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Optimizing the Preventive Maintenance Scheduling Based on Dynamic Deterministic Demand in The Cement Manufacturing

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Abstract. *Preventive maintenance is a planned and scheduled maintenance method that is carried out before a machine failure occurs. The maintenance schedule can be determined based on experience, historical data, or recommendations. Selecting the maintenance schedule greatly affects the production system. The Clin machine in cement manufacturing has an important role in the cement production process. During treatment, the client machine cannot produce clinker, so it is necessary to plan a production system to meet the demand. This paper aims to design an optimization model for determining the preventive maintenance schedule for cement manufacturing by considering the production process and inventory control. Mathematical models with binary options are used to model that system. The model supports showing the optimal preventive maintenance schedule for the ciln machines with a binary decision each period. This mathematical model describes the interaction of production planning, inventory control, and scheduling of total maintenance on a kiln machine. The goal of this system is to determine the optimal preventive maintenance schedule with minimum costs. In addition, the system's output is the optimal production and inventory decision rule for each period. Based on the analysis and simulation of the model with the deterministic and dynamic demand, the optimal preventive maintenance schedule is in the 9th and 21st periods. The kiln machines are maintained every July with minimal costs. The model scenario shows the interaction of the variables and the sensitivity of the production capacity and demand to the decision rule of the variable.*

Keywords: *Optimization, Preventive Maintenance, Production Process, Cement Manufacturing*

I. INTRODUCTION

Efficiency looks at how well resources are used in an activity. Good efficiency, namely, the higher the output with a certain input and the lower the input with a certain output target in an activity (Daellenbach & McNickle, 2005). Efficiency is a company's strategy in competition. Every company competes for maximum profit. Profits are influenced by the level of revenue and total costs. Several strategies to get maximum benefits, such as maximizing revenue or revenue management, manage the price and quantity of a product or service. Another strategy is to minimize costs. Cost minimization can be done with efficiency within the company.

Optimizing the production system is one way for companies to achieve efficiency. Maximizing production capacity to meet customer demand, maximizing sales revenue, minimizing production costs, and maximizing the cost of working hours are efficiency strategies (Jong et al., 2018; Ma et al., 2010). Production and inventory planning are ways of optimizing the production system. Good planning is needed to schedule production and inventory at each period. In addition to efficiency strategies, companies must also be responsive to demand. An optimal production system can be developed by considering production, inventory, and transportation planning (Rianthong & Dumrongsiri, 2012).

Inventory is an important variable in the production system in the company. Inventory includes finishing good inventory or inventory that is ready to sell, raw material inventory, work-in-process inventory, and materials still in progress or production process. Companies can reduce inventory costs if the company can calculate and predict the amount of inventory needed at the right time so that the inventory becomes small or zero. In addition, to supply the demands and needs of the production process,

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good inventory is the increase or decrease in the number of vulnerable goods or a predetermined pattern (Assauri, 2008). A trade-off in inventory is the supply is higher, it will not be financially profitable, but it can meet demand or production process needs. Conversely, if the supply is smaller, it will result in financial benefits, but there is the possibility of disrupting production activities and the inability to meet consumer demand.

The methods used in production planning and inventory control begin with the heuristic method, mathematical programming method, and simulation system. A mathematical model can be applied to determine the optimal production sequence (Liu et al., 2020). Mathematical modeling with mixed-integer programming can determine optimal production (Rianthong & Dumrongsiri, 2012). Several mathematical models in production planning combine several variables such as distribution processes, production decisions, inventory, and total working hours (Ma et al., 2010).

The cement production process generally has several stages. The first stage is to convert raw materials such as limestone, clay, sand, and additive materials into clinkers. Clinker is the main ingredient in cement making (Romadlon et al., 2020). The process uses a high-temperature kiln machine and a chemical process. Then the clinker is processed into PCC or OPC by grinding and QC processes. There are two types of cement produced: OPC (Ordinary Portland Cement) and PCC (Portland Composite Cement). PCC (Portland Composite Cement) has better quality, environmentally friendly, and a more economical price. PCC consists of several raw materials, including clinker, gypsum, and additives such as limestone, fly ash, and trass. At the same time, OPC is not added with additives in fly ash and trass (Hariawan, 2007). After becoming a PCC or OPC, it is ready to be delivered to consumers. PCC is sold in smaller lot sizes than OPC. PCC is usually used at a smaller development scale than OPC, used for large-scale development projects.

The cement company has extensive machine tools that are integrated into the production system. These machines need to be maintained and updated so that effectiveness and efficiency can be maintained and work optimally. The maintenance process for each device is carried out according to a specified schedule. One of the main machines in a machine company is a kiln machine. The kiln machine is a cylindrical tubular machine (large pipe) made of steel plate with a predetermined thickness. The kiln machine in the cement production process is the main component. The machine is well maintained, so it doesn't interfere with the production process. The kiln machine consists of several components, such as a rotary kiln, which raises the material to a high temperature (calcination) of 1400oC. The process aims to burn the material so that it melts together. In addition, there is a kiln engine drive in the form of the main gear and a reducer to reduce the kiln motor rotation. In a kiln machine, a chemical process and the raw material (raw mix) form a clinker (Drastiawati et al., 2020).

Maintenance is a support activity in the production system. Machine maintenance in the production system is expected to reduce the

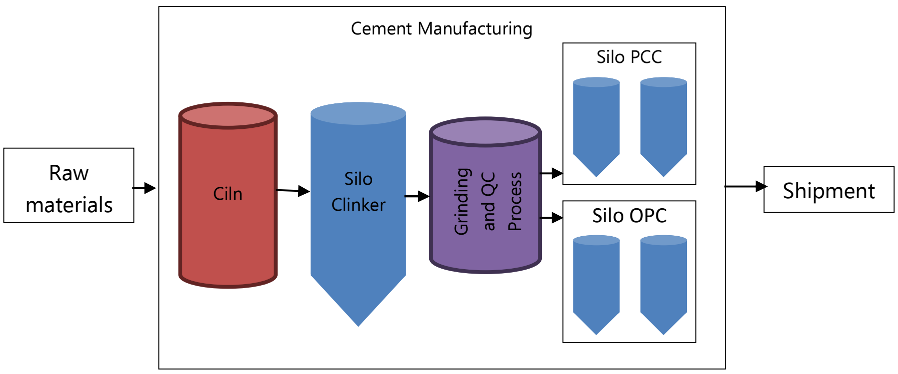

Figure 1. Cement Manufacturing Process

possibility of engine failure. Machine failure causes the machine to become unusable, thus disrupting the production process. Some machine maintenance in cement manufacturing includes Corrective maintenance, Reliability Centered Maintenance, Total Productive Maintenance, Preventive Maintenance, and Predictive Maintenance (Galankashi & Khorramrouz, 2020). Preventive maintenance is a planned and scheduled maintenance method that is carried out before a machine failure occurs (Anthony, 1992). Effective preventive maintenance aims to solve problems related to machines or components (Bevilacqua & Braglia, 2000). Preventive maintenance is an activity of checking, replacing, or replacing components based on the frequency of failure rates. Preventive maintenance is divided into two types of activities, namely periodic maintenance, and routine maintenance. Periodic maintenance is machines or equipment carried out at time intervals based on experience, past data, or recommendations. Determining the maintenance schedule is very influential and important in the production process (Assauri, 2008). The duration of the maintenance process for a machine can take a short or long time, resulting in unusable production machines. The company is expected to be able to anticipate the influence of maintenance activities.

The preventive maintenance schedule can be determined by several methods, such as integer linear programming, taking into account the capacity of working hours and machines (Wirdianto et al., 2020). Integer linear programming is used to indicate the time for preventive maintenance by considering set up costs and maintenance intervals (Gustavsson et al., 2014). In the production process, mathematical modeling can determine the optimum production cost value based on machine utilization by entering binary decisions on each machine (Wu & Wang, 2011). Determination of preventive maintenance schedules with binary decisions can also be done using genetic algorithm methods considering costs, machine reliability, and downtime prediction (Javanmard & Koraeizadeh, 2016).

The decision of the preventive maintenance schedule on ciln machines affects production scheduling and inventory control. Preventive maintenance on kiln machine is carried out when the stop engine condition. When the kiln machine is stopped, it cannot produce a clinker. The duration of maintenance or the kiln machine stopped is three to four weeks. To started and stopped the machine requires a high cost. So the company must prepare and determine a strategy to provide clinker as the raw material PCC and OPC. Companies can order clinker at clinker suppliers. In addition, the company can schedule production and inventory control to provide the needs of the clicker as long as the machine cannot operate. For example, a strategy is to increase the quantity of production and inventory before the machine maintenance schedule by considering production and inventory capacity.

The purpose of this paper is to model a system in manufacturing cement. The system consists of several variables, namely production, inventory, and maintenance, that interact with each other to achieve certain goals. The goal of this system is to determine the optimal preventive maintenance schedule. Besides that, the output of the model provides the production and inventory decisions quantity for each period.

II. RESEARCH METHOD

The problem with the optimization problem can be solved by mathematical calculations (Popov et al., 2019). Mathematical modeling is the process of interpreting real conditions or problems in the form of abstract symbols. A mathematical description is called a mathematical model, whereas the process of obtaining it is called mathematical modeling. Mathematical modeling is both a science and an art. Mathematical modeling is called science because it deals with the topics discussed to complete the various steps in the modeling process (Daellenbach & McNickle, 2005). In mathematical modeling, art is needed because it requires creativity, intuition, and foresight, especially since there are no similar problems in the real world.

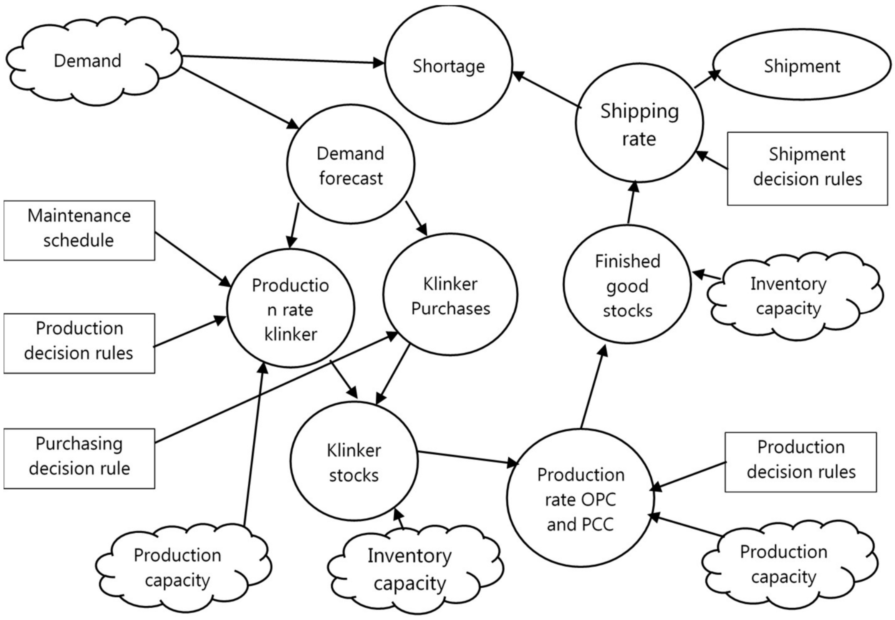

Figure 2. Influence diagram of cement production system

The method used in this research is the mathematical modeling method. Mathematical models express the relationships between various components or entities in a system, which are defined in quantitative terms. This method produces decisions with the optimal goal, which is minimizing costs. In mathematical modeling, several data such as variable data affecting the system, system objectives, and constrain of the system are required. This model was developed by adding binary options that indicate conditions in the production system, such as scheduling preventive maintenance decisions.

The research method has several stages. The research stages consisted of problem articulation, system characterization, mathematical modeling, validation and verification, analysis, and concluding. Problem articulation (boundary selection) is determining the limits and variables to be modeled. System characterization identifies the characters in the system to determine the appropriate model according to real conditions. Mathematical modeling, changing from real-condition schemes to mathematical forms such as determining objectives and limitations in the optimization model. Determination of different goals will produce different optimal solutions. However, it doesn't always happen. It is possible that two different goals could lead to the same solution. The limitations of the problem can influence the formation of unique solutions. Then, validation and verification are the stages of testing whether the resulting model represents real conditions. Several validation and verification tests methods, such as testing with small case studies, testing with extreme conditions, and adjusting to existing theories, can be done with expert opinion. The last stage is analysis and conclusion, taking the information obtained from the designed model (H. Paul Williams, 2013).

III. RESULT AND DISCUSSION

Problem Description

A system consists of several entities or variables that interact to achieve certain goals (Daellenbach & McNickle, 2005). In the production system, several entities interact to achieve the goal of supplying consumer demand. The entities in this system are shown in Figure 2. The cloud symbol is an uncontrollable input data constrain. The rectangle symbol indicates the control input or decision rule. Oval is an output variable. Circle shows system variables, component attributes, and state variable values.

Meanwhile, arrows show the influence relationships between entities. Production and inventory planning is needed to achieve these goals. In addition, cement manufacturers are also planning a machine maintenance schedule. This is done because machine maintenance in cement manufacturing is very influential on production scheduling and inventory decisions. Machine maintenance in cement manufacturing requires a long time and expensive setup costs to influence production planning and inventory decisions.

Cement manufacturers produce two types of products, such as PCC and OPC. To supply the two products, it is necessary to determine the optimal inventory. If the manufacturer cannot supply demand, the company will get a loss called shortage cost (Hamdy A. Taha, 2007). The shortage cost variable can be added to a mathematical model because it affects the production system (Li et al., 2020). The company is unable to supply demand if inventory is smaller than demand for a certain period. The level of production and demand influences finished goods inventory. Inventory increased because the number of OPC and PCC production increased. OPC and PCC inventories are reduced as these supplies are delivered to consumers. Inventory in this period is also affected by inventory in the previous period. Likewise, clinker inventory is affected by the amount of clinker production. In addition, it is influenced by the number of clinkers ordered from other companies. The amount of clinker inventory reduced because it is used as raw material for OPC and PCC production. The company has two alternatives for obtaining a clinker, such as by producing using a kiln machine or ordering from a clinker supplier.

The system being modeled has dynamic and deterministic characteristics. The system is referred to as a dynamic system because time has a role in the system so that the variable value changes every time (t). Several dynamic variables are production rate and inventory level. This system is deterministic because the variable or change in value is predictable with certainty. Stochasticity is not found in the model. Changes in the value of variables in the model based on time are discrete.

Optimization in this case study aims to find the minimum cost of the production system. Each stage has its costs, such as production costs for kiln and grinding machines. Other costs include setup, inventory, and costs incurred when the company chooses to order clinker from outside the company. To minimize production costs, the company can minimize the amount of production, but the company will not be able to supply demand, so that shortage costs arise. This is one of the trade-offs in this model. This mathematical model integrates production decisions, inventory control, and maintenance schedules. When maintaining a chill machine in cement manufacturing, the machine cannot operate or be used to produce a clinker. Inventory and purchasing decision rules are used when the company cannot produce clinker. The company can anticipate by increasing inventory or ordering from other companies. This model is expected to be able to solve these problems by producing optimal solutions.

$$Min\ Z = \sum_{t=1}^{n} Bpc * w_t * j_t + \sum_{t=1}^{n} Bppc * y_t + \sum_{t=1}^{n} Bpoc * z_t + \sum_{t=1}^{n} Boc * x_t + \sum_{t=1}^{n} Bic * ik_t + \sum_{t=1}^{n} Bip * ip_t + \sum_{t=1}^{n} Bio * io_t + \sum_{t=1}^{n} Bs * \max(0, w_i - w_{i-1}) + \sum_{t=1}^{n} Bsp * (a_t - sa_t) + \sum_{t=1}^{n} Bso * (b_t - sb_t) \quad \ldots (1)$$

Subject to :

$$ik_t \leq csk \quad \ldots (2)$$

$$ip_t \leq csp \quad \ldots (3)$$

$$io_t \leq cso \quad \ldots (4)$$

$$ip_t = ip_{t-1} + y_t - sa_t \quad \ldots (5)$$

$$io_t = io_{t-1} + z_t - sb_t \quad \ldots (6)$$

$$ik_t = ik_{t-1} + j_t + x_t - y_t - z_t \quad \ldots (7)$$

$$sa_t \geq a_t * fr \quad \ldots (8)$$

$$sb_t \geq b_t * fr \quad \ldots (9)$$

$$(ik_{t-1} + j_t + x_t) * pc \geq y_t + z_t \quad \ldots (10)$$

$$ip_{t-1} + y_t \geq sa_t \quad \text{... (11)}$$

$$io_{t-1} + z_t \geq sb_t \quad \text{... (12)}$$

$$y_t + z_t \leq cg \quad \text{... (13)}$$

$$j_t \leq cc \quad \text{... (14)}$$

$$w_t = w_{t+pm} \quad \text{... (15)}$$

$$w_t \; integer \begin{cases} 1 \; mechine \; on \; in \; period \; t \\ 0 \; mechine \; off \; in \; period \; t \end{cases} \quad \text{... (16)}$$

In this mathematical programming, several limitations are described, such as that the inventory level in each section, such as clinker inventory, OPC, and PCC, cannot exceed the capacity of each inventory (Eq. 2) (Eq. 3) (Eq. 4).

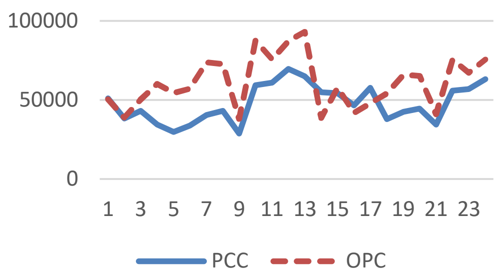

Figure 3. Demand PCC and OPC

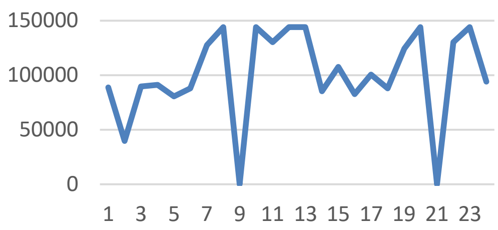

Figure 4. Production level

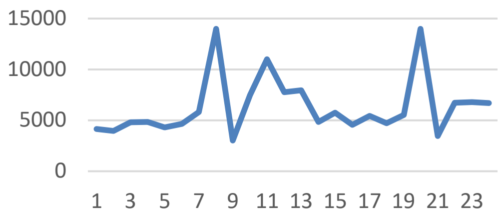

Figure 5. Inventory level

Table 1. Symbol and Description

Notation	Description
Z	Total Minimum cost
t	Time / Period per month
Bpc	Biaya produksi klinker per ton
w_t	A binary option, 1 machine on and 0 machine off (maintenance)
j_t	The number of clinkers produced in period t
BBC	The production cost of PCC products on grinding machines
y_t	The number of PCC produced in period t
$Bloc$	Production costs for OPC products on grinding machines
z_t	The number of OPCs produced in period t
Boc	Clinker Price, if company order from other / outside the company
x_t	The number of clinkers ordered in period t
Bic	Clinker inventory cost
ik_t	The number of clinker inventory in period t
Bip	PPC inventory cost
ip_t	The number of inventory PCC pada period t
Bio	OPC inventory cost
io	The number of inventory OPC pada period t
Bs	Set up the cost of the kiln machine
Bsp	PCC shortage cost
Bso	OPC shortage cost
a_t	Demand PCC at period t
b_t	Demand OPC at period t
sa_t	The number of PCC delivered to consumers
sb_t	The number of OPC delivered to consumers
pc	Percentage of clinker required for OPC and PCC production process
csk	Silo clinker capacity
CSP	Silo PCC capacity
cso	Silo OPC capacity
fr	Fill rate
CG	The maximum capacity of production of grinding machine
cc	The maximum capacity of production of kiln machine
pm	Time Interval of preventive maintenance

Inventory levels of PCC and OPC are influenced by inventory in the previous period, production of OPC and PCC, as well as PCC and OPC, delivered to consumers (Eq.5) (Eq.6). Meanwhile, clinker inventory is influenced by inventory levels in the previous period, the amount of clinker produced or ordered, and the amount of clinker used for the OPC and PCC production processes. The fill rate is the minimum percentage of demand that the company must meet. The fill rate is zero, which means that the company does not supply-demand or deliver products to consumers during that period (Eq. 8) (Eq. 9). According to the material flow in the production process, the clinker inventory used in period t is greater or the same as the clinker used in that period for the production of OPC and PCC (Eq. 10). Clin and grinding machines have a maximum capacity, so the clinker, PCC, and OPC produced cannot exceed these capacity limits (Eq.13) (Eq.14). Binary numbers indicate the decision of the machine on or off. When the machine dies, total maintenance is carried out on the kiln engine. The company determines machine maintenance intervals based on machine reliability (Eq. 15) (Eq.16) (Hillier & Lieberman, 2010).

Numerical Experiment

Based on a mathematical model designed, it is then analyzed based on numerical experiments with the data obtained. PCC's demand has an average of 47772.46 tons with a minimum value of 28785.97 tons and a maximum of 69664.37 tons, while OPC has an average value of 61254.02 tons with a minimum value of 38023.9 tons and a maximum of 93016.78 tons. The optimal time for machine maintenance is obtained in the 9th and 21st periods or every July from the demand data. You can also find out the production and inventory levels at each period.

Optimal inventory that the company can do based on maintenance schedule decisions and production level:

The average inventory under these conditions is 6336.66. Inventory decisions resulted in the 7th and 8th periods as well as the 19th and 20th periods increased due to anticipation of inventory when the machine could not produce during the maintenance period.

Scenario 1

The first scenario is to test the optimal schedule results based on changes in production capacity.

Based on the scenario results, the engine maintenance schedule changes because of changes in engine capacity to 70%. The machine schedule changed in the 2nd and 14th periods. Likewise, the production and inventory levels in each period changed in Figure 6 and Figure 7.

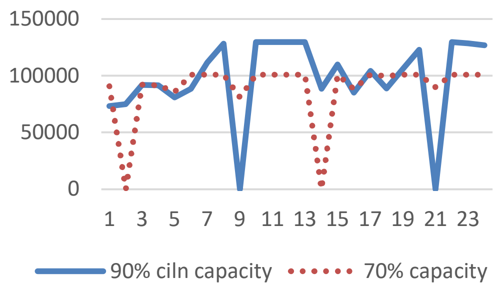

Figure 6. Production level scenario 1

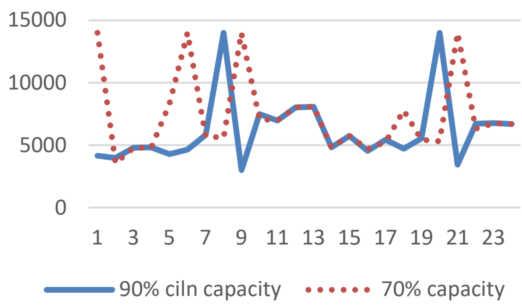

Figure 7. Inventory level scenario 1

Scenario 2

The second scenario examines the effect of demand patterns on machine maintenance schedules. Demand for periods 9 and 21 is changed to be larger.

Based on the scenario results, the engine maintenance schedule changes because PCC and OPC requests. The machine schedule changed in the 2nd and 14th periods. Likewise, each period's production and inventory levels experienced changes, as in Figure 9 and Figure 10.

Scenario 3

The third scenario tests the machine maintenance schedule against the amount of historical demand data used. Demand data can be obtained based on the company's historical data or demand forecasting. The amount of request data used is 36 periods.

Based on the scenario, the machine maintenance schedule does not change. Machine maintenance schedules are carried out in periods 9, 21, and 28. Likewise, the production and inventory levels in each period are shown in Figure 12 and Figure 13.

Model analysis

The system has objective goals based on objective functions. The model, which represents the production system in cement manufacturing, has the objective of minimizing costs. Mathematical modeling can identify variables that have a significant correlation or interaction in a system. Inventory decisions will influence the level of shortages in the company. Inventory aims to provide supplies for the production system for production demands and needs. Production decisions influence the level of inventory. The higher the level of production, the higher the inventory. The simulation results show that companies tend to keep more inventory before the machine maintenance schedule and decrease drastically during the machine maintenance period. So that the decision on the preventive maintenance schedule influences production and inventory decisions.

Capacity in the production process and demand patterns can change optimize solutions. Production capacity is the maximum number of products that can be produced. Meanwhile, inventory capacity is the availability of storage space for a product or raw material. The production system tends to increase inventory in

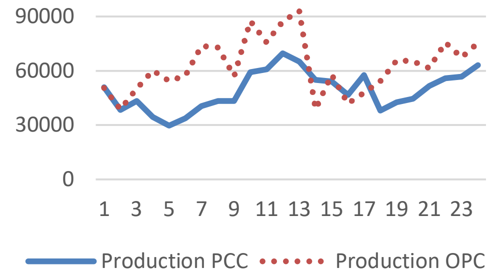

Figure 8. Demand PCC and OPC scenario 2

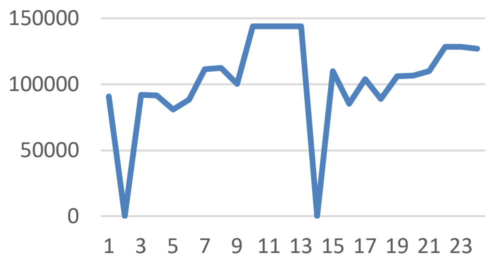

Figure 9. Production level scenario 2

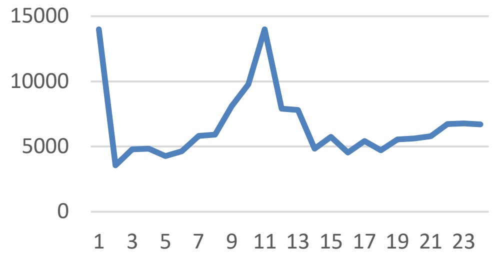

Figure 10. Inventory level scenario 2

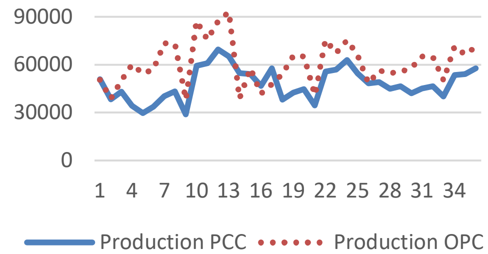

Figure 11. Demand PCC and OPC scenario 3

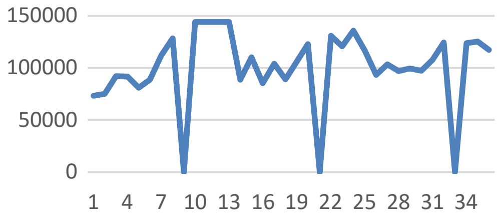

Figure 12. Production level scenario 3

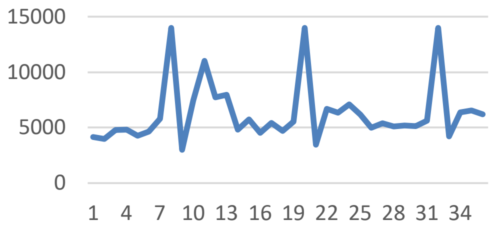

Figure 13. Inventory level scenario 3

the period before the machine maintenance schedule. If the company cannot meet the demand with existing supplies, the company will be a shortage or reduce the fill rate and customer responsiveness. Likewise with production, to get the maximum supply, a company must produce the maximum amount but is limited by capacity, so the company must prepare for several production periods beforehand. Changes in demand can change the optimal decision, or it is said that different conditions in a mathematical model can produce different outputs. However, there are some conditions that do not change specific decisions. At some point, changes in demand and capacity can change machine maintenance decisions.

IV. CONCLUSION

Mathematical models can describe the optimization model in a cement production system by considering several variables such as production planning, inventory control, and scheduling of total maintenance on a kiln machine. Based on the analysis of the model, the ciln machine maintenance is carried out every July, resulting in a minimum cost for the company. In addition, it is also known that the optimal production and inventory decision rule for each period. Each variable has an influence on the system. Based on the scenario and analysis, changes in production capacity and demand patterns will change machine maintenance schedules.

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