubicost TRB application does not allow the simultaneous display of all structures, making it challenging to visually verify that the rebar details are accurately represented according to site conditions. Furthermore, contractors are encouraged to select the most appropriate algorithm based on the type and demand pattern of materials to minimize total costs and improve material planning efficiency. The choice of method depends on the demand pattern, with the Wagner-Whitin Algorithm being more suitable for stable demand conditions that require a structured approach, while the Silver-Meal Algorithm is more practical for varying demand patterns.

Based on these findings, future research can further evaluate the accuracy of Cubicost TRB by comparing it with other software and testing its application in larger, more complex structures. The Silver-Meal and Wagner-Whitin algorithms can also be applied to other materials to assess their effectiveness in inventory optimization. Additionally, integrating Cubicost TRB into construction management systems could enhance quantity takeoff validation, ensuring better alignment with site conditions.

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Master Project Schedule

| No | Job Descripton | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | **Beam and Slab of the 7th Floor** | **14 days** | **07/05/24** | **18/07/24** |
| | **Zone 1** | **7 days** | **07/05/24** | **11/07/24** |
| | -Formwork | 3 days | 07/05/24 | 07/07/24 |
| | -Reinforcement Bar Work | 3 days | 07/08/24 | 10/07/24 |
| | -Concreting | 1 day | 07/11/24 | 11/07/24 |
| | **Zone 2** | **7 days** | **07/12/24** | **18/07/24** |
| | -Formwork | 3 days | 07/12/24 | 14/07/24 |
| | -Reinforcement Bar Work | 3 days | 07/15/24 | 17/07/24 |
| | -Concreting | 1 day | 07/18/24 | 18/07/24 |
| 2 | **Column and Shear Wall of the 7th Floor** | **13 days** | **07/12/24** | **24/07/24** |
| | **Zone 1** | **6 days** | **07/12/24** | **17/07/24** |
| | -Formwork | 2 days | 07/15/24 | 16/07/24 |
| | -Reinforcement Bar Work | 3 days | 07/12/24 | 14/07/24 |
| | -Concreting | 1 day | 07/17/24 | 17/07/24 |
| | **Zone 2** | **6 days** | **07/19/24** | **24/07/24** |
| | -Formwork | 2 days | 07/22/24 | 23/07/24 |
| | -Reinforcement Bar Work | 3 days | 07/19/24 | 21/07/24 |
| | -Concreting | 1 day | 07/24/24 | 24/07/24 |
| 3 | **Beam and Slab of the 8th Floor** | **14 days** | **07/19/24** | **01/08/24** |
| | **Zone 1** | **7 days** | **07/19/24** | **25/07/24** |
| | -Formwork | 3 days | 07/19/24 | 21/07/24 |
| | -Reinforcement Bar Work | 3 days | 07/22/24 | 24/07/24 |
| | -Concreting | 1 day | 07/25/24 | 25/07/24 |
| | **Zone 2** | **7 days** | **07/26/24** | **01/08/24** |
| | -Formwork | 3 days | 07/26/24 | 28/07/24 |
| | -Reinforcement Bar Work | 3 days | 07/29/24 | 31/07/24 |
| | -Concreting | 1 day | 08/01/24 | 01/08/24 |
| 4 | **Column and Shear Wall of the 8th Floor** | **13 days** | **07/26/24** | **07/08/24** |
| | **Zone 1** | **6 days** | **07/26/24** | **31/07/24** |
| | -Formwork | 2 days | 07/29/24 | 30/07/24 |
| | -Reinforcement Bar Work | 3 days | 07/26/24 | 28/07/24 |
| | -Concreting | 1 day | 07/31/24 | 31/07/24 |
| | **Zone 2** | **6 days** | **08/02/24** | **07/08/24** |
| | -Formwork | 2 days | 08/05/24 | 06/08/24 |
| | -Reinforcement Bar Work | 3 days | 08/02/24 | 04/08/24 |
| | -Concreting | 1 day | 08/07/24 | 07/08/24 |
| 5 | **Beam and Slab of the 9th Floor** | **14 days** | **08/02/24** | **15/08/24** |
| | **Zone 1** | **7 days** | **08/02/24** | **08/08/24** |
| | -Formwork | 3 days | 08/02/24 | 04/08/24 |
| | -Reinforcement Bar Work | 3 days | 08/05/24 | 07/08/24 |
| | -Concreting | 1 day | 08/08/24 | 08/08/24 |
| | **Zone 2** | **7 days** | **08/09/24** | **15/08/24** |
| | -Formwork | 3 days | 08/09/24 | 11/08/24 |
| | -Reinforcement Bar Work | 3 days | 08/12/24 | 14/08/24 |
| | -Concreting | 1 day | 08/15/24 | 15/08/24 |
| 6 | **Column and Shear Wall of the 9th Floor** | **13 days** | **08/09/24** | **21/08/24** |
| | **Zone 1** | **6 days** | **08/09/24** | **14/08/24** |
| | -Formwork | 2 days | 08/12/24 | 13/08/24 |
| | -Reinforcement Bar Work | 3 days | 08/09/24 | 11/08/24 |
| | -Concreting | 1 day | 08/14/24 | 14/08/24 |
| | **Zone 2** | **6 days** | **08/16/24** | **21/08/24** |
| | -Formwork | 2 days | 08/19/24 | 20/08/24 |
| | -Reinforcement Bar Work | 3 days | 08/16/24 | 18/08/24 |
| | -Concreting | 1 day | 08/21/24 | 21/08/24 |
| 1 | **Beam and Slab of the 10th Floor** | **14 days** | **08/16/24** | **29/08/24** |
| | **Zone 1** | **7 days** | **08/16/24** | **22/08/24** |
| | -Formwork | 3 days | 08/16/24 | 18/08/24 |
| | -Reinforcement Bar Work | 3 days | 08/19/24 | 21/08/24 |
| | -Concreting | 1 day | 08/22/24 | 22/08/24 |
| | **Zone 2** | **7 days** | **08/23/24** | **29/08/24** |
| | -Formwork | 3 days | 08/23/24 | 25/08/24 |
| | -Reinforcement Bar Work | 3 days | 08/26/24 | 28/08/24 |
| | -Concreting | 1 day | 08/29/24 | 29/08/24 |
| 2 | **Column and Shear Wall of the 10th Floor** | **13 days** | **08/23/24** | **04/09/24** |
| | **Zone 1** | **6 days** | **08/23/24** | **28/08/24** |
| | -Formwork | 2 days | 08/26/24 | 27/08/24 |
| | -Reinforcement Bar Work | 3 days | 08/23/24 | 25/08/24 |
| | -Concreting | 1 day | 08/28/24 | 28/08/24 |
| | **Zone 2** | **6 days** | **08/30/24** | **04/09/24** |
| | -Formwork | 2 days | 09/02/24 | 03/09/24 |
| | -Reinforcement Bar Work | 3 days | 08/30/24 | 01/09/24 |
| | -Concreting | 1 day | 09/04/24 | 04/09/24 |
| 7 | **Beam and Slab of the 11th Floor** | **13 days** | **08/30/24** | **11/09/24** |
| | **Zone 1** | **7 days** | **08/30/24** | **05/09/24** |
| | -Formwork | 3 days | 08/30/24 | 01/09/24 |
| | -Reinforcement Bar Work | 3 days | 09/02/24 | 04/09/24 |
| | -Concreting | 1 day | 09/05/24 | 05/09/24 |
| | **Zone 2** | **7 days** | **09/05/24** | **11/09/24** |
| | -Formwork | 3 days | 09/05/24 | 07/09/24 |
| | -Reinforcement Bar Work | 3 days | 09/08/24 | 10/09/24 |
| | -Concreting | 1 day | 09/11/24 | 11/09/24 |
| 8 | **Column and Shear Wall of the 11th Floor** | **12 days** | **09/06/24** | **17/09/24** |
| | **Zone 1** | **6 days** | **09/06/24** | **11/09/24** |
| | -Formwork | 2 days | 09/09/24 | 10/09/24 |
| | -Reinforcement Bar Work | 3 days | 09/06/24 | 08/09/24 |
| | -Concreting | 1 day | 09/11/24 | 11/09/24 |
| | **Zone 2** | **6 days** | **09/12/24** | **17/09/24** |
| | -Formwork | 2 days | 09/15/24 | 16/09/24 |
| | -Reinforcement Bar Work | 3 days | 09/12/24 | 14/09/24 |
| | -Concreting | 1 day | 09/17/24 | 17/09/24 |
| 9 | **Beam and Slab of the 12th Floor** | **13 days** | **09/13/24** | **25/09/24** |
| | **Zone 1** | **7 days** | **09/13/24** | **19/09/24** |
| | -Formwork | 3 days | 09/13/24 | 15/09/24 |
| | -Reinforcement Bar Work | 3 days | 09/16/24 | 18/09/24 |
| | -Concreting | 1 day | 09/19/24 | 19/09/24 |
| | **Zone 2** | **7 days** | **09/19/24** | **25/09/24** |
| | -Formwork | 3 days | 09/19/24 | 21/09/24 |
| | -Reinforcement Bar Work | 3 days | 09/22/24 | 24/09/24 |
| | -Concreting | 1 day | 09/25/24 | 25/09/24 |
| 10 | **Column and Shear Wall of the 12th Floor** | **12 days** | **09/20/24** | **01/10/24** |
| | **Zone 1** | **6 days** | **09/20/24** | **25/09/24** |
| | -Formwork | 2 days | 09/23/24 | 24/09/24 |
| | -Reinforcement Bar Work | 3 days | 09/20/24 | 22/09/24 |
| | -Concreting | 1 day | 09/25/24 | 25/09/24 |
| | **Zone 2** | **6 days** | **09/26/24** | **01/10/24** |
| | -Formwork | 2 days | 09/29/24 | 30/09/24 |
| | -Reinforcement Bar Work | 3 days | 09/26/24 | 28/09/24 |
| | -Concreting | 1 day | 10/01/24 | 01/10/24 |
| 11 | **Beam and Slab of the 13th Floor** | **13 days** | **09/27/24** | **09/10/24** |
| | **Zone 1** | **7 days** | **09/27/24** | **03/10/24** |
| | -Formwork | 3 days | 09/27/24 | 29/09/24 |
| | -Reinforcement Bar Work | 3 days | 09/30/24 | 02/10/24 |
| | -Concreting | 1 day | 10/03/24 | 03/10/24 |
| | **Zone 2** | **7 days** | **10/03/24** | **09/10/24** |
| | -Formwork | 3 days | 10/03/24 | 05/10/24 |
| | -Reinforcement Bar Work | 3 days | 10/06/24 | 08/10/24 |
| | -Concreting | 1 day | 10/09/24 | 09/10/24 |
| 12 | **Column and Shear Wall of the 13th Floor** | **12 days** | **10/04/24** | **15/10/24** |
| | **Zone 1** | **6 days** | **10/04/24** | **09/10/24** |
| | -Formwork | 2 days | 10/07/24 | 08/10/24 |
| | -Reinforcement Bar Work | 3 days | 10/04/24 | 06/10/24 |
| | -Concreting | 1 day | 10/09/24 | 09/10/24 |
| | **Zone 2** | **6 days** | **10/10/24** | **15/10/24** |
| | -Formwork | 2 days | 10/13/24 | 14/10/24 |
| | -Reinforcement Bar Work | 3 days | 10/10/24 | 12/10/24 |
| | -Concreting | 1 day | 10/15/24 | 15/10/24 |