Application of Exponential Smoothing Models for Coal Demand Forecasting in Cement Plants

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ABSTRACT

Energy forecasting plays an important role in maintaining operational stability and inventory efficiency in the cement manufacturing industry, where coal remains the primary source of thermal energy. This study aims to develop an accurate forecasting model to predict coal demand in the procurement and warehouse division of a cement manufacturing plant in West Java, Indonesia. A quantitative approach was applied using three time-series forecasting methods, namely Moving Average (MA), Single Exponential Smoothing (SES), and Holt's Double Exponential Smoothing (DES). Monthly coal consumption data from 2022 to 2024 were analyzed and divided into training and testing datasets to evaluate out-of-sample forecasting performance. Several parameter combinations were tested to obtain the optimal forecasting configuration for each model. Forecasting accuracy was assessed using Mean Absolute Deviation (MAD), Mean Squared Error (MSE), and Mean Absolute Percentage Error (MAPE). The results show that Holt's DES achieved the best forecasting performance, with a MAPE of 6.21%, outperforming SES and MA, which had MAPE values of 9.84% and 11.47%, respectively. The selected model also reduced the average deviation between forecasted and actual coal demand to below 500 tons per month, thereby minimizing the risk of overstocking and stockouts. These findings demonstrate that quantitative forecasting can support more effective procurement planning, improve inventory control, and enhance energy management practices in cement manufacturing operations. Nevertheless, this study is limited to a three-year observation period and focuses on a single industrial case, which may limit the generalizability of the results.

Keywords: coal demand forecasting, cement industry, exponential smoothing, inventory management, energy efficiency

1. Introduction

The cement industry plays a strategic role in supporting infrastructure development and economic growth, particularly in developing countries where the demand for construction materials continues to increase. Alongside its economic contribution, the industry is recognized as one of the most energy-intensive manufacturing sectors due to its reliance on large-scale thermal processes in clinker and cement production. Previous studies have reported that energy consumption accounts for approximately 40–60% of total cement production costs, with coal remaining the dominant fuel due to its high calorific value, stable supply, and lower operational costs than alternative fuels (Bramantiyo, Lestianingrum, & Cahyono, 2024). Nevertheless, the extensive use of coal also raises concerns about operational efficiency, fuel management, and environmental sustainability, particularly regarding greenhouse gas emissions and industrial decarbonization efforts (Wali, Qayum, Algarni, Malik, & Jan, 2025; Liu, Zhao, Wang, & Li, 2024).

Within cement manufacturing operations, the procurement and warehouse divisions play an important role in maintaining fuel availability to support uninterrupted kiln activity. In practice, inaccurate forecasting often creates discrepancies between projected and actual coal consumption. These discrepancies may lead to overstock conditions that increase storage costs and inventory holding, or stockout conditions that disrupt production continuity and reduce operational reliability. Similar issues were identified at a cement manufacturing plant in West Java,

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Indonesia, where coal demand was still estimated manually using historical averages and operational judgment, without a structured forecasting model. As a result, significant deviations between forecasted and actual coal consumption frequently occurred, affecting procurement planning, warehouse utilization, and fuel distribution efficiency.

The importance of forecasting accuracy in industrial energy management has been discussed in various previous studies. Febriani and Fatichah (2024) found that conventional forecasting methods often struggle to capture fluctuations in coal demand within thermal power plant operations, particularly when consumption patterns change dynamically over time. In response to these limitations, several studies have explored more advanced forecasting approaches. Alvin et al. (2024), for example, developed a hybrid forecasting framework that combined statistical and machine-learning techniques to improve the accuracy of coal price predictions in Indonesia. Their study highlighted that data-driven forecasting models can significantly improve prediction performance compared with conventional estimation approaches.

Forecasting studies have also been integrated with inventory and supply chain management. Kurniyawan and Febryanto (2025) applied the ARIMA model together with the Economic Order Quantity (EOQ) concept to optimize coal procurement decisions and reduce inventory costs. Hasan and Pulansari (2023) demonstrated that inventory control methods, such as Min-Max Stock, were effective in reducing raw material imbalances in cement manufacturing operations. At a broader scale, Kurniadi et al. (2024) showed that coal demand across the Asia Pacific region is expected to remain substantial despite ongoing energy transition policies, indicating that industrial energy management will continue to depend heavily on forecasting reliability in the coming years. Xu, Gong, and Yan (2023) further emphasized that accurate forecasting systems are essential for supporting low-carbon transformation strategies in the cement industry.

In addition to forecasting and inventory management, operational optimization has increasingly become part of industrial energy efficiency initiatives. Gusman et al. (2022) reported that integrating artificial intelligence into process optimization systems could significantly reduce electricity consumption in cement plants. These findings indicate that operational efficiency in energy-intensive industries is determined not only by production technology but also by the quality of planning and decision-making within the supply chain, including fuel procurement and inventory management.

Despite the growing body of literature on energy forecasting and industrial optimization, studies specifically on coal demand forecasting in Indonesia’s cement industry remain limited. Most previous studies concentrated on sectors such as mining, aviation, or power generation, while practical forecasting applications in process-based manufacturing industries have received less attention. As a consequence, many industrial decision-making processes related to fuel procurement still rely on manual estimation and historical judgment rather than systematic quantitative analysis.

Therefore, this study aims to develop and evaluate coal demand forecasting models for the procurement and warehouse division of a cement manufacturing plant in West Java, Indonesia. Three time-series forecasting techniques, namely Moving Average (MA), Single Exponential Smoothing (SES), and Holt’s Double Exponential Smoothing (DES), are compared to determine the most suitable forecasting model based on forecasting accuracy indicators, including Mean Absolute Deviation (MAD), Mean Squared Error (MSE), and Mean Absolute Percentage Error (MAPE).

This study contributes both practically and academically. From a practical perspective, the proposed forecasting framework can support more accurate procurement planning, improve inventory control, reduce operational uncertainty, and enhance energy management efficiency within cement manufacturing operations. From an academic perspective, the study contributes to the discussion on forecasting implementation in energy-intensive industries, particularly by demonstrating that classical forecasting methods can remain reliable decision-support tools when properly calibrated and evaluated in real industrial contexts.

2. Methodology

This study employed a quantitative approach to develop a forecasting model to predict coal demand in the procurement and warehouse division of a cement manufacturing plant in West Java, Indonesia. The research focused on improving forecasting accuracy to support procurement planning and maintain the continuity of kiln operations, which heavily depend on stable coal availability. Historical operational data were obtained from the company's internal records for the period January 2022 to December 2024. The dataset consisted of monthly coal consumption, procurement quantities, inventory levels, and production-related information. Before the analysis was conducted, the data were examined to ensure consistency and completeness. Incomplete records were verified using operational reports and production logs to minimize potential discrepancies during the forecasting process.

Three classical time-series forecasting methods were evaluated in this study, namely Moving Average (MA), Single Exponential Smoothing (SES), and Holt's Double Exponential Smoothing (DES). These methods were selected because they are widely applied in industrial forecasting, relatively easy to implement in operational environments, and capable of producing reliable short-term demand predictions using limited historical data.

The Moving Average method forecasts future demand by averaging several previous observations. In this study, three trailing-average periods were tested, namely 3-, 6-, and 12-month windows, to identify the most suitable forecasting horizon. The forecasting equation for the Moving Average model is expressed by Equation (1).

$$F_{t+1} = \frac{A_t + A_{t-1} + \cdots + A_{t-n+1}}{n} \qquad (1)$$

where F_{t+1} represents the forecast for the next period, A_t denotes the actual demand at period t, and n is the number of periods used in the averaging process. The optimal period length was determined by the lowest forecasting error in model evaluation.

The Single Exponential Smoothing method was used to assign greater weight to more recent observations, enabling the model to respond more effectively to short-term fluctuations in coal consumption. Several smoothing constants (α) values were tested, namely 0.1, 0.3, 0.5, 0.7, and 0.9. The initial smoothing value (S_0) was determined using the first actual observation in the dataset. The SES forecasting equation is described by Equation (2).

$$F_{t+1} = \alpha A_t + (1-\alpha) F_t \qquad (2)$$

where α is the smoothing constant, ranging from 0 to 1. The optimal α value was selected based on the smallest Mean Absolute Percentage Error (MAPE) produced during model evaluation.

To accommodate the presence of trend patterns in coal consumption data, Holt's Double Exponential Smoothing method was also applied. Unlike SES, this method incorporates both level and trend components, allowing the model to capture gradual increases or decreases in demand over time. The DES model uses two smoothing parameters, namely the level parameter (α) and the trend parameter (β). Parameter combinations ranging from 0.1 to 0.9 were tested using an iterative grid-search approach to identify the optimal forecasting configuration. The initial level (L_0) was defined using the first actual observation, while the initial trend (T_0) was calculated based on the difference between the first two observations. The DES equations are expressed as follows:

$$L_t = \alpha A_t + (1 - \alpha)(L_{t-1} + T_{t-1}) \ldots .(3)$$

$$T_t = \beta(L_t - L_{t-1}) + (1 - \beta)T_{t-1} \ldots ..(4)$$

$$F_{t+m} = L_t + mT_t \ldots \ldots \ldots \ldots \ldots \ldots \ldots .(5)$$

where L_t represents the smoothed level component, T_t denotes the trend component, and F_{t+m} is the forecast value for the next m periods.

The forecasting process was conducted using Microsoft Excel and cross-validated using Jamovi version 2.6.44 to ensure computational consistency. The dataset was divided into two groups: 80% of the observations were used for training, and the remaining 20% for out-of-sample testing. This validation approach was intended to evaluate each forecasting model's predictive capability on unseen data.

Forecasting performance was evaluated using three statistical indicators: Mean Absolute Deviation (MAD), Mean Squared Error (MSE), and Mean Absolute Percentage Error (MAPE). MAD was used to measure the average magnitude of forecasting deviation; MSE emphasized larger forecasting errors by squaring deviations; and MAPE expressed forecasting accuracy as a percentage of actual demand, allowing comparison across forecasting models. The model with the lowest MAPE value was considered the most appropriate for operational implementation.

To strengthen the reliability of the analysis, the forecasting results were also reviewed through expert validation involving practitioners and academics familiar with industrial forecasting and inventory management. In addition, the selected forecasting model was compared with actual coal procurement data from the subsequent operational period, January to March 2025, to assess the consistency of its forecasting performance under real operational conditions.

3. Results and Discussion

The forecasting analysis was conducted using three time-series methods, namely Moving Average (MA), Single Exponential Smoothing (SES), and Holt's Double Exponential Smoothing (DES), to predict monthly coal demand within the procurement and warehouse division of the cement manufacturing plant. The evaluation focused on identifying the forecasting model that produces the most accurate and operationally reliable predictions to support procurement planning and inventory management.

The comparison between actual coal consumption and the forecasts produced by each model is shown in Figure 1. Figure 1 shows that the DES model more closely followed the actual consumption pattern than the MA and SES models, particularly during periods of increasing production activity. While the MA model produced relatively rigid forecasts and SES responded moderately to changes in consumption, the DES model captured both the level and trend movements of the data more effectively. This indicates that coal demand during the observation period did not fluctuate randomly, but instead exhibited a gradual upward trend associated with changes in production intensity and operational demand.

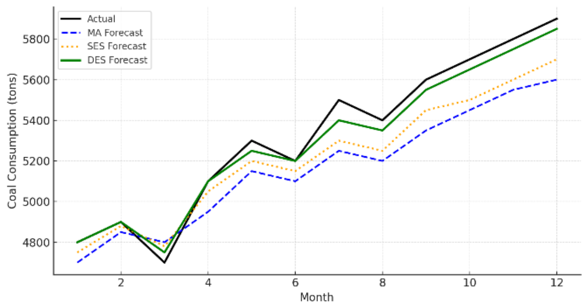

Figure 1. Comparison of actual coal consumption and model-based forecasts using MA, SES, and DES methods

To strengthen the evaluation of forecasting, several parameter configurations were tested for each model. In the Moving Average method, 3-month, 6-month, and 12-month trailing windows were evaluated. For SES, smoothing constants (α) ranging from 0.1 to 0.9 were tested, while Holt's DES used combinations of level (α) and trend (β) parameters optimized through an iterative grid-search process. The parameter configuration producing the lowest forecasting error was selected as the final model for each method. The optimization results are

Table 1.The optimization results

Model	Parameter Configuration	Selected Parameter	MAPE
Moving Average (MA)	3, 6, and 12-month windows	6-month trailing average	11.47%
Single Exponential Smoothing (SES)	α=0.1−0.9	$\alpha = 0.3$	9.84%
Holt's Double Exponential Smoothing (DES)	α=0.1−0.9 β=0.1−0.9	$\alpha = 0.3$ $\beta = 0.2$	6.21%

summarized in Table 1. The quantitative comparison of forecasting accuracy is presented in Figure 2. Among the evaluated models, Holt's DES achieved the lowest forecasting error, with a MAPE of 6.21%, outperforming SES and MA, which had MAPE values of 9.84% and 11.47%, respectively. The DES model also yielded the lowest MAD and MSE values, indicating smaller deviations between forecast and actual coal consumption throughout the observation period. These findings confirm that incorporating both level and trend components significantly improves forecasting performance when demand patterns exhibit gradual directional movement over time.

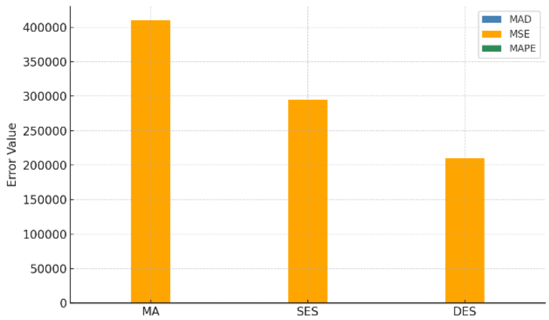

Figure 2. Comparison of forecast accuracy metrics (MAD, MSE, MAPE) among the three time-series models.

Compared with the company's previous manual estimation approach, implementing the DES model substantially reduced forecasting deviation. Historical operational records showed that manual forecasting often produced monthly deviations exceeding 1,200 tons, particularly during periods of increased production activity. After applying the DES forecasting framework, the average deviation decreased to below 500 tons per month. From an operational perspective, this improvement provides significant benefits for procurement scheduling, warehouse utilization, and fuel allocation planning. More accurate forecasting enables procurement activities to be planned proactively rather than reactively, thereby reducing the likelihood of emergency purchasing and minimizing unnecessary inventory accumulation.

The findings also demonstrate that forecasting accuracy directly affects supply chain stability within energy-intensive manufacturing operations. Improved synchronization between projected coal demand, procurement lead time, and warehouse capacity allows the company to maintain more stable fuel availability for kiln operations. This is particularly important in cement manufacturing, where interruptions in fuel supply may affect production continuity and operational efficiency. The results are consistent with Hasan and Pulansari (2023), who reported that systematic inventory control approaches can significantly reduce material imbalance within cement production systems.

The superior performance of Holt's DES in this study also supports previous research emphasizing the importance of trend-sensitive forecasting methods in industrial energy management. Febriani and Fatichah (2024) similarly found that exponential smoothing approaches yielded more reliable forecasting performance than conventional averaging methods for predicting coal consumption in thermal power plants. The comparable forecasting accuracy obtained in the present study suggests that classical forecasting models remain highly relevant for industrial applications when properly calibrated and evaluated using operational data.

In addition to operational efficiency, the forecasting framework developed in this study contributes to broader energy management and sustainability objectives. Accurate forecasting reduces excessive procurement and unnecessary storage cycles, both of which contribute to inefficient energy utilization and higher operational costs. By aligning procurement quantities more closely with actual production requirements, the company can improve inventory turnover while reducing the risk of inefficient fuel handling practices. This finding aligns with Xu, Gong, and Yan (2023), who emphasized that data-driven forecasting systems are essential for supporting sustainable industrial transformation and long-term energy efficiency in the cement sector.

From a broader industrial perspective, the study also highlights the practical contribution of quantitative forecasting in Indonesia's manufacturing sector, where many operational decisions remain heavily dependent on manual estimates and managerial judgment. The results demonstrate that relatively simple forecasting models, such as Holt's DES, can deliver meaningful operational improvements without requiring highly complex computational systems. This practical applicability becomes particularly important for manufacturing companies seeking to improve operational resilience and cost efficiency while working within existing industrial infrastructure.

Overall, the results confirm that Holt's Double Exponential Smoothing provides the most reliable forecasting performance for predicting coal demand in the observed cement manufacturing environment. The integration of quantitative forecasting into procurement and warehouse operations not only improves forecasting accuracy but also strengthens inventory stability, operational planning, and energy-management performance. These findings indicate that forecasting should be viewed not merely as a statistical activity but as an important decision-support mechanism for achieving efficient and sustainable industrial operations.

4. Conclusion

This study evaluated the performance of three time-series forecasting methods: Moving Average (MA), Single Exponential Smoothing (SES), and Holt's Double Exponential Smoothing (DES) for predicting coal demand within the procurement and warehouse division of a cement manufacturing plant in West Java, Indonesia. Based on the forecasting evaluation results, Holt's DES achieved the highest accuracy and the lowest forecasting error among the tested models, with a MAPE of 6.21%. The model captured both the level and trend patterns of coal consumption more effectively than MA and SES, resulting in forecasts that were more consistent with actual operational demand.

The implementation of the DES model significantly reduced the deviation between forecasted and actual coal consumption, lowering the average monthly deviation from more than 1,000 tons to below 500 tons. From an operational perspective, this improvement supports more accurate procurement planning, better inventory control, and more stable warehouse operations. More reliable forecasting also reduces the risk of overstocking and stockouts, enabling procurement activities to be conducted more proactively and efficiently in accordance with production requirements.

The findings of this study indicate that quantitative forecasting can provide meaningful operational benefits for energy-intensive manufacturing industries, particularly in environments where procurement decisions remain heavily dependent on manual estimates and historical judgment. In addition to improving operational efficiency, more accurate coal demand forecasting can contribute to better energy management by reducing unnecessary inventory accumulation and improving the alignment between fuel supply and production demand.

This study contributes to the discussion on the application of classical forecasting methods in industrial energy management. The results demonstrate that relatively simple statistical approaches, such as Holt's Double Exponential Smoothing, can still provide reliable decision support tools when properly calibrated and evaluated using real operational data. This finding is particularly relevant for manufacturing companies seeking practical forecasting solutions without relying on highly complex computational systems.

Nevertheless, this study has several limitations. The analysis was conducted using a three-year observation period and focused on a single cement manufacturing facility, which may limit the generalization of the findings to other industrial contexts. Future studies are therefore encouraged to incorporate longer historical datasets, compare forecasting performance across multiple manufacturing plants, and explore integrating machine learning approaches to further improve forecasting robustness and adaptability.

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