



An Integrated Decision Support Framework for Demand Forecasting and Gypsum Inventory Optimization in Cement Manufacturing

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SUBMITTED: 28 July 2026; REVISED: 9 September 2026; ACCEPTED: 10 September 2026

ABSTRACT: This study developed an integrated decision support framework that linked gypsum demand forecasting with the Economic Order Quantity (EOQ) and Periodic Order Quantity (POQ) inventory control methods. Historical gypsum consumption data from PT Lafarge Cement Indonesia for 2023–2024, together with ordering costs, holding costs, and replenishment lead times, were analyzed to develop an inventory planning strategy for 2025. Three forecasting methods quadratic, exponential, and cyclical forecasting were evaluated using Mean Absolute Percentage Error (MAPE), and the model with the lowest MAPE was selected to estimate future gypsum demand. The results showed that the selected cyclical forecasting method predicted an annual gypsum demand of 73,167.64 tons for 2025. Under the existing inventory policy, the total inventory cost was IDR6,475,551.63. The EOQ model yielded an optimal order quantity of 6,233 tons and a total inventory cost of IDR5,297,287.41, representing savings of IDR1,178,264.22, or 18.20%. The POQ model resulted in a replenishment interval of approximately 1.02 months, with a safety stock of 15,712.24 tons and a reorder point of 22,475.05 tons. This approach resulted in a total inventory cost of IDR5,239,614.91. Compared with the existing policy, the POQ model provided estimated savings of IDR1,235,936.72, equivalent to a 19.09% reduction in inventory costs. These findings demonstrated that integrating demand forecasting with EOQ and POQ provided a practical approach to improving gypsum inventory planning, reducing inventory costs, and maintaining material availability in cement manufacturing.

Keywords: Gypsum inventory; demand forecasting; EOQ; POQ; inventory optimization

1. Introduction

Building and infrastructure sectors continued to grow, resulting in increased demand for cement. Consequently, cement manufacturers needed to maintain efficient and uninterrupted production processes. The production of Ordinary Portland Cement (OPC) and Portland Composite Cement (PCC) required several raw materials and additives, including gypsum.

Although gypsum was used in smaller quantities than limestone or clinker, it played an important role in controlling cement setting time and ensuring the stability of the finishing process. Inadequate gypsum inventory could cause material shortages and production interruptions, whereas excessive inventory could increase storage and inventory costs [1–3]. Therefore, effective gypsum inventory planning was essential for cement manufacturers, particularly when demand and production requirements fluctuated.

Inventory planning under uncertain demand involved two interrelated decisions: estimating future material requirements and determining an appropriate replenishment strategy. Demand forecasting provided estimates of the quantities of materials required in future periods, whereas inventory control determined when orders should be placed and how much material should be ordered. Time-series forecasting methods, including exponential smoothing and ARIMA, had been widely applied to identify trends, patterns, and fluctuations in demand [4–8]. Although these methods provided useful demand estimates, forecasting accuracy alone did not establish an economically efficient replenishment policy. A forecast could indicate expected future demand but did not directly determine the optimal order quantity, ordering frequency, safety stock, or reorder point. Therefore, using forecasting as a standalone decision-making tool could create a gap between demand estimation and practical inventory decisions.

In contrast, traditional inventory management models, such as EOQ and POQ, provided quantitative mechanisms for determining replenishment decisions based on demand and inventory-related costs [9–13]. EOQ determined an economically optimal order quantity by balancing ordering and holding costs, whereas POQ determined an appropriate replenishment interval based on periodic demand requirements. Nevertheless, these models were commonly applied using historical or assumed demand parameters and might not accurately represent future variations when demand changed over time. In particular, applying a fixed demand parameter to a material with variable consumption could result in order quantities or replenishment intervals that did not correspond to actual future production requirements. Therefore, inventory control models should not be considered independently of demand forecasting when the objective was to improve inventory planning under demand uncertainty.

Previous studies had addressed various aspects of demand forecasting and inventory control; however, several important research gaps remained. First, many demand forecasting studies primarily emphasized model accuracy and forecast errors, with limited consideration of how forecast results could be translated into practical inventory replenishment decisions [3, 14, 15]. Consequently, a highly accurate forecast did not necessarily result in lower inventory costs or improved ordering performance. Second, studies applying EOQ or POQ generally focused on optimizing order quantities, ordering frequencies, or inventory costs without integrating forecasting methods capable of representing expected future demand patterns [10, 16–18]. Such approaches might therefore be less responsive when material demand varied over time.

Furthermore, most studies integrating forecasting and inventory management had focused on general materials or other industrial applications, with limited attention given to cement additives such as gypsum. This issue was particularly important because gypsum consumption was closely associated with clinker production and the cement finishing process. Excessive gypsum inventory could also create storage constraints and increase working capital requirements. Therefore, the application of an integrated forecasting and inventory control framework to gypsum represented an important area for further investigation.

Gypsum inventory management presented specific challenges within the cement industry. Unlike conventional purchasing decisions, gypsum inventory planning required consideration of continuous cement production and the need to maintain adequate material availability. Excessive gypsum inventory could result in limited storage capacity, increased material-handling requirements, potential material deterioration, and unnecessary capital tied up in inventory. Therefore, effective gypsum inventory planning required consideration of future demand trends, replenishment quantities, ordering frequencies, safety stock levels, reorder points, and total inventory costs. Approaches that evaluated these factors independently could be insufficient because they did not establish a clear analytical relationship between expected material consumption and the resulting inventory strategy.

To address these limitations, this study developed an integrated decision-support framework that linked demand forecasting with EOQ and POQ inventory control. Rather than treating forecasting and inventory management as separate analytical activities, the proposed framework used forecasted gypsum demand to determine replenishment requirements and subsequently evaluated the economic implications of alternative inventory strategies. The framework also incorporated safety stock, reorder points, ordering frequency, and total inventory costs to provide a comprehensive assessment of inventory performance. This integration was particularly relevant to gypsum because its consumption was closely associated with cement production requirements, necessitating an inventory policy that could respond to changes in expected demand.

The novelty of this study was the integration of cyclical demand forecasting with EOQ and POQ within a sequential inventory decision-support framework. Cyclical forecasting was used to identify recurring patterns in historical gypsum consumption, and the resulting demand estimates served as inputs for EOQ and POQ calculations. In addition, the framework was empirically evaluated using actual operational data from PT Lafarge Cement Indonesia, providing an industry-based application rather than a purely theoretical evaluation of inventory models. The principal contribution of the study was therefore the direct linkage between forecasted demand and inventory control decisions, followed by an evaluation of the resulting policies based on their operational and economic performance. This approach provided a more practical basis for gypsum inventory planning than methods that evaluated forecasting accuracy or inventory cost optimization independently.

Accordingly, this study aimed to develop and evaluate an integrated gypsum inventory planning framework that combined cyclical demand forecasting with EOQ and POQ inventory control at PT Lafarge Cement Indonesia. The analysis examined key inventory parameters, including forecasted demand, order quantity, ordering frequency, safety stock, reorder point, and total inventory cost. By linking demand forecasts with replenishment strategies, the proposed framework was intended to provide a more responsive and cost-effective approach to inventory planning while contributing practical insights into the management of additive raw materials in cement manufacturing.

2. Research Methods

2.1. Study Area and Data Collection.

The research was conducted at PT Lafarge Cement Indonesia to develop a gypsum inventory plan for cement manufacturing. Both primary and secondary data were used. Secondary data

were provided by the company and included historical gypsum consumption, ordering costs, holding costs, and replenishment lead times. Historical gypsum demand data covered the period from January 2023 to December 2024, while the forecasting horizon was 2025. Primary data were collected through interviews with staff members involved in gypsum procurement and inventory management to determine the company's existing ordering patterns, inventory policies, and replenishment procedures. The historical demand dataset consisted of 24 monthly observations of gypsum consumption from 2023 to 2024. These data were used to identify demand patterns and develop the forecasting models. The resulting demand forecast for 2025 was subsequently used as an input for the proposed inventory control policies.

The main parameters used in the inventory analysis were annual demand (D), order quantity (Q), ordering cost per order (S), annual holding cost per unit (H), and replenishment lead time. The company's actual fixed order quantity was not available from its records. Therefore, an estimated order quantity of 12,000 tons was used to represent the existing inventory practice. This value was derived from the observed minimum and maximum gypsum inventory levels of approximately 4,000 and 16,000 tons, respectively, based on the assumption that the effective replenishment quantity corresponded to the difference between the upper and lower inventory levels. The value of 12,000 tons was therefore treated as an estimated benchmark for the existing inventory policy rather than as a directly reported company parameter. This assumption was explicitly stated and consistently applied when comparing the existing practice with the proposed EOQ and POQ policies.

2.2. Demand Forecasting Methods.

Three forecasting approaches were evaluated to estimate gypsum demand for 2025: quadratic, exponential, and cyclical forecasting. These methods were selected to represent different demand patterns and to identify the model that best represented the historical gypsum consumption data. The quadratic forecasting model was used to capture nonlinear trends in gypsum demand. The general form of the quadratic model was expressed as:

$$\hat{Y}_t = a + bt + ct^2$$

where $\hat{Y}_t$ is the forecasted demand in period t , t is the time variable, and a , b , and c are the estimated model parameters.

Exponential forecasting was used to represent demand patterns characterized by exponential trends. The general form was expressed as:

$$\hat{Y}_t = ae^{bt}$$

where $\hat{Y}_t$ is the forecasted demand in period t , t is the time variable, and a and b are the estimated model parameters.

Cyclical forecasting was applied to capture recurring fluctuations in gypsum demand. This approach was considered appropriate for representing recurring demand patterns associated with variations in production and market conditions. The forecasting models were developed using the 24 monthly observations from January 2023 to December 2024. Each model generated monthly demand forecasts for 2025. Forecasting performance was evaluated

using the Mean Absolute Percentage Error (MAPE), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE). MAPE measured the average percentage deviation between actual and forecasted demand, MAE measured the average absolute forecast error in tons, and RMSE measured the square root of the mean squared forecast errors, thereby assigning greater weight to larger deviations. These metrics provided a more comprehensive assessment of forecasting performance. MAPE was calculated as:

$$MAPE = \frac{\sum_{t=1}^n |PE_t|}{n}$$

With Percentage Error (PE_t) is

$$PE_t = \left(\frac{T_t - Y'_t}{T_t} \right) \times 100\%$$

where (T_t) is the actual demand, (Y'_t) is the forecasted demand, and (n) is the number of observations. The forecasting model with the lowest MAPE was selected as the best-performing model and its 2025 forecast was subsequently used as the demand input for the inventory control analysis. Based on the selected forecasting model, the estimated gypsum demand for 2025 was 73,167.64 tons.

2.3. Inventory Control Models.

Following the demand forecasting analysis, inventory optimization was conducted using the EOQ and POQ methods. The forecasted annual gypsum demand for 2025 was consistently used as the demand parameter for both inventory control approaches.

2.3.1 EOQ.

The EOQ model was applied to determine the optimal order quantity that minimized the combined ordering and holding costs. The EOQ was calculated as:

$$EOQ = \sqrt{\frac{2SD}{H}}$$

where D is the annual gypsum demand (tons/year), S is the ordering cost per order (IDR/order), and H is the annual holding cost per ton (IDR/ton/year).

The number of orders per year was calculated as:

$$TIC = \frac{D}{Q} \times S + \frac{Q}{2} \times h$$

Safety stock and the reorder point were also determined to maintain adequate gypsum availability during the replenishment lead time.

2.3.2 POQ.

The POQ method was applied to determine an appropriate replenishment interval based on forecasted demand and inventory requirements. Unlike EOQ, which determines a fixed quantity for each order, POQ determines the appropriate interval between replenishments. The POQ analysis considered forecasted demand, ordering costs, holding costs, and replenishment requirements. The resulting replenishment interval was subsequently used to determine the corresponding order quantity for each replenishment cycle. For both the EOQ and POQ analyses, several common assumptions were applied. Demand during the planning horizon was based on the selected 2025 forecast; ordering and holding costs were assumed to remain constant throughout the analysis period; replenishment lead time was assumed to follow the company's observed lead-time conditions; shortages were not intentionally planned; and both inventory policies were evaluated using the same cost parameters to ensure a consistent comparison.

2.4. Inventory Performance Evaluation.

The performance of the proposed EOQ and POQ policies was evaluated against the company's existing inventory practice based on order quantity, ordering frequency, safety stock, reorder point, and total inventory cost. Total inventory cost was calculated as the sum of annual ordering and holding costs.

Under the company's existing inventory policy, the forecasted annual gypsum demand was 73,167.64 tons, the estimated order quantity was 12,000 tons, the ordering cost was IDR225,600 per order, and the annual holding cost was IDR850 per ton. Based on these parameters, the total inventory cost was estimated at IDR6,475,551.63.

The EOQ analysis produced an optimal order quantity of 6,233 tons. At this order quantity, the annual ordering cost was IDR2,648,262.41 and the annual holding cost was IDR2,649,025.00, resulting in a total inventory cost of IDR5,297,287.41. Compared with the company's existing inventory cost of IDR6,475,551.63, the EOQ policy generated estimated savings of IDR1,178,264.22, equivalent to an 18.20% reduction in total inventory cost.

The same evaluation procedure was applied to the POQ policy. The POQ analysis resulted in a replenishment interval of approximately 1.02 months, a safety stock of 15,712.24 tons, and a reorder point of 22,475.05 tons. The resulting total inventory cost was IDR5,239,614.91. Compared with the company's existing policy, POQ generated estimated savings of IDR1,235,936.72, corresponding to a 19.09% reduction in total inventory cost. Therefore, although both methods improved inventory cost efficiency, POQ provided slightly greater cost savings than EOQ under the analyzed conditions.

2.5. Statistical Analysis and Model Selection.

The statistical analysis focused on evaluating the predictive accuracy of the three demand forecasting models. Mean Absolute Percentage Error (MAPE) was used as the primary model-selection criterion because it expressed forecasting errors as percentages, enabling direct comparison among the forecasting methods. Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) were used as complementary measures to assess the magnitude of forecasting errors. MAPE, MAE, and RMSE were calculated using the historical monthly demand observations. The forecasting models were ranked primarily according to their MAPE

values, and the model with the lowest MAPE was selected as the final model. No additional statistical significance tests were performed because the objective of the forecasting analysis was to identify the model with the highest predictive accuracy rather than to test statistical hypotheses. The selected forecasting model was subsequently used as the demand input for both EOQ and POQ calculations. All forecasting, inventory optimization, and cost-comparison calculations were performed using spreadsheet-based analytical tools. The procedures were structured to ensure that the forecasting results, inventory parameters, and cost estimates could be reproduced using the reported historical demand and inventory cost data.

4. Results and Discussions

4.1. Forecasting Performance.

The forecasting analysis was based on historical gypsum consumption from January 2023 to December 2024, together with relevant inventory parameters, including ordering costs, holding costs, and replenishment lead times. The average ordering cost was estimated at IDR225,600 per order. Historical gypsum consumption was first analyzed to characterize the underlying demand pattern before forecasting the material requirements for 2025. As presented in Table 1, monthly gypsum consumption fluctuated considerably during the 24-month observation period. In 2023, consumption ranged from 5,045 tons in June to 7,779 tons in November, whereas in 2024 it ranged from 2,535 tons in July to 7,232 tons in April. These variations indicated that gypsum requirements were not constant across months and supported the need for a forecasting approach capable of representing temporal fluctuations rather than relying solely on average historical consumption.

Table 1. Historical gypsum consumption at PT Lafarge Cement Indonesia.

Year	Month	Period (t)	Amount Used (y) (Tons)
2023	January	1	6198
	February	2	7347
	March	3	7524
	April	4	7150
	Mei	5	5123
	Juny	6	5045
	July	7	5935
	August	8	6038
	September	9	5265
	Oktober	10	6135
	November	11	7779
	Desember	12	6165
2024	January	13	5065
	February	14	5174
	March	15	4497
	April	16	7232
	Mei	17	7128
	Juny	18	4541
	July	19	2535
	August	20	4067
	September	21	5584
	Oktober	22	6087
	November	23	4555
	Desember	24	4116

The temporal distribution of historical gypsum consumption is illustrated in Figure 1. The figure provides a clearer representation of month-to-month fluctuations and shows that the

consumption pattern did not follow a simple constant trend. The presence of repeated increases and decreases provided the basis for evaluating forecasting methods capable of representing nonlinear and cyclical behavior.



Figure 1. Monthly distribution of gypsum consumption during 2023–2024.

Three forecasting methods—quadratic, exponential, and cyclical forecasting—were evaluated to determine the most appropriate model for estimating gypsum demand. Among these alternatives, the cyclical method was selected based on forecasting-error performance. The parameter calculations used to construct the cyclical forecasting model are presented in Table 2. These calculations incorporated the 24 historical observations and the corresponding cyclical components used to estimate monthly gypsum consumption.

Table 2. Parameter estimation for the cyclical forecasting model.

Year	t	Actual y (tons)	$\sin \theta$	$\cos \theta$	$y \sin \theta$	$y \cos \theta$	$\sin^2 \theta$	$\cos^2 \theta$	$\sin \theta \cos \theta$	Forecast $\hat{y}$ (tons)
2023	1	6,198	0.26	0.97	1,611.48	6,012.06	0.07	0.94	0.25	5,660.09
	2	7,347	0.50	0.87	3,673.50	6,391.89	0.25	0.76	0.44	5,831.32
	3	7,524	0.71	0.71	5,342.04	5,342.04	0.50	0.50	0.50	5,994.86
	4	7,150	0.87	0.50	6,220.50	3,575.00	0.76	0.25	0.44	6,136.12
	5	5,123	0.97	0.26	4,969.31	1,331.98	0.94	0.07	0.25	6,244.98
	6	5,045	1.00	0.00	5,045.00	0.00	1.00	0.00	0.00	6,313.19
	7	5,935	0.97	-0.26	5,756.95	-1,543.10	0.94	0.07	-0.25	6,343.32
	8	6,038	0.87	-0.50	5,253.06	-3,019.00	0.76	0.25	-0.44	6,325.25
	9	5,265	0.71	-0.71	3,738.15	-3,738.15	0.50	0.50	-0.50	6,263.42
	10	6,135	0.50	-0.87	3,067.50	-5,337.45	0.25	0.76	-0.44	6,160.41
	11	7,779	0.26	-0.97	2,022.54	-7,545.63	0.07	0.94	-0.25	6,027.01
	12	6,165	0.00	-1.00	0.00	-6,165.00	0.00	1.00	0.00	5,867.67
2024	13	5,065	-0.26	-0.97	-1,316.90	-4,913.05	0.07	0.94	0.25	5,696.99
	14	5,174	-0.50	-0.87	-2,587.00	-4,501.38	0.25	0.76	0.44	5,525.76
	15	4,497	-0.71	-0.71	-3,192.87	-3,192.87	0.50	0.50	0.50	5,362.22
	16	7,232	-0.87	-0.50	-6,291.84	-3,616.00	0.76	0.25	0.44	5,220.96
	17	7,128	-0.97	-0.26	-6,914.16	-1,853.28	0.94	0.07	0.25	5,112.10
	18	4,541	-1.00	0.00	-4,541.00	0.00	1.00	0.00	0.00	5,043.89
	19	2,535	-0.97	0.26	-2,458.95	659.10	0.94	0.07	-0.25	5,013.76
	20	4,067	-0.87	0.50	-3,538.29	2,033.50	0.76	0.25	-0.44	5,031.83
	21	5,584	-0.71	0.71	-3,964.64	3,964.64	0.50	0.50	-0.50	5,093.66
	22	6,087	-0.50	0.87	-3,043.50	5,295.69	0.25	0.76	-0.44	5,196.67
	23	4,555	-0.26	0.97	-1,184.30	4,418.35	0.07	0.94	-0.25	5,330.07
	24	4,116	0.00	1.00	0.00	4,116.00	0.00	1.00	0.00	5,489.41
Total 300		136,285	0.00	0.00	7,666.58	-2,284.66	12.08	12.08	0.00	136,284.96

The accuracy of the cyclical model was subsequently evaluated by comparing the actual and forecasted values for the historical period. As presented in Table 3, the absolute percentage errors varied across months, reflecting differences between observed and model-estimated gypsum consumption. Most periods showed relatively moderate deviations, although larger errors occurred during months with unusually low or high consumption. For example, the substantial deviation observed in July 2024 was associated with the unusually low actual consumption of 2,535 tons compared with the model estimate of 5,013.76 tons. This result suggested that the cyclical model represented the general recurring pattern but was less responsive to isolated or irregular demand shocks.

Table 3. Forecasting Errors for the Cyclical Forecasting Model.

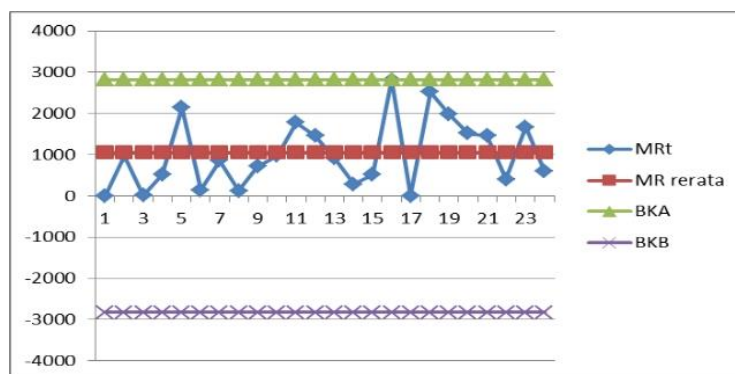
Year	Month	T	Amount Used (y) (Tons)	Amount (y') (Tons)	yy'	percentage (%)	PE _t (%)
2023	January	1	6198	5660,09	537,91	0,09	0,09
	February	2	7347	5831,32	1515,68	0,21	0,21
	March	3	7524	5994,86	1529,14	0,20	0,2
	April	4	7150	6136,12	1013,88	0,14	0,14
	Mei	5	5123	6244,98	-1121,98	-0,22	0,22
	Juny	6	5045	6313,19	-1268,19	-0,25	0,25
	July	7	5935	6343,32	-408,32	-0,07	0,07
	August	8	6038	6325,25	-287,25	-0,05	0,05
	September	9	5265	6263,42	-998,42	-0,19	0,19
	Oktober	10	6135	6160,41	-25,41	0,00	0,00
	November	11	7779	6027,01	1751,99	0,23	0,23
	Desember	12	6165	5867,67	297,33	0,05	0,05
2024	January	13	5065	5696,99	-631,99	-0,12	0,12
	February	14	5174	5525,76	-351,76	-0,07	0,07
	March	15	4497	5362,22	-865,22	-0,19	0,19
	April	16	7232	5220,96	2011,04	0,28	0,28
	Mei	17	7128	5112,1	2015,9	0,28	0,28
	Juny	18	4541	5043,89	-502,89	-0,11	0,11
	July	19	2535	5013,76	-2478,76	-0,98	0,98
	August	20	4067	5031,83	-964,83	-0,24	0,24
	September	21	5584	5093,66	490,34	0,09	0,09
	Oktober	22	6087	5196,67	890,33	0,15	0,15
	November	23	4555	5330,07	-775,07	-0,17	0,17
	Desember	24	4116	5489,41	-1373,41	-0,33	0,33
Total		300	136285	136285	0,04	-1,29	4,71

Forecast verification was subsequently performed to determine whether the selected cyclical forecasting function adequately represented the historical gypsum demand pattern. Table 4 presents the actual and forecasted gypsum consumption, forecast errors, and moving-range (MR) values used in the verification process. The forecast error represented the difference between actual and predicted consumption, while the moving range measured the change in forecast errors between two consecutive periods. This analysis was used to evaluate whether the forecasting errors remained stable over time rather than relying solely on aggregate accuracy measures such as MAPE. The results in Table 4 showed considerable month-to-month variation in the magnitude and direction of the forecast errors, reflecting fluctuations in actual gypsum consumption.

Table 4. Verification Results Calculation.

Year	Month	T	Amount Used (y) (Tons)	Amount (y') (Tons)	e	MRT
2023	January	1	6198	5660,09	537,91	0
	February	2	7347	5831,32	1515,68	977,77
	March	3	7524	5994,86	1529,14	13.46
	April	4	7150	6136,12	1013,88	515,26
	Mei	5	5123	6244,98	-1121,98	2135,86
	Juny	6	5045	6313,19	-1268,19	146,21
	July	7	5935	6343,32	-408,32	859,87
	August	8	6038	6325,25	-287,25	121,07
	September	9	5265	6263,42	-998,42	711,17
	Oktober	10	6135	6160,41	-25,41	973,01
	November	11	7779	6027,01	1751,99	1777,4
	Desember	12	6165	5867,67	297,33	1454,66
2024	January	13	5065	5696,99	-631,99	929,32
	February	14	5174	5525,76	-351,76	280,23
	March	15	4497	5362,22	-865,22	513,46
	April	16	7232	5220,96	2011,04	2818,26
	Mei	17	7128	5112,1	2015,9	4,86
	Juny	18	4541	5043,89	-502,89	2518,79
	July	19	2535	5013,76	-2478,76	1975,87
	August	20	4067	5031,83	-964,83	1513,93
	September	21	5584	5093,66	490,34	1455,17
	Oktober	22	6087	5196,67	890,33	399,99
	November	23	4555	5330,07	-775,07	1665,4
	Desember	24	4116	5489,41	-1373,41	598,34
Total		300	136285	136284,96	0,04	24359,36

The moving-range chart derived from the verification analysis is presented in Figure 2. All observations remained within the established control limits, indicating that no abnormal variation was detected in the sequence of forecasting errors. The cyclical forecasting function was therefore considered sufficiently stable for estimating gypsum requirements for the subsequent planning period.

**Figure 2.** Moving-range chart for gypsum forecasting errors.

Following model selection and verification, the cyclical forecasting model was applied to estimate monthly gypsum consumption for January–December 2025. As shown in Table 5, forecasted monthly demand ranged from 5,660.09 tons in January to a maximum of 6,343.32 tons in July, before gradually declining to 5,867.67 tons in December. This pattern indicated a

moderate cyclical increase during the first half of the year followed by a decline toward the end of the year.

Table 5. Forecasted monthly gypsum demand for 2025.

Year	Month	Period	Forecast
2025	January	25	5660,093
	February	26	5831,322
	March	27	5994,859
	April	28	6136,121
	Mei	29	6244,977
	Juny	30	6313,190
	July	31	6343,324
	August	32	6325,251
	September	33	6263,424
	Oktober	34	6160,408
	November	35	6027,005
	Desember	36	5867,670
Total		366	73167,64

The total forecasted gypsum demand for 2025 was 73,167.64 tons, as summarized in Table 5. This annual forecast was subsequently used as the demand parameter in the inventory optimization analysis. Using forecasted demand rather than a simple historical average allowed the inventory calculations to better reflect the expected material requirements for the 2025 planning horizon. The forecasting results also provided the analytical link between demand estimation and inventory decision-making. Forecasting alone indicated the expected quantity and temporal pattern of gypsum consumption but did not determine the economically appropriate replenishment quantity or frequency. Therefore, the forecasted annual demand of 73,167.64 tons was incorporated into the subsequent EOQ and POQ analyses. This integration enabled the study to translate the expected gypsum demand into practical inventory decisions involving order quantity, replenishment frequency, safety stock, reorder point, and total inventory cost. One issue should be corrected before publication: the manuscript currently states that three methods were compared using MAPE, but the displayed Table 2 is actually the parameter-calculation table for the cyclical method rather than a comparative table of MAPE, MAE, and RMSE for all three forecasting methods. I recommend adding a short comparison table such as “Forecasting Method | MAPE | MAE | RMSE | Rank” before presenting the detailed cyclical calculations. This would provide direct quantitative evidence for selecting the cyclical model.

4.2. EOQ Analysis.

The EOQ method was applied to determine the economically optimal gypsum order quantity by balancing annual ordering and holding costs. The analysis used the forecasted gypsum demand for 2025 as the primary demand input, thereby directly linking the forecasting results with the inventory optimization stage. The resulting inventory parameters are summarized in Table 6. It shows that the forecasted annual gypsum demand was 73,167.64 tons. Based on the EOQ calculation, the optimal order quantity was approximately 6,233 tons per order, corresponding to approximately 12 replenishment cycles per year, or one order every 1.02 months. This ordering pattern provided a systematic basis for replenishment rather than relying solely on the company's existing inventory practice. The EOQ policy also resulted in a safety stock of 15,807 tons and a reorder point of 22,040 tons. Thus, when the available inventory

approached 22,040 tons, a new order would need to be initiated to maintain sufficient stock during the replenishment lead time.

Table 6. Inventory Parameters Based on EOQ.

Parameter	EOQ Result
Forecasted annual demand	73,167.64 tons
Average monthly demand	6,233 tons
Ordering frequency	12 orders/year (1.02 months/order)
Safety stock	15,807 tons
Reorder point	22,040 tons
Total inventory cost (TIC _{EOQ})	IDR. 5.297.287,41

The total inventory cost under the EOQ policy was estimated at IDR5,297,287.41. This cost represented the balance between the cost of placing more frequent orders and the cost associated with maintaining inventory. Therefore, the EOQ result provided not only an optimal order quantity but also an economically structured inventory policy that could support continuous gypsum availability while controlling inventory-related expenditure.

4.3. POQ Analysis.

The POQ method was subsequently applied to determine an appropriate replenishment interval based on forecasted gypsum demand and inventory cost parameters. Unlike EOQ, which primarily determines an economically optimal quantity per order, POQ focuses on establishing an appropriate time interval between replenishments. This distinction allows inventory replenishment to be organized according to a periodic schedule while considering expected material requirements. The resulting POQ parameters are presented in Table 7.

Table 7. Inventory Parameters Based on POQ.

Parameter	POQ Result
Forecasted annual demand	73,167.64 tons
Average monthly demand	6,233 tons
Ordering frequency	12 orders/year (1.02 months/order)
Safety stock	15,712.24 tons
Reorder point	22,475.05 tons
Total inventory cost (TIC _{POQ})	IDR5,239,614.91

As shown in Table 7, the POQ analysis used the same forecasted annual demand of 73,167.64 tons to ensure comparability with the EOQ analysis. The resulting replenishment interval was approximately 1.02 months, equivalent to approximately 12 orders per year. The POQ policy produced a safety stock of 15,712.24 tons and a reorder point of 22,475.05 tons. The slightly lower safety stock than that obtained using EOQ suggested that the periodic replenishment approach could maintain material availability with a marginally lower buffer inventory under the assumptions applied in this study.

The estimated total inventory cost under the POQ policy was IDR5,239,614.91. This value was slightly lower than the EOQ cost, indicating a potential economic advantage of scheduling replenishment according to an optimized periodic interval. Nevertheless, the difference should be interpreted in conjunction with operational considerations because EOQ and POQ are based on different replenishment principles. EOQ emphasizes the optimal quantity per order, whereas POQ emphasizes the timing of replenishment. Consequently, the

preferred policy should consider both inventory cost and the company's operational ability to implement the proposed ordering schedule.

Overall, the cyclical forecasting model provided a common annual demand estimate of 73,167.64 tons for both inventory models. Using the same forecasted demand ensured that differences between EOQ and POQ reflected their respective inventory-control principles rather than differences in assumed demand. The integration of forecasting with both models therefore established a consistent basis for comparing alternative gypsum replenishment strategies.

4.4. Comparison with Current Inventory Practice.

To determine the practical benefits of inventory optimization, the proposed EOQ and POQ policies were compared with the company's existing inventory practice. The comparison considered key operational and economic indicators, including order quantity, ordering frequency, safety stock, reorder point, ordering and holding costs, and total inventory cost. The comparative results are summarized in Table 8.

Table 8. Comparison of Current Practice, EOQ, and POQ.

Parameter	EOQ Method	POQ Method
Forecasted Annual Demand (tons)	73,167.64	73,167.64
Order Quantity (tons)	6,233	6,233
Ordering Frequency	1.02 months/order	1.02 months/order
Safety Stock (tons)	15,807	15,712
Reorder Point (tons)	22,040	22,475
Ordering Costs (IDR)	5,236,657	2,654,118
Storage Costs (IDR)	2,649,025	2,649,025
Ordering Costs (IDR)	2,648,262.41	2,648,262.41
Holding/Storage Costs (IDR)	2,649,025.00	2,649,025.00
Total Inventory Costs (IDR)	5,297,287.41	5,297,287.41

As shown in Table 8, both optimized policies provided more systematic replenishment parameters than the existing inventory practice. The EOQ method established an optimal order quantity of approximately 6,233 tons, whereas the POQ method established an optimized replenishment interval of approximately 1.02 months. Although the resulting ordering schedules were relatively similar under the forecasted demand conditions, the two methods differed in their underlying decision criteria: EOQ minimized the combined ordering and holding costs through quantity optimization, whereas POQ organized replenishment according to an economically appropriate ordering period.

The most important difference among the inventory policies was observed in total inventory cost. Under the company's existing policy, the total inventory cost was estimated at IDR6,475,551.63. In comparison, EOQ reduced the total inventory cost to IDR5,297,287.41, representing savings of IDR1,178,264.22, or 18.20%. POQ produced the lowest total inventory cost of IDR5,239,614.91, corresponding to savings of IDR1,235,936.72, or 19.09%, relative to the existing policy. Thus, both optimization approaches provided substantial cost reductions, although POQ generated a slightly greater economic benefit.

The difference between EOQ and POQ was relatively small, with POQ reducing inventory costs by an additional IDR57,672.50 compared with EOQ. Therefore, the results should not be interpreted as indicating that one method was universally superior. Rather, both methods substantially improved cost efficiency relative to the existing practice, while POQ

provided a marginal cost advantage under the demand and cost assumptions applied in this study.

Differences between the company's existing inventory levels and the optimized values could be attributed to the use of relatively static inventory policies, warehouse-capacity considerations, and variations in gypsum requirements associated with clinker production. Integrating cyclical demand forecasting with EOQ or POQ therefore provided a more dynamic approach in which expected future consumption directly informed replenishment decisions. This integration is particularly relevant for gypsum because, although it is used in smaller quantities than major cement raw materials, insufficient stock could disrupt the finishing process, whereas excessive stock could unnecessarily increase inventory and storage costs.

4.5. Discussion.

The findings demonstrated that integrating demand forecasting with inventory optimization provided a more comprehensive approach to gypsum inventory planning than treating forecasting and inventory control as independent activities. The forecasting stage estimated future material requirements, while the EOQ and POQ models translated these estimates into operational decisions concerning order quantity, replenishment frequency, safety stock, reorder point, and inventory cost. This sequential relationship represented an important feature of the proposed decision-support framework.

The EOQ analysis demonstrated that inventory efficiency could be improved by determining an economically appropriate order quantity rather than relying exclusively on the company's existing ordering practice. In contrast, POQ provided a complementary approach by determining an appropriate replenishment interval based on forecasted demand and inventory costs. Differences between the EOQ and POQ results were therefore expected because the two approaches optimized different dimensions of inventory replenishment. Nevertheless, both methods used the same forecasted annual demand, allowing their economic and operational performance to be compared consistently.

The economic implications of these results were particularly important. Compared with the company's existing inventory practice, EOQ reduced total inventory cost by 18.20%, whereas POQ achieved a slightly greater reduction of 19.09%. Although the difference between the two optimized policies was less than one percentage point, both generated meaningful reductions in recurring inventory-related expenditure. For an operation requiring approximately 73,167.64 tons of gypsum annually, these savings indicated that relatively simple improvements in replenishment decisions could contribute to better cost control and more efficient use of working capital.

Beyond cost savings, the optimized safety stock and reorder-point values provided a more systematic basis for maintaining material availability. Safety stock served as a buffer against variability during replenishment, whereas the reorder point indicated when a new procurement cycle should be initiated. Consequently, the benefits of the proposed framework extended beyond reducing inventory costs; it also provided operational decision parameters that could help reduce the risk of both excessive inventory and material shortages.

The principal contribution of this study was therefore the integration of cyclical demand forecasting with EOQ and POQ specifically for gypsum inventory management in cement manufacturing. Rather than evaluating forecasting accuracy or inventory optimization independently, forecasted demand was directly incorporated into subsequent replenishment

decisions, and the resulting policies were evaluated against the company's existing practice. This integrated approach provided a practical decision-support framework for translating expected demand into economically and operationally appropriate inventory policies. One correction is needed in Table 8 before finalizing the manuscript: the current table contains duplicated “Ordering Costs” and “Holding/Storage Costs” rows, and the values shown for POQ appear inconsistent with the stated POQ total inventory cost of IDR5,239,614.91. These rows should be recalculated or removed so that Table 8 is fully consistent with Tables 6 and 7.

5. Conclusion

This study developed an integrated forecasting–inventory framework for gypsum management at PT Lafarge Cement Indonesia. The cyclical forecasting model projected gypsum demand of 73,167.64 tons for 2025, which was subsequently used as the demand input for EOQ and POQ optimization. The EOQ model generated an optimal order quantity of 6,233 tons, approximately 12 orders per year, a safety stock of 15,807 tons, and a reorder point of 22,040 tons, resulting in a total inventory cost of IDR5,297,287.41. The POQ model established a replenishment interval of approximately 1.02 months, with a safety stock of 15,712.24 tons and a reorder point of 22,475.05 tons, resulting in a lower total inventory cost of IDR5,239,614.91. Compared with the existing inventory cost of IDR6,475,551.63, EOQ and POQ reduced costs by 18.20% and 19.09%, respectively, indicating a slight economic advantage for POQ. The findings demonstrated that directly linking forecasted demand with inventory decisions provided a practical approach to balancing material availability and inventory costs. The proposed framework could therefore support more systematic gypsum procurement and replenishment decisions in cement manufacturing. Future studies should incorporate real-time demand and inventory data, variable lead times, supplier reliability, and supply-chain disruptions to improve the framework's responsiveness and robustness under uncertain operating conditions.

Competing Interests

The authors declare that they have no competing financial or non-financial interests that could have influenced the work reported in this study.

Author Contributions

All authors contributed equally to the conceptualization, methodology, data analysis, interpretation of the results, manuscript preparation, review, and editing. All authors read and approved the final version of the manuscript.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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