SCHEDULING AND DYNAMIC ENERGY OPTIMIZATION IN CEMENT MILLS

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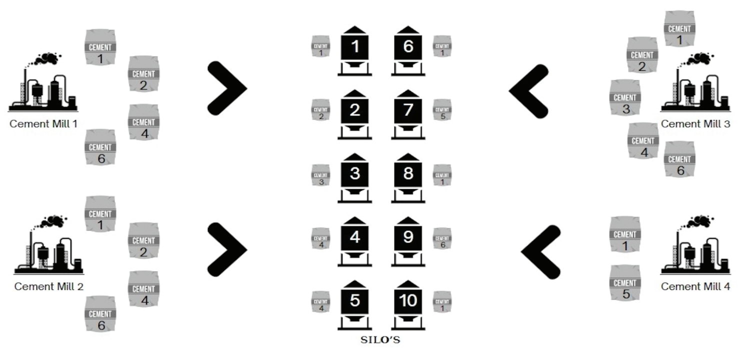
1 ABOUT COMPANY

The project is implemented at the Oyak Cement Factory in Ankara. Owned 6 different cement production factories around Turkey.

2 CURRENT SYSTEM



Workflow Diagram

The project includes 4 cement mills, 6 products and 10 different SILOs. Cements can be produced in different mills and go to different SILOs.

3 PROBLEM DEFINITION

1. Inefficient production schedule
2. Inability to determine the amount of energy needed
3. Increase in energy cost

Scheduling and Dynamlc Energy Optimization In Cement MIlls

Purpose: Providing optimum production planning schedule based on sales projections while reducing energy costs

4 OBJECTIVE OF THE PROJECT

This study aims to optimize energy use, cut costs, and reduce environmental impact at OYAK Cement, a top Turkish cement producer. The focus is on forecasting energy prices and creating efficient production schedules to manage hourly energy cost fluctuations, thereby reducing costs and emissions. This aligns with OYAK Cement's sustainability goals of producing high-quality, eco-friendly products, enhancing its industry leadership and supporting Turkey's construction sector.

5 METHODOLOGY

5.1. PRICE PREDICTION

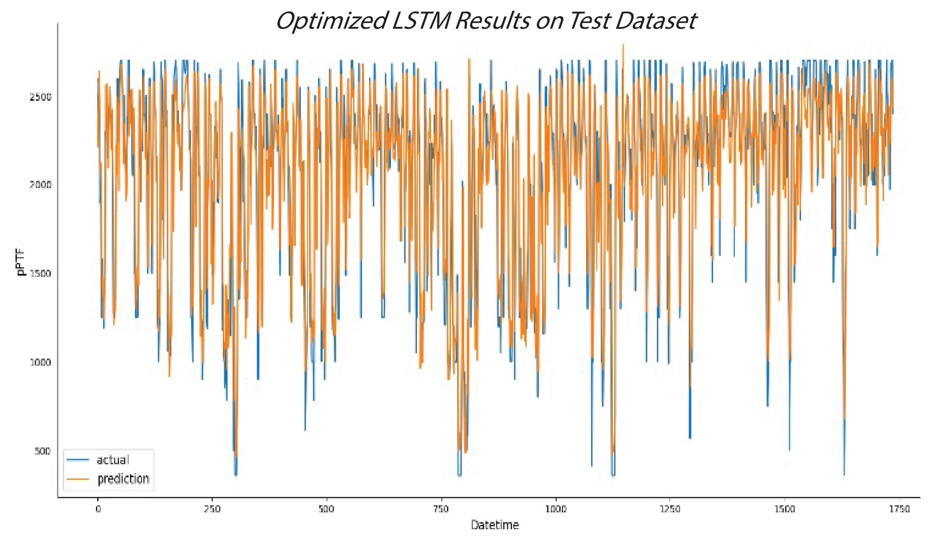
To create an hourly production schedule, hourly electricity price forecast was required. For this purpose, various models, primarily statistical but also including some machine learning models, were used to forecast prices. Except for the XGBoost method, other methods were designed to predict future prices based on past price data. In the XGBoost method, four different attributes, ask amount, bid amount, volume, and amount of imbalance—were used to predict future price data. The dataset consists of the price between 21.03.2023-21.03.2024. The error rates of these models are presented below.

RMSE and MAPE of All Methods

Method	RMSE	MAPE%
Linear Regression	559,9	32,7
Seasonal Regression	499,4	29,0
Moving Average(24)	485,9	25,5
Moving Average(168)	538,4	31,1
Moving Average(720)	545,0	32,0
Simple Exponential Smoothing	895,0	39,7
Holt's Linear	2600,1	113,5
Additive Holt's Winter	1060,2	45,1
Multiplicative Holt's Winter	1200,1	50,0
ARIMA (1,1,1)	298,3	11,7
ARIMA (24,1,24)	499,2	29,3
ARIMA (12,1,7)	596,9	33,6
SARIMA (5,0,15) (0,1,0)24	955,2	41,3
SARIMA (24,0,24) (0,1,0)24	498,8	27,6
Auto ARIMA(1,1,1) (1,1,1)24	511,4	27,9
LSTM	253,1	11,5
XGBoost	318,4	16,4
Optimized LSTM	247,9	11,3

These results show the RMSE and MAPE values of different hourly electricity price forecasting models. Among suitable models, machine learning models such as LSTMs and XGBoost stand out. Since the optimized LSTM model has the lowest error rate, we chose it as our price forecast method.

Optimized LSTM Results on Test Dataset



5.2. MATHEMATICAL MODEL

Case I - Transition Just Less Additives to More Additives Product

Minimization Model

The main purpose of "Minimization Model" is to strategically optimize the production planning program in order to minimize energy costs effectively.

Sets and Indices

- i Products indexed by i, m (1 to 6)
- j Cement Mills (1 to 4)
- k SILO Types (1 to 10)
- d Days (1 to 14)
- t Time Ranges (1 to 672)

Parameters

- D_{id} The demand quantity of product i on day d (tons).
- A_k The capacity of SILO k.
- EC_{ij} The energy consumed in 30 mins while producing product i in mill j (kWh).
- PC_{ij} The amount of product i produced by mill j in 30 mins (tons/30 mins).
- IE_j The amount of energy consumed by mill j when idle (kWh).
- EP_t The energy price forecast on time range t (TL).
- I_{ij} Manufacturability of product i on mill j (binary).
- P_{ik} Storability of product i on SILO k (binary).
- IC_{ik} The initial inventory amount of product i on SILO k.
- T_{mi} Transition from additive to non-additive when switching from product m to product i.

Decision Variables

- X_{ijt} 1, if product i is produced in cement mill j in time range t, 0, ow.
- Y_{ijtk} Quantity of product i assigned to SILO at time t from mill j (tons).
- SC_{itk} The inventory amount of product i in SILO k at the end of time range t (tons).
- O_{itk} The quantity of product release (output) from SILO k in time range t (tons).
- B_{jd} 1, if there is maintenance in cement mill j on day d, 0, ow.
- Q_{jt} 1, if there is warm-up period in cement mill j in time range t, 0, ow.
- S_{ijt} 1, if the product i is exported from in cement mill j in time range t, 0, ow.

Objective Function

$$\text{Minimize} \sum_i \sum_j \sum_t EC_{ij}\, X_{ijt}\, EP_t PC_{ij} + \sum_j \sum_t IE_j\, Q_{jt}\, EP_t$$

Constraints

$\sum_i X_{ijt} \le 1 \quad \forall j, t \ne 1$ (2)

$\sum_i X_{ijt} = 0 \quad \forall j, t = 1$ (3)

$IC_{ik} + \sum_j Y_{ijtk} - O_{itk} = SC_{itk} \quad \forall i,k,t = 1$ (4)

$SC_{i(t-1)k} + \sum_j Y_{ijtk} - O_{itk} = SC_{itk} \quad \forall i,k,t \ne 1$ (5)

$S_{ijt} \cdot PC_{ij} = \sum_k Y_{ijtk} \quad \forall i,j,t$ (6)

$\sum_i SC_{itk} \le A_k \cdot 0.9 \quad \forall k,t$ (7)

$\sum_i SC_{itk} \ge A_k \cdot 0.25 \quad \forall k,t$ (8)

$\sum_{t=((d-1)\cdot 48)+1}^{t=48\cdot d} \sum_k O_{itk} \ge D_{id} \;\forall i,d$ (9)

$O_{itk} \le SC_{itk} \quad \forall i,k,t$ (10)

$\sum_i X_{ijt} + Q_{jt} \le 1 \quad \forall j,t$ (11)

$\sum_i X_{ijt} + Q_{jt} \ge \sum_i X_{ij(t+1)} \quad \forall j, t \ne 672$ (12)

$\sum_i X_{ij(t+1)} \ge Q_{jt} \quad \forall j, t \ne 672$ (13)

$\sum_i X_{ijt} = \sum_i S_{ijt} \quad \forall j,t$ (14)

$X_{ijt} \ge S_{ijt} \quad \forall i,j,t$ (15)

$X_{ijt} - \sum_m (X_{mj(t-2)} \cdot T_{mi}) \le S_{ijt} \;\forall i,j,t > 2 \text{ and } m \epsilon i$ (16)

$X_{mj(t-2)} \cdot T_{mi} + X_{ijt} \le S_{mjt} + 1 \quad \forall m \epsilon i, i, j, t > 2$ (17)

$\sum_{m \ne i} X_{mj(t-1)} + X_{ijt} \le X_{ij(t+1)} + 1 \quad \forall m \epsilon i, i, j, t > 1 \text{ and } t < 671$ (18)

$B_{jd} = 0 \quad \forall j$, d =6,7,13,14 (19)

$\sum_j B_{jd} \le 1 \quad \forall d$ (20)

$\sum_{d=1}^{d=5} B_{jd} = 1 \quad \forall j$ (21)

$\sum_{d=8}^{d=12} B_{jd} = 1 \quad \forall j$ (22)

$\sum_i \sum_{t=((d-1)\cdot 48)+17}^{t=((d-1)\cdot 48)+17+15} X_{ijt} \le (1 - B_{jd}) \cdot 16 \quad \forall j,d$ (23)

$\sum_{t=((d-1)\cdot 48)+17}^{t=((d-1)\cdot 48)+17+15} Q_{jt} \le (1 - B_{jd}) \cdot 16 \quad \forall j,d$ (24)

$X_{ij(t+1)} \le X_{ijt} + X_{ij(t+2)} \;\forall i,j,t < 670$ (25)

$X_{ij(t+1)} \le X_{ijt} + X_{ij(t+3)} \;\forall i,j,t < 669$ (26)

$X_{ij(t+1)} \le X_{ijt} + X_{ij(t+4)} \;\forall i,j,t < 668$ (27)

$Y_{ijtk} \le P_{ik} \cdot A_k \cdot I_{ij} \;\forall i,j,t,k$ (28)

$SC_{itk} \le P_{ik} \cdot A_k \quad \forall i,t,k$ (29)

$X_{ijt} \le I_{ij} \quad \forall j,i,t$ (30)

$O_{itk} \le P_{ik} \cdot A_k \quad \forall i,t,k$ (31)

$X_{ijt} \in \{0,1\} \quad \forall i,j,t$ (32)

$S_{itk} \in \{0,1\} \quad \forall m \ne i, i, j, t$ (33)

$B_{jd} \in \{0,1\} \;\forall j,d$ (34)

$Q_{jt} \in \{0,1\} \;\forall j,t$ (35)

$Y_{ijtk} \ge 0 \quad \forall i,j,t,k$ (36)

$SC_{itk} \ge 0 \quad \forall i,t,k$ (37)

$O_{itk} \ge 0 \quad \forall i,t,k$ (38)

Case II - Permitted Transitions More Additives to Less Additives Product

A transition is made from a more additive product to a less additive product, the product is produced with less additive capacity during the transition, but it goes to the silo of a more additive product.

$\cancel{X_{ijt} \ge S_{ijt} \quad \forall i,j,t}$ (15)

For the product transitions in this scenario, constraint (15) given in "Case " was removed and rewritten.

Maximization Model

New objective function "Maximization Model" considered production and the energy consumption.

Parameters

- F_i The price of product i per ton

Objective Function

$$\text{Maximize } \sum_i \sum_t \sum_k O_{itk} F_i - \left(\sum_i \sum_j \sum_t EC_{ij}\, X_{ijt}\, EP_t PC_{ij} + \sum_j \sum_t IE_j\, Q_{jt}\, EP_t\right)$$

Constraints

$\sum_{t=((d-1)\cdot 48)+1}^{t=48\cdot d} \sum_k O_{itk} \le D_{id} \cdot 1.3 \;\forall i,d$ (9)

Case III - Number of Product Transitions is Limited

During the 1-hour product transitions in cement mills, it is possible to transition from a product with more additives to one with fewer additives; however, in practice, frequent transitions are not feasible.

Decision Variables

K_{jt} 1, if product transition occurred, 0, ow.

Constraints

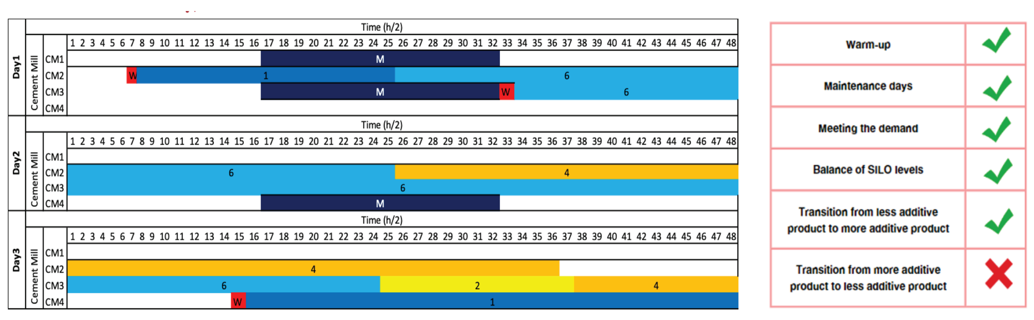
$\sum_{t=((d-1)\cdot 48)+1}^{t=48\cdot d} K_{jt} \le 2, \;\forall j$ (28)

$\sum_{m \ne i} X_{mj(t+1)} + X_{ijt} \le K_{jt} + 1 \quad \forall m \epsilon i, i, j, t < 671$ (29)

6 RESULTS

Case I - Transition Just Less Additives to More Additives Product

Minimization Model :July, 2023



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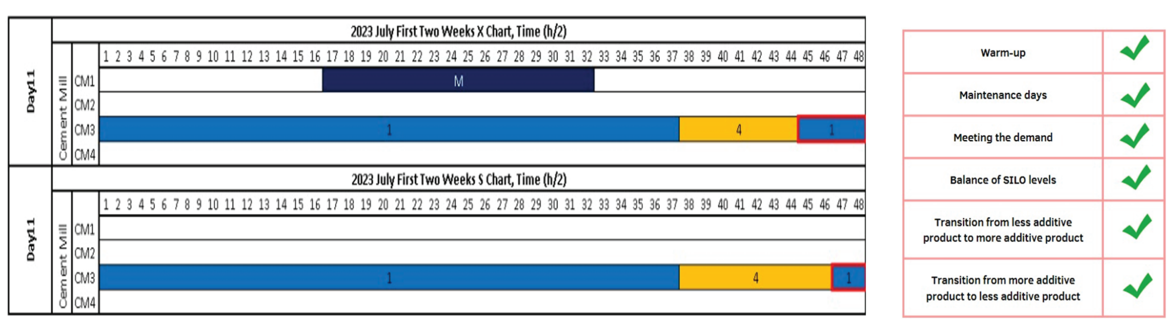
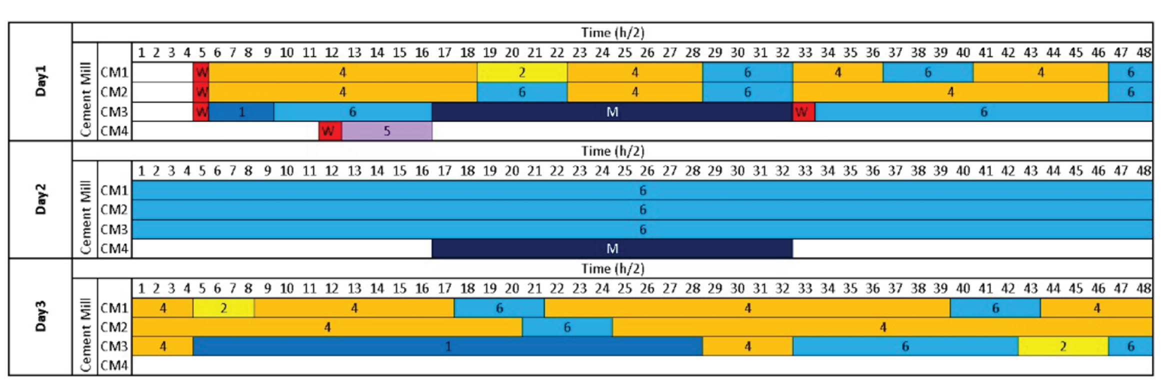
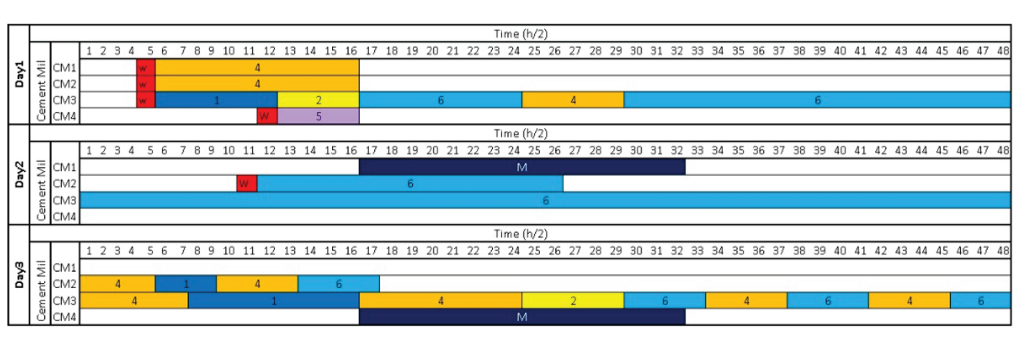


Maximization Model: July, 2023

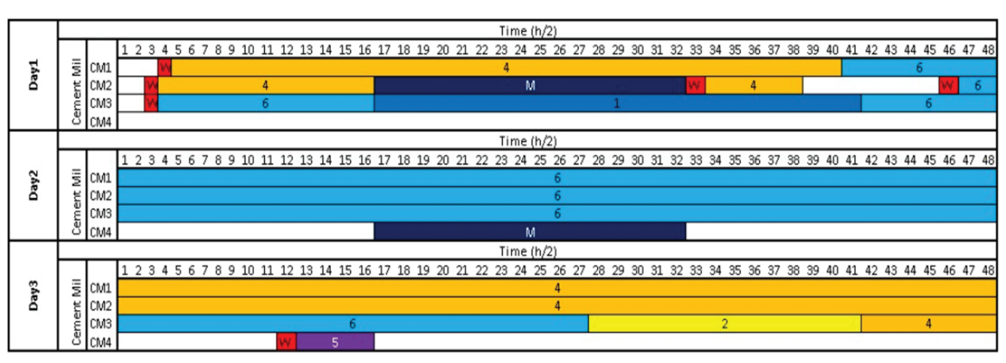


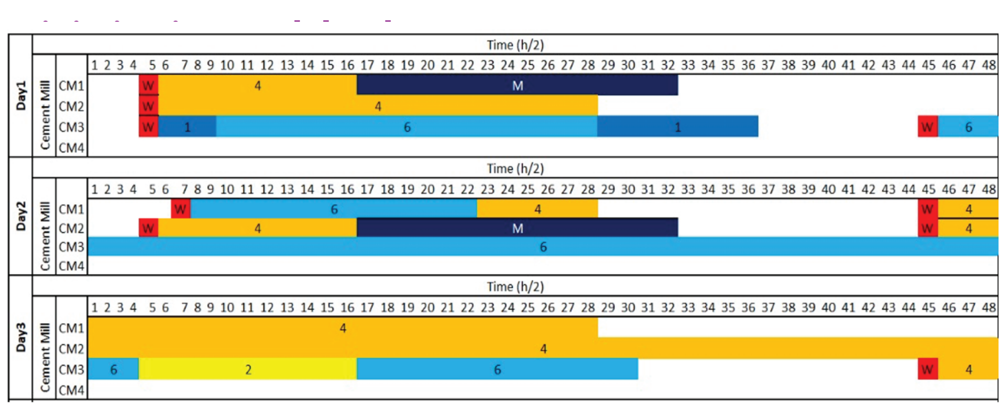
Case II - Minimization Model: July, 2023



Case III - Number of Product Transitions is Limited

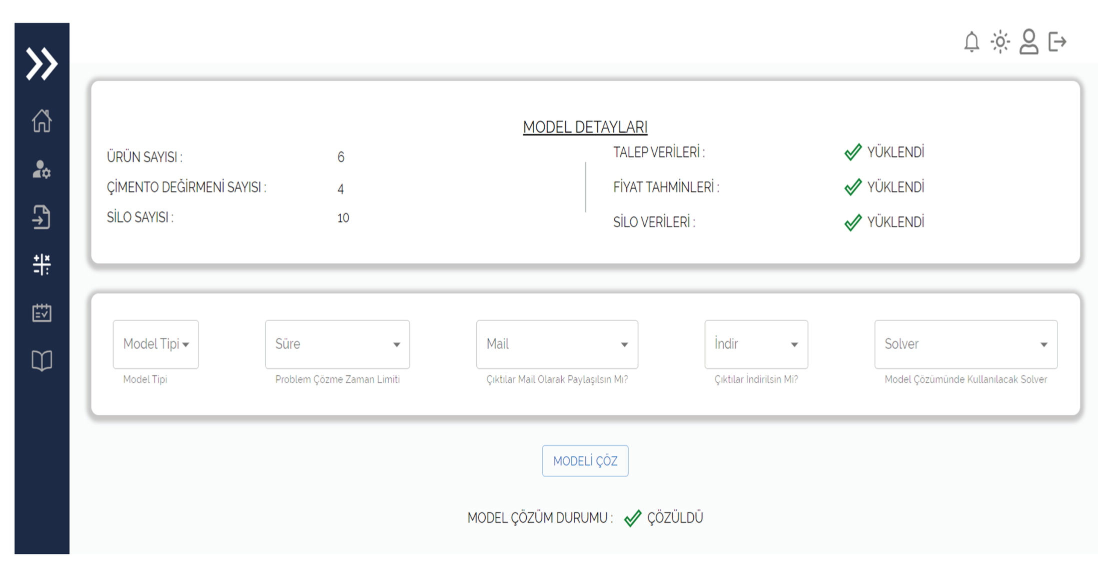
During the 1-hour product transitions in cement mills, it is possible to transition from a product with more additives to one with fewer additives; however, in practice, frequent transitions are not feasible. Number of product transitions is limited.





7 INTERFACE

The interface of the project is created using modern web technologies. This application not only provides a user-friendly interface that simplifies the operators' tasks but also solves complex optimization problems with powerful backend algorithms. In the interface there are 6 different pages which are login page, summary page, management page, data input page, a page for solving mathematical model, and results page.



8 CONCLUSION

This study optimized production schedules for four cement mills over two weeks, considering maintenance and transitions between different cement types. Using the GUROBI solver, the model achieved optimal results within 6-48 hours.
The methodology price forecast section used XGBoost, LSTM, ARIMA, and ETS methods.
The mathematical model part of the methodology was developed over 3 cases.
2 objective functions were used in the cases, these are " Maximization of Profit" and "Minimization of Energy Consumption".
Overall, the study highlights the model's effectiveness in reducing energy costs and managing transitions, offering significant benefits to the cement industry.

INDUSTRIAL ENGINEERING

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