



THESIS- TI185401

COST MINIMIZATION IN MULTI-ECHELON PLANT USING MIXED INTEGER LINEAR PROGRAMMING - CASE STUDY PT. XYZ CEMENT MANUFACTURER

NALENDRA PERMANA
02411850077014

SUPERVISOR
Dr. Ir. Sri Gunani Partiwi, M.T.
Dr.Eng Erwin Widodo, S.T., M.Eng.,

MAGISTER PROGRAM
DEPARTMENT OF INDUSTRIAL AND SYSTEM ENGINEERING
FACULTY OF INDUSTRIAL TECHNOLOGY AND SYSTEMS ENGINEERING
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TESIS - TI185401

**OPTIMASI BIAYA PRODUKSI PADA *MULTI-ECHELON PLANT* DENGAN MENGGUNAKAN
METODE *MIXED INTEGER LINEAR PROGRAMMING* - STUDI KASUS PT. SEMEN XYZ**

**NALENDRA PERMANA
02411850077014**

**Dosen Pembimbing
Dr. Ir. Sri Gunani Partiwi, M.T.
Dr.Eng Erwin Widodo, S.T., M.Eng.,**

**MAGISTER PROGRAM
DEPARTEMEN TEKNIK SISTEM DAN INDUSTRI
FAKULTAS TEKNOLOGI INDUSTRI DAN REKAYASA SISTEM
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
2020**

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LEMBAR PENGESAHAN TESIS

Tesis disusun untuk memenuhi salah satu syarat memperoleh gelar

Magister Teknik (MT)

Di

Institut Teknologi Sepuluh Nopember

Oleh:

NALENDRA PERMANA

NRP: 02411850077014

Tanggal Ujian: 10 Agustus 2020

Periode Wisuda: September 2020

Disetujui Oleh:

Pembimbing:

1. Dr. Ir. Sri Gunani Partiwi, M.T.
NIP: 196605311990022001

2. Dr.Eng. Erwin Widodo, S.T., M.Eng.
NIP: 197405171999031002

Penguji:

1. Prof. Ir. Budi Santosa, M.Sc., Ph.D.
NIP: 196905121994021000

2. Dr. Ir. Bambang Syairudin, M.T.
NIP: 196310081990021001

Kemendikbud
KEMENTERIAN PENDIDIKAN DAN KEBUDAYAAN
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
Fakultas Teknologi Industri dan Rekayasa Sistem



Nurul Hikmati, M.S.I.

NIP: 197005231996011001

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LEMBAR PERNYATAAN KEASLIAN TESIS

Saya yang bertanda tangan di bawah ini:

Nama : Nalendra Permana

NRP : 02411850077014

Program Studi : Magister Teknik Industri - ITS

Menyatakan bahwa tesis dengan judul

**“COST MINIMIZATION IN MULTI-ECHELON PLANT
USING MIXED INTEGER LINEAR PROGRAMMING
– CASE STUDY PT. XYZ CEMENT MANUFACTURER”**

adalah benar-benar hasil karya intelektual mandiri, diselesaikan tanpa menggunakan bahan-bahan yang tidak diijinkan dan bukan merupakan karya pihak lain yang saya akui sebagai karya sendiri.

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Surabaya, 17 Agustus 2020

Yang membuat pernyataan



Nalendra Permana

NRP. 02411850077014

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**COST MINIMIZATION IN MULTI-ECHELON PLANT USING MIXED
INTEGER LINEAR PROGRAMMING**
- CASE STUDY PT. XYZ CEMENT MANUFACTURER

Name : Nalendra Permana
NRP : 02411850077014
Supervisor : Dr. Ir. Sri Gunani Partiwi, M.T.
Dr.Eng Erwin Widodo, S.T., M.Eng.,

The competition in Indonesian cement market has been getting severe since in 2015. Total installed cement plant capacity greatly increase from 65 MTon/year become 113,5 MTon/year. This condition reduce cement plant utilization and reduce revenue and margin profit. PT. XYZ are cement company, which operates 4 integrity plant, has to take cost transformation by reduce production cost. PT.XYZ has to produce the cement at certain level production rate to meets cement demand at minimum cost. This thesis are objected to provide holistic solution and recommendation to operational manager in order to minimize production cost. First step in this thesis is develop mathematical model using mixed integer linear programming(MILP). MILP will calculate and minimize cost by changing decision variable of production allocation for each plant. The MILP model has to be verified and validated before fully apply the model. next step is the demand forcasting. Forecast needed to determine future demand using historical data before the MILP can give operational recommendation about near-future demand. This thesis examines suitable forecasting method using moving average, single exponential smoothing, Trend-Corrected exponential smoothing (Holt's Method, and seasonal & trend -corrected exponential smoothing (winter's method) . The forecasted demand checked for accuration using MAD, MSE, and MAPE method and choose one forecasting method which has smallest error. This thesis also does sensitivity analysis to find dependency and impact of electrical energy consumption cost (Rp/KWh) and coal price(Rp/Ton) to Total production cost because cement manufacturer need to use both electrical and coal thermal energy. The result is MILP application can reduce production cost by 3.29%. this research best-known forecast method is monthly forecast using winter's method with $\alpha=0.38$ and $\beta=0.3$ with MAPE 8%. Then the MILP recommendation for near-future demand is to shutdown a Kiln for entire year, then maximize production to other plant. Sensitivity analysis indicates that coal price has higher impact to total production cost than electrical energy consumption cost . 50% coal price increased impact 22% total production cost and 50% electrical energy consumption cost increased impact 17% total production cost. This result shown that secure coal supply chain and price are more crucial than build corporate-owned powerplant.

Keyword : Cost minimization, Mixed integer linear programming, demand forecasting, sensitivity analysis.

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**OPTIMASI BIAYA PRODUKSI PADA *MULTI-ECHELON PLANT* DENGAN
MENGGUNAKAN METODE *MIXED INTEGER LINEAR PROGRAMMING*
– STUDI KASUS PT. SEMEN XYZ**

Name : Nalendra Permana
NRP : 02411850077014
Pembimbing : Dr. Ir. Sri Gunani Partiwi, M.T.
Dr.Eng Erwin Widodo, S.T., M.Eng.,

Persaingan di pasar semen indonesia semakin ketat sejak tahun 2015. Total kapasitas terpasang pabrik semen meningkat pesat dari 65 mton / tahun menjadi 113,5 mton / tahun. Kondisi ini menurunkan utilisasi pabrik semen serta menurunkan pendapatan dan keuntungan margin. PT. XYZ merupakan perusahaan semen yang mengoperasikan 4 pabrik terintegrasi, harus melakukan transformasi biaya dengan menekan biaya produksi. PT. XYZ harus memproduksi semen pada tingkat produksi tertentu untuk memenuhi kebutuhan semen dengan biaya minimum. Thesis ini bertujuan untuk memberikan solusi dan rekomendasi yang holistik kepada manajer operasional guna meminimalkan biaya produksi. Langkah pertama dalam tesis ini adalah mengembangkan model matematika dengan menggunakan Mixed Integer Linear Programming (MILP). MILP akan menghitung dan meminimalkan biaya dengan mengubah variabel keputusan alokasi produksi untuk setiap pabrik. Model milp harus diverifikasi dan divalidasi sebelum menerapkan model sepenuhnya. Langkah selanjutnya adalah permintaan peramalan. Prakiraan diperlukan untuk menentukan permintaan di masa mendatang dengan menggunakan data historis kemudian MILP dapat memberikan rekomendasi operasional tentang permintaan dalam waktu dekat. Tesis ini mengkaji metode peramalan yang sesuai dengan menggunakan metode moving average, single exponential smoothing, trend-corrected exponential smoothing (metode holt,) Seasonal & trend –corrected exponential smoothing (metode winter's). Permintaan yang diramalkan diperiksa akurasinya menggunakan metode MAD, MSE, dan MAPE dan memilih salah satu metode peramalan yang memiliki error terkecil. Tesis ini juga melakukan analisis sensitivitas untuk mengetahui ketergantungan dan dampak biaya konsumsi energi listrik (rp / kwh) dan harga batubara (rp / ton) terhadap total biaya produksi karena produsen semen perlu menggunakan keduanya. Energi panas batubara dan listrik. Hasilnya aplikasi milp dapat menekan biaya produksi sebesar 3.29%. Metode peramalan yang paling akurat dalam penelitian ini adalah peramalan bulanan menggunakan metode winter's dengan $\alpha = 0.38$ dan $\beta = 0.3$ dengan mape 8%. Kemudian rekomendasi MILP untuk permintaan dalam waktu dekat adalah mematikan kiln sepanjang tahun, kemudian memaksimalkan produksi ke pabrik lain. Analisis sensitivitas menunjukkan bahwa harga batubara memiliki dampak yang lebih tinggi terhadap total biaya produksi dibandingkan dengan biaya konsumsi energi listrik.

Peningkatan 50% harga batubara berdampak pada 22% total biaya produksi dan 50% biaya konsumsi energi listrik berdampak pada peningkatan 17% total biaya produksi. Hasil ini menunjukkan bahwa mengamankan rantai pasokan dan harga batubara lebih penting daripada membangun pembangkit listrik sendiri milik perusahaan.

Keyword : Cost minimization, Mixed integer linear programming, demand forecasting, sensitivity analysis.

Foreword

Bismi-llāhi ar-rahmāni ar-rahīmi, Al-Ḥamdu lillāhi Rabbil a'lammin, Allahumma shalli ala Muhammad. Atas berkat rahmat ALLAH SUBHANA WA TAA'LA hingga kami diberi kemampuan untuk menyelesaikan pendidikan Magister di TI ITS kemudian kami ucapan sholawat untuk Rasulullah Shalalahu alaihi wasalam. Penelitian ini dilakukan untuk menyelesaikan studi magister teknik di Departemen Teknik Sistem dan Industri, Institut Teknologi Sepuluh Nopember Surabaya.

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CHAPTER 1 INTRODUCTION

1.1 Background

PT.XYZ is cement manufacturer in Indonesia. Cement industry reach its peak utilization production in 2014. After 2014, many competitor company construct many new cement plant. It make the cement market competition is getting tough. There are 9 Cement industries in 2013 with total installed capacity 65 MT/Year become 19 Cement Industries in 2016 with total 113.5 MT/Year. Total cement consumption 2016 is 62 MT/Year. It make average national cement plant's utilization only 54.6%. PT. XYZ also reduce its % utilization from 95% in 2014 reduce to 85% in 2018 [Corp-presentation-december-2019].

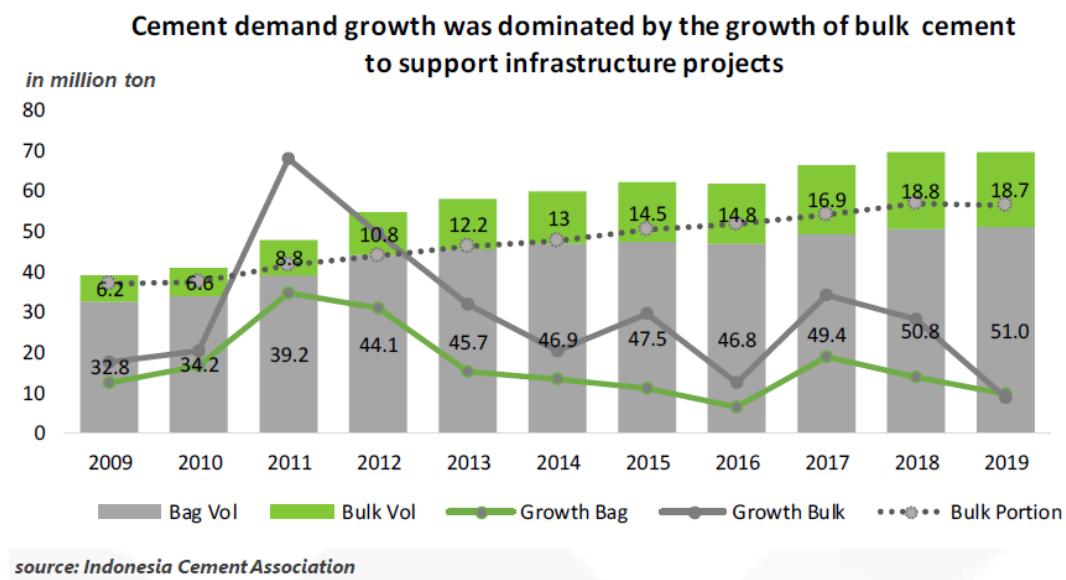


Figure 1.1 Graphic demand and installed capacity cement plant in Indonesia [source Annual Report PT.XYZ 2019]

Cement is made from limestone, clay, gypsum, and other pozzolan material. Lime stone and clay are mine from open mining owned by corporate. Limestone crush in crusher until 10 cm diameter. Crushed limestone mix together with 80% limestone and 20% clay and stocked in Raw Mix Pile in Reclaimer (RR). Raw Mix Pile in RR will deliver to Raw Mill (RM). Raw Mill will grind Raw Mix pile until fine powder. Fine Powder will be stored in Blending silo (BS). Blending silo supply the kiln (KL) feed. Blending Silo's stock must be confirmed to prevent kiln production slowdown or stop. Kiln product is Clinker then stored in clinker dome. Clinker stored in clinker dome (DC) supply the finish mill (FM). clinker will mix with gypsum and any other pozzolan in finish mill then grind until become fine product and stored at cement silo (CS).

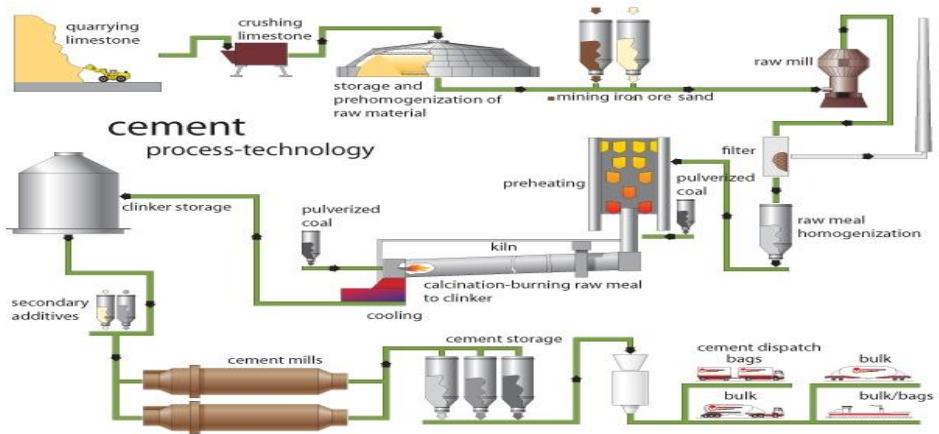


Figure 1.2 Flow diagram in cement industries. [source : <https://www.civileblog.com/cement-manufacturing-process/>]

PT. XYZ has installed capacity 14 Million Metric Ton per year. PT.XYZ Main Equipment consist of 4 Reclaimer, 4 Raw Mill, 7 Blending silo, 4 Kiln, 4 Dome Clinker, 9 Finish Mill, 16 Silo Cement. There are 3 kind of main equipment, Rawmill (RM), Kiln (KL), and Finish mill (FM). Main Equipment are the only production facility which operator can adjust its Production rate to fulfill its demand. Main equipment has its own production cost (Rp/Ton) to determine the efficiency of each main equipment. Due to aging factor and maintenance policy is condition based, every main equipments has different fixed cost, idle up cost, and variable cost. This cost difference make the production each main equipment needs to be cost-optimized.

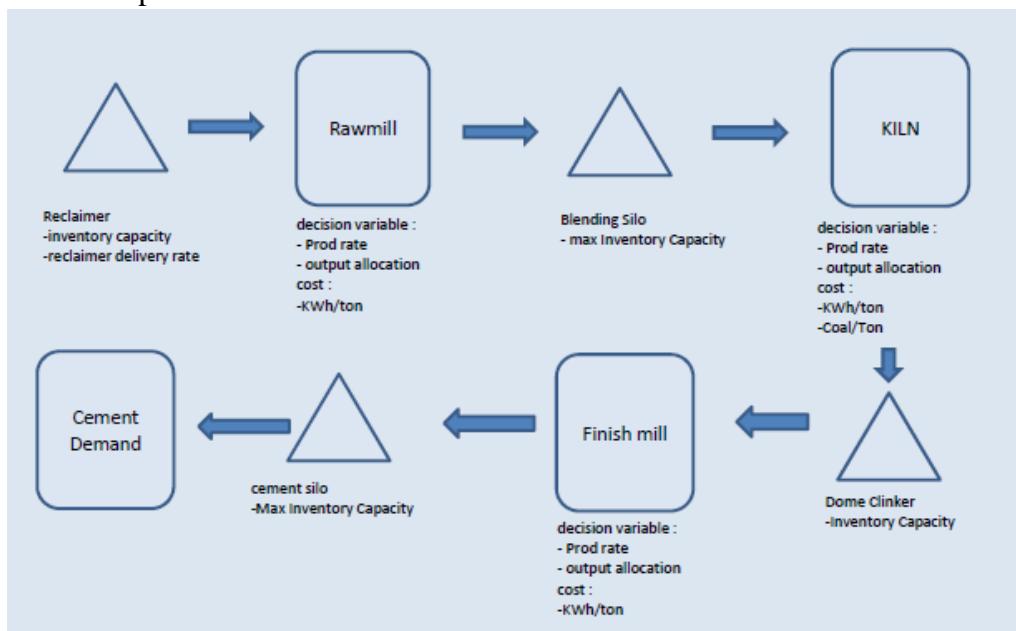


Figure 1.3 Model conceptual

Cement competition is getting fierce in 2015. Cement demand on PT. XYZ plant is reduced. Finish mill suffer Start-Stop Operational condition due to High level Cement Silo. dome clinker's inventory stock will rise. there is an option to prevent dome clinker from over load by transport the clinker out of dome using truck for some cost. Kiln's operation always needs free space of dome clinker. Kiln needs Industrial Diesel Oil (IDO) to heating up. IDO is expensive fuel will cause high heating up cost of kiln. Kiln's high heating up cost make "stop the kiln" will be last option to choose. In 2019, when situation getting worse. PT. XYZ top management instingly decide to stop 1 kiln out of 4 kiln stop for 45 days because out of space to store clinker the dome. PT. XYZ cannot afford high cost transport-out clinker from dome. PT. XYZ should be expected Kiln Stop because of high level dome clinker every year. Raw mill has high capacity that could quickly fill up the blending silo. After the blending silo is full then the rawmill stop. Current "Start-stop Raw Mill operational" policy will increase power consumption and also reduce the equipment running time.

PT. XYZ has 1 Rawmill-Kiln-Coalmill Operation division consist 4 Operation Manager for Rawmill-kiln (OPRKC1,OPRKC2,OPRKC3,OPRKC4), 1 Finish Mill Operation Division consist of 2 Operation Manager (OPFM12, OPFM34), and 1 Production Planning and control Division (PPC). PT. XYZ Operation Manager current policy to handle its demand is by set main equipment production rate at "as high as main equipment can reach". this production policy will make inventory stock high level soon and the main equipment will stop. PT. XYZ operational manager neglected equipment back order cost. PT. XYZ production planning manager need to optimize whole plant performance and balance within production and Cost of Goods Manufacture (COGM). PT. XYZ Plant currently has no tools to decide how to handle its production rate to meets its demand and produce cement at minimum cost. Current production policy will be shown in table 1.1

Table 1.1 Current production policy in PT. XYZ and task responsibility

No	Area	Current Policy	In charge
1	Raw Mill	Run full Production Rate, inventory Blending silo full, stop for service, At all production cost	OPRKC1, OPRKC2, OPRKC3, OPRKC4,
2	Kiln	Minimize Downtime, Kiln running full production rate as quality, inventory dome clinker must not full- reject clinker and store it in open yard for later use, transport cost reject clinker at all cost	OPRKC1, OPRKC2, OPRKC3, OPRKC4,
3	Kiln	Try to minimize reject clinker due too high transport cost	PPC

Table 1.1 Current production policy in PT. XYZ and task responsibility (continued)			
4	Finishmill	Run full Production Rate, inventory Cement silo full, stop for service, At All Production Cost	OPFM1-2, OPFM3-4
5	finishmill	Production type balancing between each finishmill	PPC

This Research Main concern is to develop Tool to help OPRKC manager, OPFM Manager and PPC manager determine main equipment production rate. Mixed Integer Linear Programming will calculate cost of every level of demand and determine the day-to-day production scenario has to take to minimize cost. This research will do sensitivity analysis to determine dependency the production rate each main equipment to total production cost and also apply demand forecasting and try give recommendation with future possible demand.

1.2 Problem statement

In this case-based report focused on determine Production Rate of Raw Mill, Kiln, and Finish Mill using Mixed Integer Linear Programming. In order to determine production rate, company has to consider total production cost. Production cost consists of electric power cost, fuel coal cost, transportation cost, and back order cost. This thesis also test forecasted demand to determine future production rate.

Q1: How to build mathematical model of PT. XYZ Production plant?

Q2: How much total production cost saving by applying Mixed Integer Linear Programming into plant model?

Q3: How to select production line of the plant to efficiently fulfill near future demand?. Moreover, how to investigate the relationship between electrical energy consumption cost as well as coal price to total production cost?.

1.3 Research Objective

According to Problem statement, Research objective will be done by:

1. Developing Mixed Integer model about PT. XYZ plant with its production's constraint, Fixed Cost, Variable cost, and demand using determined data from 2017-2019.
2. Run the model using determined actual demand 2019 and compare the actual cost for actual production rate and MILP cost minimization and calculate the potential cost saving using MILP.
3. Forecast the demand, then apply it to model, analyzed and give production suggestion for forecasted demand 2020. And also do sensitivity analysis to determine dependency between energy electricity price and Coal price to total production cost

1.4 Problem restriction and assumption

Research will be done with several restriction and assumption. Research restriction will be:

1. Data demand, inventory capacity, Fuel Coal consumption, inventory capacity constrain, transport capacity constrain are secondary data from 2017-2019.
2. Data Electrical power consumption are Primary data monthly from 2017-2019.
3. Production rate determination are only for production rate Rawmill, Kiln, and Finish mill PT. XYZ Plant.

This research are also use several assumption :

1. Assumption electrical energy and coal price is fixed. All energy cost converted into Rp/ton with conversion rate for electrical energy price is Rp 977/KWh and coal is Rp 680.000 / Ton
2. Government Policy are fixed, Indonesia's Cement Plant Installed capacity are fixed due to "moratorium pabrik semen", and no more new competitor entry beyond 2018. Assumption no any force majeur, political stability, pandemic, etc
3. Market share are fixed beyond 2018.
4. Assumption material discussed in this thesis is limestone, clay, silica sand, cooperslag, gypsum, pozzolan, and flyash. Any other addition material are neglected due to insignificant use
5. Assumption plant's top management allow operational manager to follow cost-minimization production suggestion. Political factor are neglected.

1.5 Contribution

This research is expected to be the basis in the research of cost minimization the multi-eschelon complex manufacturing industry. For PT. XYZ Plant, this research is useful as a production rate decision at minimize cost to keep company competitiveness. And also Provide holistic solution from forecast near-future demand and also giving cost-minimized production suggestion for Production Manager to make production planning decision to fulfill future demand

1.6 Writing systematic

This thesis is made with a systematic six (6) chapters whose chapters will be explained in the following explanation:

1. CHAPTER 1. INTRODUCTION

Chapter 1 is the beginning of an explanation of the entire research that explains the related background of research, assumptions and limitations of the study, and the objectives to be obtained in the study.

2. CHAPTER 2. LITERATURE REVIEW

This chapter explains the related theoretical basis and previous studies used as a reference in this study. This chapter contains explanations obtained from books, journals, articles, and others.

3. CHAPTER 3. RESEARCH METHODOLOGY

The Research Methodology Chapter is an explanation related to the order in which the research is conducted which can give an idea that the research is structured and systematic.

4. CHAPTER 4. MODELING

Chapter 4 describes how the methods in Chapter 3 were developed in this study. This chapter also explains the process of combining analytical methods to produce good information.

5. CHAPTER 5. DATA PROCESSING & RESULT DISCUSSION

This chapter consists of an explanation of the price characteristics that are experimented on samples, collection, processing, analysis, and interpretation of the data obtained.

6. CHAPTER 6. CONCLUSIONS AND SUGGESTIONS

The final chapter in this study contains the overall conclusions of the study which certainly answers the purpose of this study. While the suggestions included are used to provide avenues for other researchers to improve or develop this research.

CHAPTER 2 LITERATURE REVIEW

Indonesia cement manufacture suffers fierce competition. The several ways to survive the competition is cost management or revenue management. Cost management notable with Cost of Goods Manufacture (COGM) or Cost of Goods Sales (COGS). COGM will show how efficient the internal manufacturer. COGS will show how the manufacture handle its supply chain.

2.1 Cement main equipment production system

Cement Integrated Plant consists of 3 Main Equipment, Raw Mill, Kiln , and Finish Mill.

2.1.1 Raw mill

Raw Mill use to grind 10cm diameter granular mixed limestone and clay into fine product. There are 4 vertical Roller Mill type Rawmill in PT. XYZ. The advantage of vertical is energy efficient. there are 4 process has done in single equipment. The process is Grinding, Drying, Separating, Transporting. Electrical energy use to rotate grinding table, fine product separator, and induction fan. Electrical energy consumption (in KWh) devided by total product (in ton) will be Spesific power consumption (in KWh/Ton). Specific power consumption converted into energy price (in Rp/KWh) will be specific electric energy cost consumption(in RP/Ton). The raw mill operator can control the Raw mill Feed (in Ton) using Weight Feeder. Weight feeder is the equipment to dosing and control Raw Mill Production Rate.

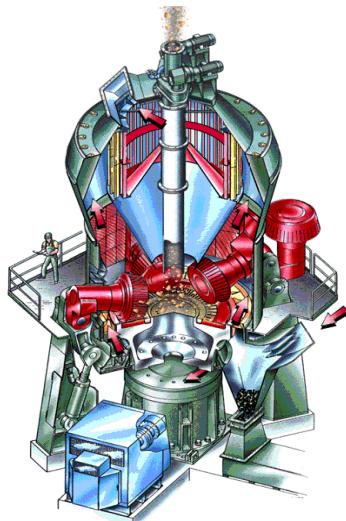


Figure 2.1 Vertical roller mill [cementequipment.org]

2.1.2 Kiln

Kiln is the equipment to chemically convert fine dust mixed limestone and clay into clinker. Clinker produced by sintering (fusing together without melting to the point of liquefaction) during the cement kiln stage. Material will be heat up to 1400°C using coal fuel. This coal fuel consumption will noted as cost of coal fuel (Ton Coal/ Ton Product) and later convert to Spesific Coal Energy cost

consumption (in Rp/Ton). Kiln also use electricity. Kiln Total Cost will be Spesific Coal Energy cost consumption and specific electric energy cost consumption(in RP/Ton). Kiln Operator Control Kiln Feed by input setpoint to Loss Of Weight Flow Control. This Loss of Weight Flow Control Actual value will be Kiln Production Rate.



Fig. 2.2 Kiln [cementequipment.org]

2.1.3 Finish mill

Finish Mill use to grind Clinker, Gypsum, any other substance into Fine Product. There are 9 Finish Mill in PT. XYZ. Finish mill consist of 6 older version tube mill with hydraulic crusher and 3 latest version Vertical Roller Mill. Finish Mill only use electrical energy to grind fine product. Finish mill energy cost will be specific electric energy cost consumption(in RP/Ton). The Finish mill operator can control the Finish mill Feed (in Ton) using Weight Feeder. Weight feeder is the equipment to dosing and control Finish Mill Production Rate.

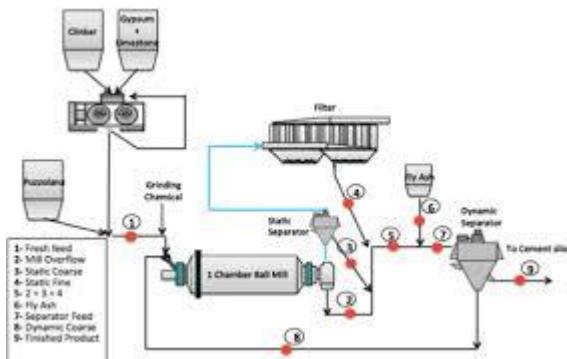


Fig. 2.3 Finish mill [cementequipment.org]

2.2 Mixed integer linear programming (MILP)

Linear programming (LP) is a tool for solving optimization problems. In 1947, George Dantzig developed an efficient method, the simplex algorithm, for solving linear programming problems (also called LP). Since the development of the simplex algorithm, LP has been used to solve optimization problems in industries as diverse as banking, education, forestry, petroleum, and trucking. In a survey of Fortune 500 firms, 85% of the respondents said they had used linear programming. [Winston, Wayne 2004]

LP is a general model that can be used to optimally solve limited resource allocation problem solving. The model used in solving company resource allocation problems is a mathematical model. All mathematical functions presented in the model must be in the form of linear functions.

There are several step to solve an optimization problem using the linear programming problem (LP):

1. Attempt to maximize (or minimize) a linear function of the decision variables. The function that is to be maximized or minimized is called the objective function.
2. The values of the decision variables must satisfy a set of constraints. Each constraint must be a linear equation or linear inequality.
3. A sign restriction is associated with each variable. For any variable x_i , the sign restriction specifies that x_i must be either nonnegative ($x_i \geq 0$) or unrestricted in sign (urs).

A linear programming problem in which some or all of the variables must be nonnegative integers is called an integer programming problem. There are several type of Integer Programming.

2.2.1 Pure integer programming [Winston, Wayne 2004]

An IP in which all variables are required to be integers is called a pure integer programming problem. For example,

$$\begin{aligned} \text{Objective max } z &= 3x_1 + 2x_2 \\ \text{s.t. } x_1 + x_2 &\leq 6 \\ x_1, x_2 &\geq 0, x_1, x_2 \text{ integer} \end{aligned}$$

This is an example of pure integer programming problem.

2.2.2 Mixed integer programming [Winston, Wayne 2004]

An IP in which only some of the variables are required to be integers is called a mixed integer programming problem. For example,

$$\begin{aligned} \text{max } z &= 3x_1 + 2x_2 \\ \text{s.t. } x_1 + x_2 &\leq 6 \\ x_1, x_2 &\geq 0, x_1 \text{ integer} \end{aligned}$$

is a mixed integer programming problem (x_2 is not required to be an integer).

2.2.3 0-1 Integer programming [Winston, Wayne 2004]

An integer programming problem in which all the variables must equal 0 or 1 is called a 0–1 IP. The following is an example of a 0–1 IP:

$$\begin{aligned}
\max z &= x_1 - x_2 \\
\text{s.t. } x_1 + 2x_2 &\leq 2 \\
2x_1 - x_2 &\leq 1 \\
x_1, x_2 &= 0 \text{ or } 1
\end{aligned}$$

2.2.4 Unit commitment on thermal power unit

Unit Commitment commonly applied in Thermal Generation Power Plant. Unit commitment is an application of Mixed Integer linear programming. Main problem in thermal power generation is the cost of starting up an electric power thermal unit is high. Therefore, the planning of the startups and shutdowns of any thermal unit should be done carefully. Unit commitment will prioritize to start most efficient powerplant, then next efficient plant, and so on until the demand is fulfilled. The electric power thermal unit commitment problem consists of determining, for a planning horizon, the startup and shutdown schedule of every unit so that the electric demand is served and total operating costs are minimized, while satisfying technical and security constraints.

Objective of Unit Commitment is minimize total cost,

the cost of unit commitment is :

1. start up cost
2. shutdown cost
3. Fixed Cost of running the powerplant
4. Variable cost of proportionally the powerplant

Constraint of unit Commitment is :

1. Minimum and maximum power output
2. Maximum rampup power output increment
3. Maximum decrement power output
4. Total power demand in planning horizon
5. Time constraint between unit from shut down to start up
6. Reserve demand

A typical planning horizon is one day divided in hours. If time intervals are denoted by k, the planning horizon consists of the periods

$$k = 1; 2; \dots; K \quad (2.1)$$

where K typically equal to 24

Startup cost

$$C_j y_{jk} \quad (2.2)$$

Where C_j is cost unit of unit j and y_{jk} is binary variable that is equal to 1 if unit j is started at the beginning of period k, and 0 otherwise

Shutdown cost

$$E_j z_{jk} \quad (2.3)$$

Where E_j is shutdown cost of unit j and z_{jk} is binary variable that is equal to 1 if unit j is shutdown at the beginning of period k, and 0 otherwise

Running Cost consist of fixed cost and variable cost, Fixed cost will symbolized

$$A_j v_{jk} \quad (2.4)$$

Where A_j is fixed cost of unit j and v_{jk} is binary variable that is equal to 1 if unit j is online at the beginning of period k, and 0 otherwise.

Variable cost will symbolized

$$B_j p_{jk} \quad (2.5)$$

Where B_j is variabel cost of unit j and p_{jk} is output power which produced from unit j during of period k

Thermal unit cannot operate below a minimum output and above maximum output

$$P_{min_j} v_{jk} \leq P_{jk} \leq P_{max_j} v_{jk} \quad (2.6)$$

From one time period to the next one, any power unit cannot increase its output power above a maximum power increment, called the rampup limit.

$$P_{jk+1} - P_{jk} \leq S_j \quad (2.7)$$

Where S_j is maximum rampup power increment

For the first Period constrain

$$P_{j1} - P_{j0} \leq S_j \quad (2.8)$$

Where P_{j0} is the power of unit j just before the first planning period

Similar about rampup, rampdown also denoted

$$P_{jk} - P_{jk-1} \leq T_j \quad (2.9)$$

Where T_j is maximum rampdown power decrement

For the first Period constrain

$$P_{j0} - P_{j1} \leq T_j \quad (2.10)$$

Where P_{j0} is the power of unit j just before the first planning period

Any unit that is online can be shut down but not started up, and analogously, any unit that is offline can be started up but not shut down. This can be expressed as

$$y_{jk} - z_{jk} = v_{jk} - v_{jk-1} \quad (2.11)$$

$$y_{j1} - z_{j1} = v_{j1} - v_{j0} \quad (2.12)$$

Every period of power demand (D_k) must be satisfied and for security reason use demand reserve (R_k)

$$\sum_{j=1}^J P_{jk} = D_k + R_k \quad (2.13)$$

And Objective function that should be minimize

$$\text{Min } Z = \sum_{k=1}^K \sum_{j=1}^J [A_j v_{jk} + B_j p_{jk} + C_j y_{jk} + E_j z_{jk}] \quad (2.14)$$

This economic dispatch theory in powerplant mainly inspire this thesis to minimize cost of multiple plant with its unique cost.

For this research, Mixed Integer Linear programming need to defining Decision Variable , Objective Function , and constraint. the decision variables should completely describe the decisions to be made. This Thesis, decision variable will be Production Rate of 4 Raw Mill, 4 Kiln, 9 Finish Mill. Objective function describe about objective to be achieved by controlling resource or Decision Variable. There are two common objective function, Maximize Profit or Minimize Cost. In this Thesis, objective function will be Minimize Cost. Constraint is mathematically impression of resources boundaries that could be optimally allocated to reach objective function. There are several constrain use in this Thesis. For example, silo maximum capacity, maximum production rate capacity, maximum belt transport capacity.

2.3 Demand forecasting

Forecasting is tool to predict future demand. Forecast is based on past demand data and scientifically analyzed to produce new . Accuracy of forecasting will affects PT. XYZ readiness to respond market demand, costs and future benefits (Fabianova, Kacmary, Molnar, & Michalik, 2016).

There are 2 kind of forecasting according to the period, short-term forecasting and long-term forecasting. Short-term forecasting will forecast within period next several days,weeks, or months. Long-term forecasting will forecast for 1-2 next years. Long term forecasting has quite low accuracy due to large possible interference from market condition, policy, etc. Short and medium term forecasting is usually based on the identification, modeling and extrapolation of patterns found in historical data. (Montgomery, Jennings, & Kulahci, 2015).

The methods used in time series forecasting consist of several methods.

- a. The simple moving average method (Moving Average). According to Firdaus (2006), this method is suitable for stationary data patterns. The advantage of this method is the amount of data entered into the flexible average value so that it can be varied according to the data pattern.
- b. Single exponential smoothing method. The Single Exponential Smoothing method is a method that shows weighting decreases exponentially with older observation values. That is the newer value given a relatively greater weight than the longer observation value. This method provides an exponential weighting moving average of all observed values previous. This method is not influenced by trends or seasons.(Hartono,2012)
- c. Trend-corrected exponential smoothing (Holt's Model). The trend-corrected exponential smoothing method is used when demand component has a level and a trend but with no seasonality. This method also give a trend value to forecasted demand (Chopra, 2016)
- d. Trend-and-Seasonality-corrected Exponential smoothing (Winters's model). This method is used when the demand component has a level, a trend, and seasonal factor. (Chopra, 2016)

2.4 Research review

In this review section of previous research has been conducted and is related to this research, both in terms of the problems and the methodology used. Table 2.1 show the journal review for research

Table 2.1 Journal review for research

No	Author (year)	Title	Method	Contribution
1.	Parlar, Mahmut et al. (2019)	Optimal control and cooperative game theory based analysis of a byproduct synergy system	Optimal Control & Game theory	Understanding Optimal Control for multiple plant
2	Silaparasetti et al. (2017)	An Intelligent Approach to Demand Forecasting	forecasting	Several method to demand forecasting depending on the historical data type
3.	Noche, Bernd and Elhasia, Tarek (2013)	Approach to innovative supply chain strategies in cement industry; Analysis and Model simulation	Supply Chain Modelling and Strategy	Identification multiple production scenario to fulfill demand
4	R. Babazadeh et al. (2019)	A linear programming model for production planning: an iranian case study in cement	Linear programming	Applying linear programming in cement plant.
5	B. Looss and A. Saltelli (2015)	Introduction to Sensitivity Analysis	Sensitivity Analysis	Understanding the sensitivity analysis

Table 2.1 is reviewed and contribution of the previous research. Previous research contribute this research to investigate the minimize cost at various plant

CHAPTER 3 RESEARCH METHOD

3.1 Collecting parameter model data

First Process will be data collecting for parameter model. Data collecting is used to gather values to be processed and tested in the model. Parameter model required is : Data Cement Demand, Production cost report, Main Equipment capacity constrain, Inventory Capacity constraint, Cost for each main equipment, and Plant flow process.

3.2 Conceptual and mathematical modelling

The research model consist of conceptual models and mathematical models. conceptual model is used to provide an illustration of the condition of the system in the production line of PT. XYZ Mathematical models emphasize quantification of system conditions symbolized in the form of notation . mathematical model will be the basis for finding the optimum solution. a mathematical model consisting of the objective cost minimization function, the decision variable in the form of the main equipment's production rate and its constraints.

The Objective function that will be discussed in this research is minimize the production cost. Decision Variabel in this model will be production rate and binary-integer start stop main equipment decision. Constraint function consist of : all plant has to fulfill demand for both type cement, production rate decision has to be lower than maximum installed capacity, Production rate has to higher than lower limit.

3.3 Verification and validation

Next process after parameter model collecting are verification and validation. verification is process to determine the model is reflected the right conceptual model. verification will check the whole equation or mathematic model is right and useable. validation is the process to determine the model is right and reflected the real system. Validation method is comparing MILP total production cost with realization total production cost using demand 2019 and analyzed the percentage error. Expected result is percentage error of the result below 5%. if the system has been validated and verificated then next process is numerical experiment.

3.4 Demand forecasting

Collected historical demand data 2017-2019 will be forecasted using several time-period and method. In this research, time –period which use is :

1. Daily Production Data
2. Monthly Production Data
3. 2-Monthly Production Data

and also the forecasting method which use is :

1. Moving Average 2 period
2. Moving average 4 period
3. Single exponential smoothing
4. Trend-corrected exponential smoothing (Holt's method)
5. Trend- Seasonality Corrected exponential smoothing (Winter's method).

After the demand forecasted, the next step is check the error using MAD, MSE, and MAPE. Choose the best time period and method for forecast cement demand which generate the smallest MAPE error. Next step is used the same chosen time-period and method to get forecasted 2020 demand. Then forecasted 2020 demand inserted to MILP model in numerical method to get operational suggestion.

3.5 Numerical experiment

Numerical experiment use to find production rate and start-stop plant operational which lowest total production cost. The solution of numerical experiment will be done with method mixed integer linear programming. The experiment will be assisted with software LINGO. Mixed integer linear programming will calculate to minimize production cost by regulate the production rate. Demand forecasting will determine forecasted demand for next 1 year. Forecasted demand will become target that all main equipment production has to be achieved. This research develop 3 scenarios.

1. Use model actual demand 2019 and realization production. Calculate the MILP model to get realization total production cost. Then, Use model actual demand 2019 and realization production.
2. Use MILP LINGO, run the demand 2019 to get cost- minimization total cost production. Then compare the realization and cost-minimization to get cost-saving production cost by applying the MILP.
3. Use forecasted demand 2020. Run MILP using LINGO to get cost-minimization total production cost, then analyzed the production, make production suggestion for production manager indicates how much saving applying MILP, what for next year planning including suggested production rate, main equipment's order of shutdown time for overhaul, and estimated production cost. Also compare total production cost between production policy “equally-spread within PT.XYZ plants” and cost-minimized total production cost.

Table 3.1 show modified MPS matrices that use to collect report from numerical experiment.

Table 3.1 Modified MPS matrices for numerical experiment report

Month	Cement Type	Finish Mill								
		FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7	FM 8	FM 9
January	OPC PCC									
February	OPC PCC									
March	OPC PCC									
April	OPC PCC									
May	OPC PCC									
June	OPC PCC									
July	OPC PCC									
August	OPC PCC									
September	OPC PCC									
October	OPC PCC									
November	OPC PCC									
December	OPC PCC									

3.6 Sensitivity analysis

This thesis will also do sensitivity analysis. A sensitivity analysis determines how different values of an independent variable affect a particular dependent variable under a given set of assumptions. Sensitivity analysis use to understanding the dependency of cost variable to production decision. Cost variable consist of Electricity energy consumption cost and Coal price. Cost variable will be increased and by step of 10 %, 20%, 30%, 50% and analyze each step about changes in production cost and production decision. All result will be recorded and be sensitivity analyzed. Sensitivity analysis result indicates which more critical for company to secured its energy supply chain

3.7 Conclusion and suggestion

This step will conclude all result of this research and give suggestion to next future possible research.

All research methodology illustrated in Fig. 3.1 research methodology below

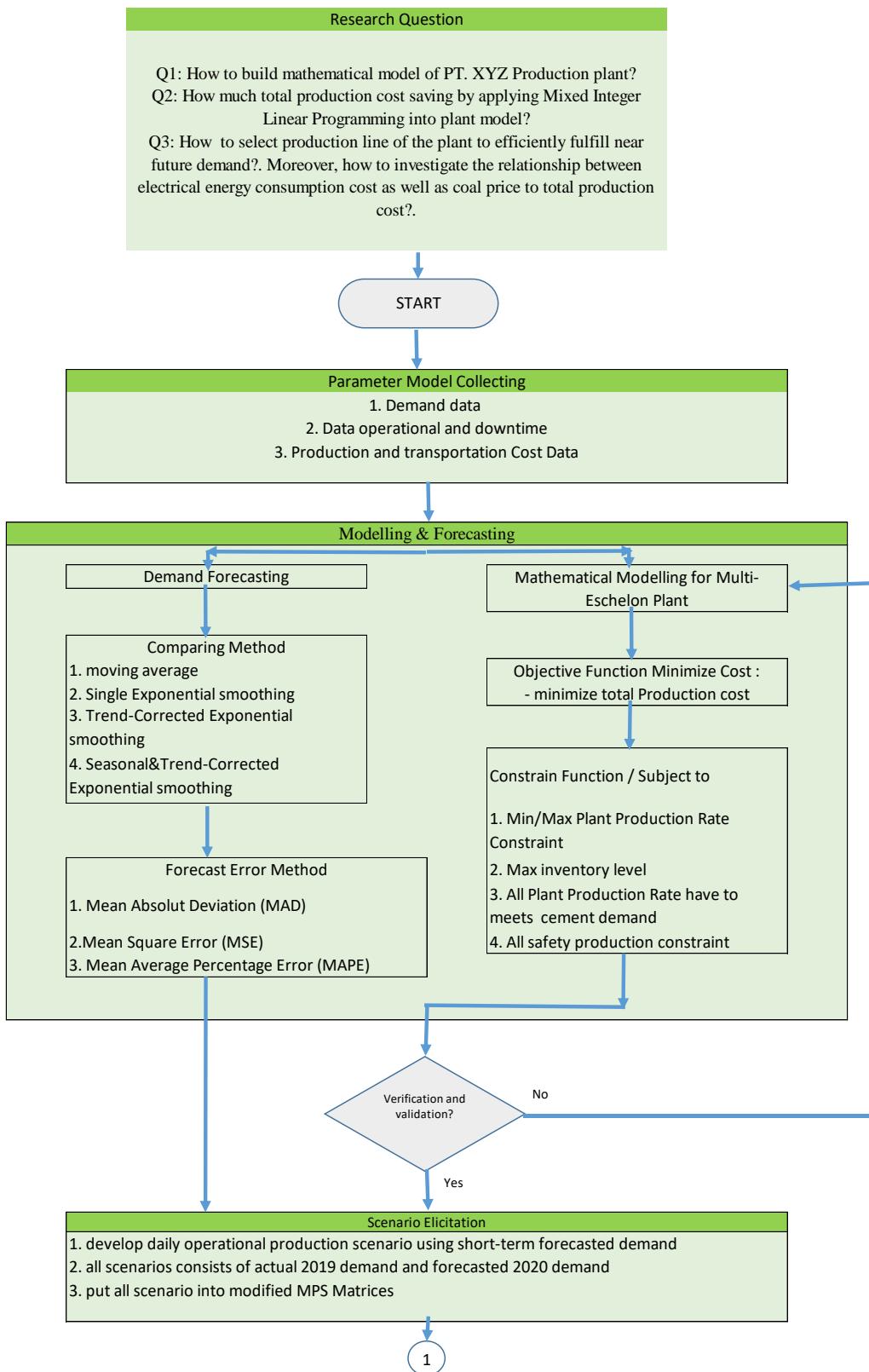


Fig. 3.1 Research methodology

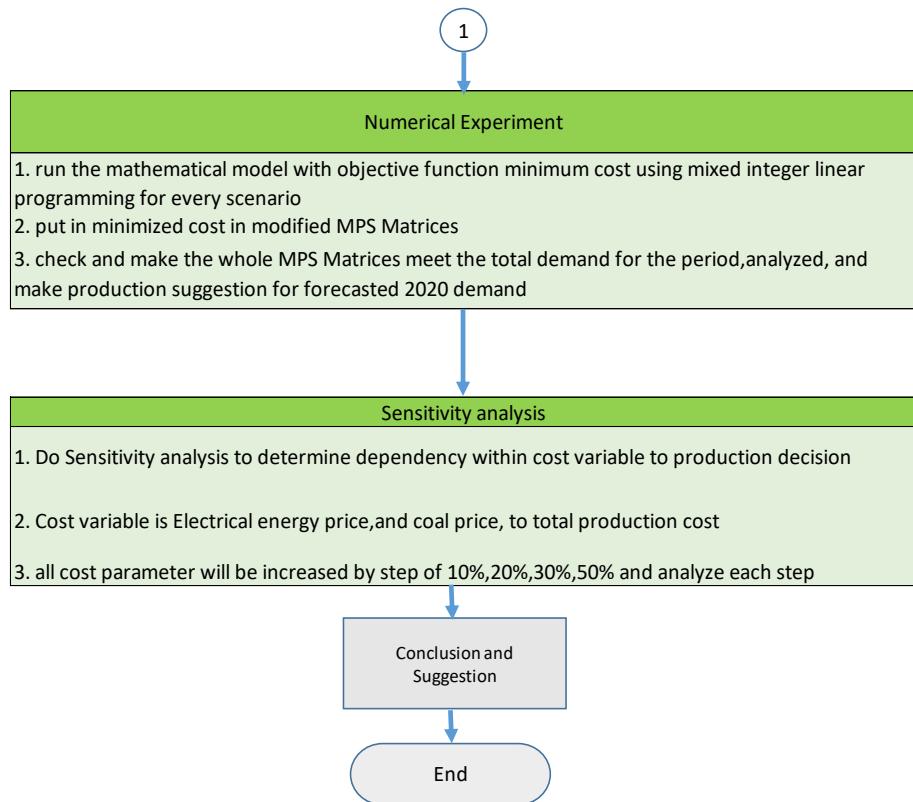


Fig. 3.1 Research methodology (continued)

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CHAPTER 4 PLANT SYSTEM MODELLING

This Chapter will discuss about Modelling in plant PT. XYZ. Fig 1.3 will inform the plant model. According to the Plant model, we can determine conceptual model and mathematical model.

4.1 Plant model

Plant model show how the plant process and determine several decision variable and cost from each equipment

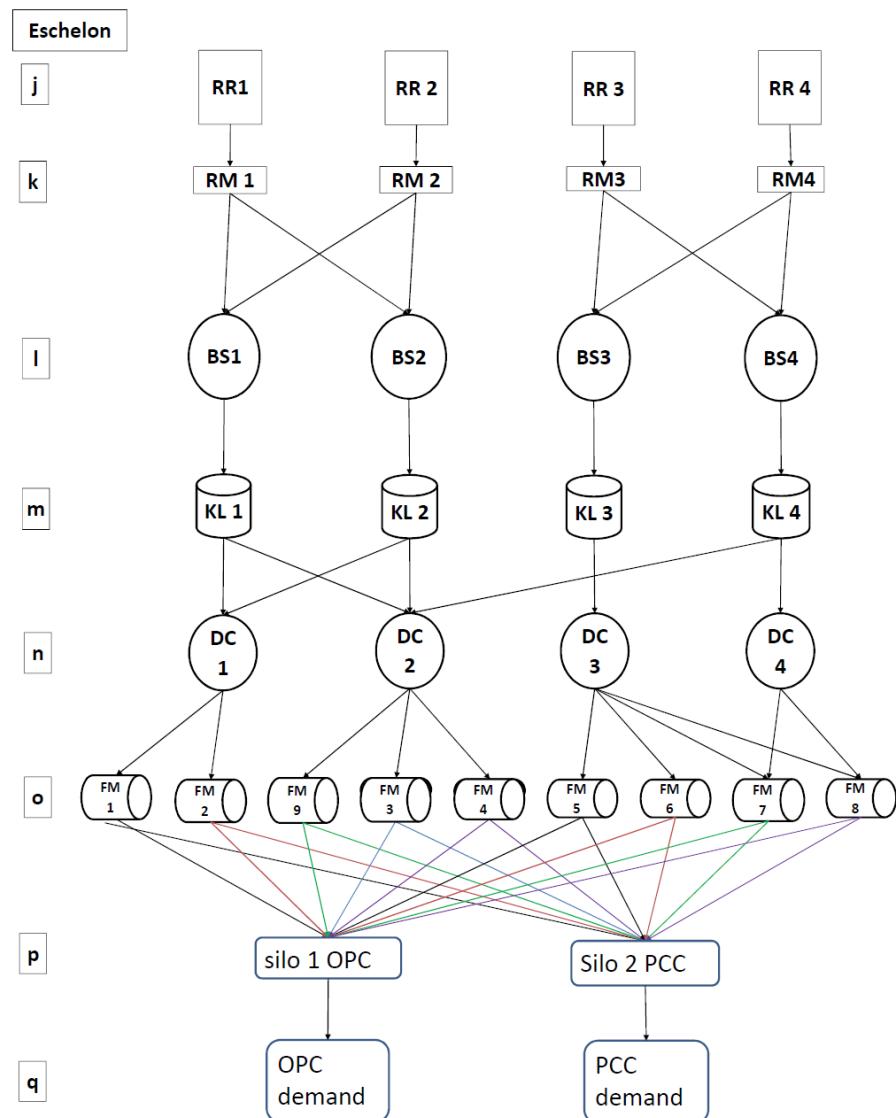


Fig 4.1 Main equipment structure in PT. XYZ plant

4.2 Mathematical model

This section is to answer “the research question 1 : How to build mathematical model PT. XYZ Production plant?”.

Mathematical model will be basic of calculation before developing linear programming tool. Mathematical model will consist of:

1. Indices, parameter, and decision variable
2. Objective Function
3. Constrain

4.2.1 Indices, parameter, and decision variable

Indices and sets

k index of rawmill which grind rawmix to fine product, , $k= 1,2..K$

l index of Blending silo which stored rawmix fine product, , $l= 1,2..L$

m index of Kiln which process rawmix fine product into clinker, $m=1,2..M$

n index of Dome clinker which stored clinker , $n=1,2..N$

o index of Finish Mill whi grind clinker and mix it with addictive to produce cement, $o=1,2..O$

p index of Cement silo which stored cement, $p=1,2..P$

q index of Type of cement production, 1=OPC, 2=PPC

t index of Time period in days a month, $t=1..T$, where T typically number days in specific month

Parameter

A_k where A_k is fixed cost of unit rawmill k

A_m where A_m is fixed cost of unit Kiln m

A_o where A_o is fixed cost of unit Finish mill o

BRM_{kl} where BRM_{kl} is variable cost of unit rawmill k fill blending silo l

BKL_{mn} where BKL_{mn} is variable cost of unit kiln m fill clinker dome n

BFM_{op} where BFM_{op} is variable cost of unit finish mill o fill silo p

C_m where C_m is start-up cost of unit m (kiln)

E_k where E_k is shut down cost of unit rawmill k . Minimum power for shutdown (ex. Lighting, oil pump circulation etc)

E_m where E_m is shut down cost of unit kiln m . Minimum power for shutdown (ex. Lighting, oil pump circulation etc)

E_o where E_o is shut down cost of unit finishmill o . Minimum power for shutdown (ex. Lighting, oil pump circulation etc)

D_{1t} Demand for type cement OPC in ton

D_{2t} Demand for type cement PCC in ton

$X_{1t}...X_{16t}$ Total tonage product fill in cement silo 1... Cement Silo 16

$IBSL_t$ Inventory Blending Silo L at period t

ICD_{nt} Inventory clinker dome n at period t

ICS_{pt} Inventory cement silo p at period t

YCS_{pqt} Connectivity matrix binary between cement silo p to demand q during period t

YFM_{opt} Connectivity matrix binary between cement finish mill o to cement mill during period t

$YYFM_{opt}$ Connectivity matrix maximum production rate finish mill o to cement mill p during period t.

4.2.2 Objective function

Objective function is minimized total cost which are divided into several sub-categories. Raw Mill production Cost, Kiln Production cost and finish mill production cost. Following the expressed production cost formula.

Raw mill production cost

$$\sum_{t=1}^T \sum_{k=1}^4 \sum_{l=1}^7 [A_k FRM_{kt} + BRM_{kl} RRM_{klt} + E_k (1 - FRM_{kt})] \quad (4.1)$$

Kiln Production Cost

$$\sum_{t=1}^T \sum_{m=1}^4 \sum_{n=1}^4 [A_m FKL_{mt} + BKL_{mn} RKL_{mnt} + C_m G_{mt} + E_m (1 - FL_{mt})] \quad (4.2)$$

Finish mill production cost

$$\sum_{t=1}^T \sum_{o=1}^4 \sum_{q=0}^1 [A_o FFM_{ot} + BFM_{op} RFM_{opt} + E_o (1 - FFM_{ot})] \quad (4.3)$$

Following represents the total costs of the system which is the summation of total production cost of every production equipment ,

$$\begin{aligned} Min Z = & \sum_{t=1}^T \sum_{k=1}^4 \sum_{l=1}^7 [A_k FRM_{kt} + BRM_{kl} RRM_{klt} + E_k (1 - FRM_{kt})] + \\ & \sum_{t=1}^T \sum_{m=1}^4 \sum_{n=1}^4 [A_m FKL_{mt} + BKL_{mn} RKL_{mnt} + C_m G_{mt} + E_m (1 - \\ & FL_{mt})] + \sum_{t=1}^T \sum_{o=1}^4 \sum_{q=0}^1 [A_o FFM_{ot} + BFM_{op} RFM_{opt} + E_o (1 - FFM_{ot})] \end{aligned} \quad (4.4)$$

4.2.3 Constraints

Demand fulfilment constrain

$$\sum_{p=1}^{16} YCS_{pq} * RCS_{pqt} * 24 \geq D_{qt}, \forall q = 1,2, t = 1..7 \quad (4.5)$$

Constraint that maximum release of a cement silo must be lower than cement silo

$$\sum_{q=1}^2 YCS_{pq} * RCS_{pqt} * 24 \leq ICS_{pt}, \forall p \quad (4.6)$$

Inventory for next period t+1

$$\sum_{o=1}^9 YFM_{op} * RFM_{opt} * 24 - \sum_{q=1}^2 YCS_{pqt} * RCS_{pqt} * 24 + ICS_{pt} = ICS_{p(t+1)}, \forall p \quad (4.7)$$

$$\sum_{m=1}^4 YKL_{mn} * RKL_{mnt} * 24 - \sum_{o=1}^9 YCD_{not} * RCD_{not} * 24 + ICD_{nt} = ICD_{n(t+1)}, \forall n \quad (4.8)$$

$$\sum_{k=1}^4 YRM_{kl} * RRM_{klt} * 24 - \sum_{m=1}^4 YBS_{lm} * RBS_{lmt} * 24 + IBS_{lt} = IBS_{l(t+1)}, \forall p \quad (4.9)$$

Constraint max production rate and inventory

Every Cement silo, Clinker dome, and Blending silo has its unique max capacity, also Constraint max capacity every Finish mill, kiln and raw mill production rate has its own unique maximum capacity rate.

Constraint max capacity every Finish mill production rate (RFMopt) differences for grinding different type of cement, and Decision variable for finish mill running

$$\sum_{p=1}^2 YFM_{op} * RFM_{opt} \leq FFM_{opt}. YYFM_{OP}, \quad (4.10)$$

$$RFM_{opt} \leq YYFM_{OP} \quad (4.11)$$

Constrain maximum Production rate kiln

$$\sum_{n=1}^4 YKL_{mn} * RKL_{mnt} \leq FKL_{mt}. 360, \quad (4.12)$$

Constrain maximum Production rate rawmill and Rawmill on/off binary decision variable

$$\sum_{l=1}^4 YRM_{kl} * RRM_{klt} \leq FRM_{kt}. 750, \quad (4.13)$$

Constraint Production Balance

Finish mill 1 -9

$$\sum_{n=1}^5 YCD_{no} * RCD_{not} \leq \sum_{p=1}^{16} RFM_{opt}. YYYFM_{OP}, \quad (4.14)$$

Kiln 1-4

$$\sum_{l=1}^7 YBS_{lm} * RBS_{lmt} \geq \sum_{n=1}^5 RKL_{mnt} * YYKL_{mn}, \quad (4.15)$$

Constraint of heating up kiln will take 2 days before production

$$\sum_{t=1}^{t+1} FKL_{mt} \leq 2(1 - G_{mt}), \quad (4.16)$$

$$FKL_{m(t+1)} - FKL_{mt} \leq M(G_{m(t-1)}) \quad (4.17)$$

4.3 Data collecting

Data use in this research is Secondary data from section production planning of PT. XYZ and primary data from plant central HMI and Electrical room for each plant to determined each plant cost. Data needed is as follow :

1. Demand Data 2017-2019, for demand forecast 2020 and model validation
2. Total energy cost 2019 as model validation
3. Stock inventory in blending silo, clinker dome, cement silo 31december 2018 dan 31 december 2019 as inventory initial value
4. Primary data energy consumption, including electrical, coal, and industrial diesel oil, during and after overhaul Rawmill and Kiln 2019, and during and after service finish mill march-april 2020.

4.3.1Demand data 2017-2019

Demand data 2017-2019 extracted from monthly report RELEASE PACKER from 2017 to 2019. The cement demand data is daily release data for example January 2017 as follow :

Table 4.1 Example of January 2017 daily demand data.

	day	TUBAN 1		TUBAN 2		TUBAN 3		TUBAN 4		
		OPC Curah	PPC Zak	OPC Curah	PPC Zak	OPC Curah	PPC Zak	PPC Zak	PPC Curah	
Jan-17	1	1609.66	1985	0	1840.6	0	2010.72	760	874	0
	2	1724.38	3065.24	1161.54	5480.16	4605.474	1806.76	4166.52	3327	27.98
	3	1481.48	5906.38	2759.86	8268.6	0	3097.66	5373.9	2798.3	0
	4	1970.02	7252.22	3653.64	9760.62	3506.808	2460.14	6284.72	5303	147.42
	5	2104.72	7449	3052.32	9205.5	0	2931.04	6413.3	5116	250.18
	6	2253.2	8351.88	1212.9	8454.7	5898.693	3019.36	5597.32	4639	58.64
	7	1931.18	8378.44	1790.84	9768.26	0	3843.1	5503.66	5321.04	57.4
	8	2107.42	5546.12	2692	6274.2	0	12823.96	5959.6	4302.2	0
	9	2271.24	3184.44	1147.98	7248.92	5821.54	2842.98	5082.8	4321.3	0
	10	2240.56	8144.44	1613.84	8589.9	2292.842	12080.68	5287.26	4694.1	0
	11	2720.94	8615.08	0	9726.24	0	3383.42	5591.32	4893.6	649.08
	12	1861.5	7268.72	2221.86	6741.6	3517.027	2229.28	5822.02	4589.22	328.26
	13	2035.24	6789.32	3998.06	5127.9	0	3267.72	5106.72	4369.2	338.36
	14	2096.28	6850.36	4029.48	5327.4	0	2667.52	5597.3	4405.7	29.36
	15	1232.66	6392.32	2522.5	5609.8	5837.656	1358.32	6027.3	4161	34.82
	16	1679.6	6546.16	2135.68	7376.08	2318.071	2248.18	5529.88	4020	35.62
	17	2103.2	8576	3170.56	9209.8	0	1906.26	6343.5	4924	55.52
	18	2084.12	9188.6	2240.28	8261.74	0	13338.44	6408.08	5294.72	64.06
	19	2056.48	8650	437.24	9122.42	0	3890.88	6064.92	4593.2	32
	20	1696.42	6865.24	0	8046.72	3519.915	14853.89	5171.46	3586.66	432.48
	21	1632.12	8926.4	0	9962.26	0	4816.18	5837.04	4155.3	382.8
	22	1498.24	5561.08	0	8113.82	0	3425.5	5444.16	3871.72	319.66
	23	1762.34	3968.44	0	6664.8	0	3335.66	5985.8	2821	35.1
	24	2193.26	8071.16	3372.76	7428.08	2273.409	14830.29	5969.32	3568	159.18
	25	2005.52	8373.6	3223.3	8505.8	0	4330.34	5903.06	3857	132.6
	26	2095.1	9699.08	596.8	10324.5	0	3956.86	5264	4278.5	102.94
	27	2343.02	6647.16	0	9094.92	5918.032	4977.16	4810.3	3630.6	468.7
	28	1946.62	5696	0	8868.6	0	14023.64	5266.62	3256.22	744.68
	29	1754.76	2963.24	2371.52	3440.08	0	2976.96	3015.88	1800.36	0
	30	1832.3	4951.56	2611.9	5014.96	3508.556	2778.8	4521.08	2655.02	0
	31	2379.16	7364.72	2870.68	8475.1	0	2662.12	5665.22	4730.96	0

Table 4.1 indicate the daily demand fo each plant. Which later ,in numerical experiment, this daily data sumed together to create monthly data as table 4.2.

Table 4.2 Monthly demand 2017-2019

	Cement Demand	
	OPC	PCC
Jan-17	273,764	786,398
Feb-17	284,928	674,128
Mar-17	315,659	717,699
Apr-17	302,597	756,190
May-17	403,000	732,056
Jun-17	255,240	514,576
Jul-17	373,822	703,346
Aug-17	445,513	771,925
Sep-17	387,389	686,757
Oct-17	492,138	763,385
Nov-17	474,560	713,759
Dec-17	403,555	620,020
Jan-18	363,058	645,550
Feb-18	309,972	524,631
Mar-18	396,555	505,715
Apr-18	377,662	489,739
May-18	451,457	676,781
Jun-18	192,979	394,359
Jul-18	449,894	780,302
Aug-18	484,357	737,449
Sep-18	499,639	742,150
Oct-18	525,048	824,617
Nov-18	472,449	775,140
Dec-18	424,662	698,742
Jan-19	346,443	632,226
Feb-19	296,883	555,620
Mar-19	357,526	546,883
Apr-19	237,505	481,343
May-19	297,721	587,416
Jun-19	156,350	459,157
Jul-19	319,155	707,209
Aug-19	286,555	648,517
Sep-19	329,980	799,286
Oct-19	336,597	894,819
Nov-19	319,423	828,728
Dec-19	243,044	675,517

Table 4.2 indicate the monthly demand fo each plant. This research also tested 2-monthly demand data by sumed together every 2 concecutive month for example Jan-feb 2017, Mar-Apr 2017, etc. table 4.3 shown example of 2-monthly demand data.

Table 4.3 2-Monthly demand 2017-2019

data	Period	Total Demand Tuban	
		OPC	PCC
1	Jan-17	558693	1460526
	Feb-17		
2	Mar-17	618256	1473890
	Apr-17		
3	Mei 17	658240	1246632
	Jun-17		
4	Jul-17	819335	1475272
	Aug-17		
5	Sep-17	879526	1450141
	Oct-17		
6	Nov-17	878115	1333779
	Des 17		
7	Jan-18	673030	1170182
	Feb-18		
8	Mar-18	774217	995454
	Apr-18		
9	Mei 18	644436	1071140
	Jun-18		
10	Jul-18	934252	1517751
	Aug-18		
11	Sep-18	1024687	1566767
	Oct-18		
12	Nov-18	897110	1473881
	Des 18		
13	Jan-19	643326	1187846
	Feb-19		
14	Mar-19	595031	1028226
	Apr-19		
15	Mei 19	454070	1046574
	Jun-19		
16	Jul-19	605710	1355726
	Aug-19		
17	Sep-19	666577	1694105
	Oct-19		
18	Nov-19	562467	1504245
	Des 19		

This daily, monthly, and 2-monthly demand data is used to find the best forecast method and time-period to forecast the cement demand. after that, using same method and time period can forecast the 2020's demand. The result of forecast 2020 demand become demand constraint in linear programming model.

4.3.2 Total energy cost 2019 & material Cost 2019

Total energy cost 2019 data is extracted from monthly production report DECEMBER 2019. The data used to validate the model by comparing the model cost with 2019 demand result with total energy cost 2019. The total energy cost 2019 shown as table 4.4

Table 4.4 Realization total energy& material cost 2019

COST of PT XYZ BUSINESS UNIT PLANT OPERATIONAL REPORT - DECEMBER 2019					
DESCRIPTION	KPI 2019 (1)	REAL 2019 (2)	REAL 2018 (3)	in millions IDR	
				% (2:1)	% (2:3)
Cost of Goods Manufacture					
Energy Consumption cost	1,582,389	1,472,824	1,629,535	93%	90%
Raw & aux. Material cost	972,013	748,274	772,772	77%	97%

4.3.3 Initial stock inventory

Initial stock inventory 2019 data is extracted from monthly production report December 2018. Also, initial stock inventory 2020 is extracted from monthly production report December 2019. The data is used for initial inventory for running the Linear programming model. Initial stock inventory 2019 and 2020 shown as table 4.5 and table 4.6

Table 4.5 Initial stock inventory 2019

RESUME PRODUCTION REPORT DECEMBER 2018					
		PLANT 1	PLANT 2	PLANT 3	PLANT 4
A. CEMENT INVENTORY STOCK	PCC	45,215	51,201	26,322	41,971
B. CLINKER INVENTORY STOCK	OPC	18,373	10,889	33,336	0
C. KILN FEED INVENTORY STOCK	CLINKER	91,371	63,267	44,461	70,193
	FINE DUST	33,620	31,440	36,859	32,062

Another secondary data was taken from production report December 2019 is initial stock inventory 2020. Table 4.6 use for numerical experiment using demand 2020.

Table 4.6 Initial stock inventory 2020

RESUME PRODUCTION REPORT DECEMBER 2019					
		PLANT 1	PLANT 2	PLANT 3	PLANT 4
A. CEMENT INVENTORY STOCK	PCC	43,593	47,892	15,641	49,872
B. CLINKER INVENTORY STOCK	OPC	14,552	15,891	6,040	0
C. KILN FEED INVENTORY STOCK	CLINKER	60,884	63,063	19,930	63,008
	FINE DUST	35,403	32,267	34,169	32,518

4.3.4 Primary data energy cost

Data energy cost data is extracted directly from HMI (Human Machine Interface) data logger and direct measurement to equipment. Data energy cost was taken when the equipment during and after annual overhaul or monthly service. Generally, there are 3 type data was taken including idle up cost, fixed cost and variable cost. And also, heating up cost for thermal unit characteristic for kiln.

Idle up cost is minimum requirement to make sure the system are ready to start again without any damage. The unit is RP/ Hour. Idle up cost may include but not limited to lubrication system, equipment cooling system, lighting, and heater etc. the idle up cost data taken from electric energy which is used during the overhaul or service.

Fixed Cost is minimum cost when the production system start with still minimum product. The unit is RP/ Hour. Especially For kiln, fixed cost data was taken right after the IDO (industrial diesel oil) stopped and kiln switch to use the coal to continue heat up.

Variable cost is cost depending on how much production rate of the equipment. The unit is RP/ Ton product. Variable cost data was taken when the equipment reach its steady state production rate then the energy use measured. After that, substracted by fixed cost and devided with current production rate.

Heating up cost is cost needed by kiln as thermal unit to heat up from idle up temperature to specific temperature that coal could self ignite. The heating up cost is consist of electric energy, coal energy and IDO energy. Unlike other cost, heating up cost is single charged cost for everytime heating up the kiln.

Table 4.7, Table 4.8, Table 4.9 shown example how to extracted idle up cost, fixed cost, variable cost, and heating up cost.

Table 4.7 Example for raw mill 1 cost data

RAW MILL 1					
DATE	HOUR	FEEDRATE (t/h)	ENERGY METER (MWh)	POWER CONSUMPTION (MWh)	DESCRIPTION
	0	634	3412332.2		
	1	620	3412341.2	9.0	
	2	634	3412351.1	10.0	
	3	635	3412360.2	9.1	
	4	633	3412371.1	10.9	
	5	628	3412380.3	9.2	
	6	634	3412389.3	9.0	
	7	620	3412399.6	10.3	
	8	620	3412410.0	10.4	
	9	631	3412419.2	9.2	
	10	627	3412428.4	9.2	
	11	0.0	3412428.6	0.2	
	12	0.0	3412428.8	0.2	
	13	0.0	3412429.1	0.3	IDLE COST
	14	0.0	3412429.5	0.3	
	15	0.0	3412429.9	0.4	
	16	0.0	3412430.4	0.5	
	17	66	3412434.9	4.5	FIXED COST
	18	65	3412443.1	8.2	
	19	620	3412452.8	9.7	
	20	634	3412462.1	9.3	RUNNING COST
	21	635	3412472.3	10.2	
	22	633	3412481.9	9.6	
	23	628	3412491.3	9.4	
DESCRIPTION		Avg Tonase	Avg Kwh	COST	VARIABLE COST
IDLE COST				Rp 325,666.67	
FIXED COST		65.3	6.4	Rp 6,214,452.75	Rp 5,631.27
RUNNING		632.5	9.6	Rp 5,631.27	

Table 4.8 Example for kiln 1 cost data

KILN 1							
MONTH	DATE	Feedrate (t/h)	MWh	COAL (t/h)	IDO (kg/j)	Status	DESCRIPTION
Feb-19	1	0	0.2	0	0	OVH	IDLE COST
	2	0	0.2	0	0	OVH	
	3	0	0.2	0	0	OVH	
	4	0	0.2	0	0	OVH	
	5	0	0.2	0	0	OVH	
	6	0	0.2	0	0	OVH	
	7	0	0.2	0	0	OVH	
	8	0	0.2	0	0	OVH	
	9	0	0.2	0	0	OVH	
	10	0	0.2	0	0	OVH	
	11	0	0.2	0	0	OVH	
	12	0	0.2	0	0	OVH	
	13	0	0.2	0	0	OVH	
	14	0	0.2	0	0	OVH	
	15	0	0.2	0	0	OVH	Trans. IDLE COST TO HEATING UP COST
	16	0	3.6	0	5026	Heating Up	HEATING UP COST
	17	0	13.1	0	35040	Heating Up	
	18	0	19.7	128	65664	Heating Up	
	19	0	4.5	118.4	11088	Heating Up	
	20	160	3	49.01	0	RUNNING	FIXED COST
	21					RUNNING	
	22					RUNNING	
	23	570	5.4	58	0	RUNNING	STEADY STATE
	TOTAL COST		KET				
IDLE COST		Rp 195,400	Rp/HOUR				
HEATING UP COST		Rp 1,218,162,227					
FIXED COST		Rp 36,257,800	Rp/HOUR				
VARIABLE COST		Rp 20,629					

Table 4.9 Example for finish mill 1 cost data

(FINISH MILL 1)				
HOUR	FEEDRATE (t/h)	ENERGY METER (MWh)	POWER CONSUMPTION (MWh)	DESC.
0	189.4	172265.4		IDLE COST
1	182.2	172272.8	7.4	
2	188.4	172279.1	6.3	
3	189.1	172286.0	6.8	
4	167.3	172289.8	3.8	
5	72.0	172291.0	1.2	
6	0.0	172291.9	0.8	
7	0.0	172292.6	0.8	
8	0.0	172293.2	0.6	
9	0.0	172294.1	0.9	
10	0.0	172294.8	0.7	
11	0.0	172295.5	0.7	
12	0.0	172296.0	0.5	
13	0.0	172296.7	0.7	
14	4.5	172297.4	0.7	FIXED COST
15	4.1	172302.2	4.9	
16	159.9	172309.8	7.6	
17	162.3	172317.5	7.7	
18	186.3	172325.1	7.7	RUNNING
19	179.4	172332.5	7.4	
20	188.4	172341.1	8.6	
21	198.1	172348.6	7.6	
22	192.7	172355.2	6.6	
23	178.4	172362.8	7.6	
DESCRIPTION		AVG TONASE	AVG KWH COST	VARIABLE COST
IDLE COST			Rp 687,029.45	
FIXED COST		4.3	2.8 Rp 2,723,387.50	Rp 26,038.07
RUNNING		183.6	7.6 Rp 26,038.07	

Material cost data 2019 is all material which use to producing cement and its percentage in weight in the output product each equipment. The cost will added directly to variable cost at specific area equipment. Material cost data shown as table 4.10.

Table 4.10 Material cost data 2019 PT. XYZ

Material Cost Data				
	Price/ton	%/Ton Product	Area Affected	Rp/ ton product
Batu kapur Blasting	Rp20,831	80%	Variable cost Rawmill	Rp16,665
Tanah liat	Rp24,617	20%	Variable cost Rawmill	Rp4,923
pasir silika	Rp46,692	1.50%	Variable cost Kiln	Rp700
cooperslag	Rp194,026	1.50%	Variable cost Kiln	Rp2,910
Gypsum	Rp266,560	5%	Variable cost Finish mill	Rp13,328
Trass	Rp76,759	17%	Variable cost Finish mill	Rp13,049
Flyash	Rp131,222	4%	Variable cost Finish mill	Rp5,249

After all data extracted, the cost data sum with material cost to get plant cost data shown on table 4.11 , table 4.12, and table 4.13

Table 4.11 Cost data of rawmill PT. XYZ

Rawmill 1		satuan	Monthly Converted
IDLE COST	325,666	Rp/Jam	234,479,520
FIXED COST	6,214,452	Rp/Jam	4,474,405,440
VARIABLE COST	27,219	Rp/Ton	
<hr/>			
Rawmill 2		satuan	Monthly Converted
IDLE COST	359,971	Rp/Jam	259,179,120
FIXED COST	2,295,950	Rp/Jam	1,653,084,000
VARIABLE COST	35,950	Rp/Ton	
<hr/>			
Rawmill 3		satuan	Monthly Converted
IDLE COST	662,082	Rp/Jam	476,699,040
FIXED COST	2,295,950	Rp/Jam	1,653,084,000
VARIABLE COST	34,788	Rp/Ton	
<hr/>			
Rawmill 4		satuan	Monthly Converted
IDLE COST	447,395	Rp/Jam	322,124,400
FIXED COST	2,491,350	Rp/Jam	1,793,772,000
VARIABLE COST	35,274	Rp/Ton	

Table 4.12 Cost data of kiln PT. XYZ

Kiln 1		satuan	Monthly Converted
IDLE COST	195,400	Rp/Jam	140,688,000
HEATING UP COST	1,218,162,227	single cost	
FIXED COST	36,257,800	Rp/Jam	26,105,616,000
VARIABLE COST	24,240	Rp/ton	

Kiln 2		satuan	Monthly Converted
IDLE COST	195,400	Rp/Jam	140,688,000
HEATING UP COST	1,343,323,102	single cost	
FIXED COST	35,893,800	Rp/Jam	25,843,536,000
VARIABLE COST	24,276	Rp/ton	

Kiln 3		satuan	Monthly Converted
IDLE COST	195,400	Rp/Jam	140,688,000
HEATING UP COST	1,226,948,710	single cost	
FIXED COST	40,828,100	Rp/Jam	29,396,232,000
VARIABLE COST	20,651	Rp/ton	

Kiln 4		satuan	Monthly Converted
IDLE COST	195,400	Rp/Jam	140,688,000
HEATING UP COST	1,173,386,658	single cost	
FIXED COST	36,257,800	Rp/Jam	26,105,616,000
VARIABLE COST	29,101	Rp/ton	

Table 4.13 Cost data of finishmill PT. XYZ

Finish Mill 1		satuan	Monthly Converted
IDLE COST	687,029	Rp/Jam	494,661,206.25
FIXED COST	2,723,388	Rp/Jam	1,960,839,000.00
VARIABLE COST	57,664	Rp/Ton	
Finish Mill 2		satuan	Monthly Converted
IDLE COST	424,364	Rp/Jam	305,542,080.00
FIXED COST	2,260,484	Rp/Jam	1,627,548,480.00
VARIABLE COST	61,981	Rp/Ton	
Finish Mill 3		satuan	Monthly Converted
IDLE COST	876,579	Rp/Jam	631,136,880.00
FIXED COST	3,419,500	Rp/Jam	2,462,040,000.00
VARIABLE COST	52,359	Rp/Ton	
Finish Mill 4		satuan	Monthly Converted
IDLE COST	590,321	Rp/Jam	425,031,120.00
FIXED COST	2,740,519	Rp/Jam	1,973,173,680.00
VARIABLE COST	59,809	Rp/Ton	
Finish Mill 5		satuan	Monthly Converted
IDLE COST	971,572	Rp/Jam	699,531,840.00
FIXED COST	3,318,612	Rp/Jam	2,389,400,640.00
VARIABLE COST	52,965	Rp/Ton	
Finish Mill 6		satuan	Monthly Converted
IDLE COST	978,221	Rp/Jam	704,319,120.00
FIXED COST	3,103,904	Rp/Jam	2,234,810,880.00
VARIABLE COST	50,565	Rp/Ton	
Finish Mill 7		satuan	Monthly Converted
IDLE COST	824,343	Rp/Jam	593,526,960.00
FIXED COST	2,747,812	Rp/Jam	1,978,424,640.00
VARIABLE COST	51,291	Rp/Ton	
Finish Mill 8		satuan	Monthly Converted
IDLE COST	970,893	Rp/Jam	699,042,960.00
FIXED COST	2,454,712	Rp/Jam	1,767,392,640.00
VARIABLE COST	51,947	Rp/Ton	
Finish Mill 9		satuan	Monthly Converted
IDLE COST	777,203	Rp/Jam	559,586,160.00
FIXED COST	4,292,938	Rp/Jam	3,090,915,360.00
VARIABLE COST	43,131	Rp/Ton	

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CHAPTER 5 DATA PROCESSING AND RESULT DISCUSSION

This chapter explain about cost optimization model of cement plant using Mixed Integer Linear Programming (MILP), verification and validation, demand forecasting for numerical experiment, numerical experiment, sensitivity analysis, and result discussion.

5.1 Model of cement plant using mixed integer linear programming (MILP)

A Mathematical model of cement plant has been successfully developed. This model converted into MILP program using Computer-Aided Software LINGO 11. The MILP also has been successfully running using Computer-Aided Software LINGO 11. MILP model has made consist of 1647 variables. All parameter including rawmill cost parameter, kiln cost parameter, finish mill cost parameter, December 31th 2018 inventory level as initial inventory, and 2019's actual demand and 2019's actual production has been entryed into model. The result shown is shown as Table 5.1, Table 5.2, & Table 5.3

Table 5.1 Finish mill result data real production 2019

Month	Cement Type	Finish Mill								
		FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7	FM 8	FM 9
January	OPC	92,258		128,472		79,960				
	PCC		91,801		130,395		83,337	152,496	151,773	152,223
February	OPC	84,809		68,691		91,569				
	PCC		48,048		118,865		114,171	114,999	121,180	154,588
March	OPC	82,035		122,673		113,293				
	PCC		65,108		113,758		120,926	82,521	121,058	130,942
April	OPC	45,399		106,064		74,623				
	PCC		73,187		106,989		103,655	116,443	86,425	137,494
May	OPC	61,549		120,539		96,420				
	PCC		76,676		101,815		82,434	136,394	127,965	161,132
June	OPC	63,301		62,831		90,529				
	PCC		88,148		74,093		60,800	47,699	88,945	12,897
July	OPC	104,097		114,894		117,670				
	PCC		134,303		126,038		89,543	142,201	121,762	132,610
August	OPC	98,364		105,646		118,270				
	PCC		139,248		142,854		107,593	123,405	149,745	127,778
September	OPC	85,101		118,703		137,610				
	PCC		124,526		136,465		124,007	127,364	148,920	163,374
October	OPC	89,720		129,484		145,429				
	PCC		136,023		143,425		132,391	146,044	151,231	176,660
November	OPC	56,525		120,458		129,012				
	PCC		132,498		135,086		126,381	153,862	152,732	181,777
December	OPC	79,309		107,476		140,745				
	PCC		136,705		125,653		119,932	159,435	133,354	156,285

Table 5.2 Kiln result data real production 2019

Date	To dome clinker	FROM KILN			
		Kiln 1	Kiln 2	Kiln 3	Kiln 4
Jan	DC1	212,869			
	DC2		253,819		
	DC3			105,393	
	DC4				248,978
Feb	DC1	71,751			
	DC2		210,138		
	DC3			231,688	
	DC4				199,687
Mar	DC1	234,062			
	DC2		242,243		
	DC3			184,470	
	DC4				121,432
Apr	DC1	157,309			
	DC2		223,404		
	DC3			207,730	
	DC4				172,029
May	DC1	242,140			
	DC2		237,610		
	DC3			153,861	
	DC4				233,738
Jun	DC1	219,017			
	DC2		70,271		
	DC3			115,956	
	DC4				148,841
Jul	DC1	170,116			
	DC2		95,379		
	DC3			232,206	
	DC4				201,764
Aug	DC1	244,714			
	DC2		230,643		
	DC3			250,985	
	DC4				202,128
Sep	DC1	235,920			
	DC2		237,596		
	DC3			221,439	
	DC4				216,068
Oct	DC1	248,355			
	DC2		243,353		
	DC3			243,133	
	DC4				231,572
Nov	DC1	237,629			
	DC2		219,432		
	DC3			235,598	
	DC4				237,210
Dec	DC1	251,543			
	DC2		245,299		
	DC3			190,607	
	DC4				235,386

Table 5.3 Raw mill result data.real production data 2019

Date	To blending silo	FROM RAWMILL			
		RM 1	RM 2	RM 3	RM 4
Jan	BS1	315,660			
	BS2		393,100		
	BS3			134,619	
	BS4				395,843
Feb	BS1	104,153			
	BS2		342,463		
	BS3			366,106	
	BS4				316,568
Mar	BS1	374,952			
	BS2		379,754		
	BS3			290,865	
	BS4				189,930
Apr	BS1	242,516			
	BS2		341,471		
	BS3			321,402	
	BS4				270,282
May	BS1	378,952			
	BS2		362,074		
	BS3			235,996	
	BS4				354,120
Jun	BS1	342,080			
	BS2		99,052		
	BS3			183,460	
	BS4				233,985
Jul	BS1	248,407			
	BS2		162,468		
	BS3			334,324	
	BS4				339,016
Aug	BS1	394,861			
	BS2		368,527		
	BS3			390,773	
	BS4				321,464
Sep	BS1	373,339			
	BS2		369,619		
	BS3			348,422	
	BS4				334,990
Oct	BS1	370,033			
	BS2		387,284		
	BS3			341,418	
	BS4				394,509
Nov	BS1	372,306			
	BS2		347,251		
	BS3			374,531	
	BS4				367,737
Dec	BS1	389,219			
	BS2		385,830		
	BS3			293,018	
	BS4				372,576

5.2 Verification and validation

Verification model process use to make sure that MILP model can be run properly without any error and give objective function value. Figure 5.1 shown MILP can be run without any error

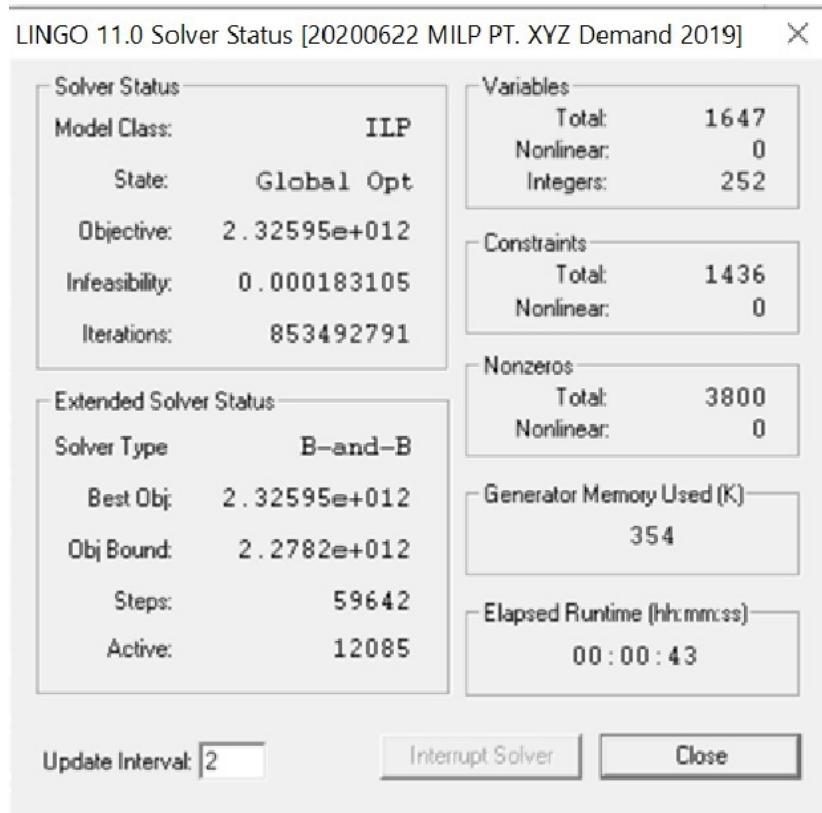


Fig. 5.1 MILP Solver status for verification

After verification successfully, the model need to be validation. Validation needed to make sure the MILP model could replicate the real condition. There are 2 indicator that validation succeed :

1. Model Verified, all entered parameter comply with all constraint and
2. total production cost comparison between realization total production cost demand 2019 and MILP total production cost demand 2019.

Demand and production data taken from 2019 data then inserted into model.

Next step, calculate MILP using demand 2019 to get result of the MILP total production cost 2019. The result total Table 5.4 shown objective function value MILP demand 2019 result

Table 5.4 MILP total production cost demand 2019.

Total Cost RM	Rp473,260,700,000
Total Cost KL	Rp1,065,570,000,000
Total Cost FM	Rp787,120,400,000
Total Cost	Rp2,325,951,100,000

After that, compare table 5.4 with realization total production cost 2019 extracted from Annual Report PT. XYZ, the total cost comparison shown at Table 5.5. Table 5.5 also indicates error percentage that occur from realization and MILP model of PT. XYZ cement plant

Table 5.5 Comparison MILP and realization Total production cost during period 2019

Total production cost MILP demand 2019	
Total Cost RM	Rp473,260,700,000
Total Cost KL	Rp1,065,570,000,000
Total Cost FM	Rp787,120,400,000
Total Cost	Rp2,325,951,100,000

Total Production cost realization 2020	
Cost Enegy	Rp1,472,824,000,000
Cost Material	Rp748,274,000,000
Total Cost	Rp2,221,098,000,000
Error	Rp104,853,100,000
%Error	4.72%

Table 5.5 shown 2019 energy consumption and material for the plant is Rp. 2.221.098.000.000. table 5.4 compared to table 5.5 there will be deviation Rp. 2.325.951.100.000 – Rp. 2.221.098.000.000 = Rp. 104.853.100.000 or error percentage 4.7%. MILP model error percentage less than 5%, then the MILP model has been validated.

The MILP result also presented and discussed with the Bureau Operational Kiln Rawmill Coal mill , Bureau Maintenance Planning, and Section Production planning. The purpose of presentation is to double check the value and parameter, and also gather feedback an information from the potential user of this MILP model. The result of presentation and discussion is the operational manager and production planning manager accepted with note that has to be consolidated with existing tool in company. The potential user also request to make it user-friendly interface. The notulen is shown in figure 5.2

Minute of Meeting

Day, Date	: Friday, 17 April 2020
Place	: Meeting room DPT2
Agenda	: <u>Sosialization and feedback production cost optimization tuban plant.</u>
Participants	: 1. <u>Mubarok – SM of Operational RKC 2</u> 2. <u>Agus Widadi – SM of Maintenance Planning</u> 3. <u>Imron Ghozali – Mgr. of Operational Planning</u> 4. <u>Asep Wahyudin – Mgr. of Instrument Maint. RKC34</u> 5. <u>Nalendra – SM of Electrical Instrumen Maint. 2 - Writer</u>

Minute of meeting:

No	Note
1	The system diagram is already match with the actual field. Minus packer machine for reasons of reducing system complexity.
2	Cost system components have been detailed, please standardize in work instructions on how to collect cost data and make <u>sosialization</u> .
3	The simulation results are still reasonable, because there are still components of energy costs, such as electricity in office areas, roads, and so on.
4	To be immediately consolidated existing tools in the company to be implemented as operating recommendations

Fig. 5.2 Minute-of-meeting with operational user

5.3 Demand forecasting

In need to give company value added, This research also forecast the future demand. There are several scenario to be analyzed using demand forecast method. Current company's forecast demand is annualy aggregate forecast demand. This current company's method is the demand forecasted annually using several previous years demand, then annual forecast demand breakdown into several month. This aggregate annual method has several problem about the respond to fulfill the spreaded demand. Thiis research intend to find and test which method are best-fit with cement demand characteristic.

Here is the scenario to be tested :

1. Daily forecast using daily demand from 1 January 2017 to 31 December 2019
2. Monthly forecast using monthly demand from January 2017 to December 2019
3. 2-Monthly forecast using monthly demand from January 2017 to December 2019 with January-february, march-april, etc. coupled together

The proposed method use to test best-fit method forecast is :

1. Moving Average 2 period
2. Moving average 4 period
3. Single exponential smoothing
4. Trend-corrected exponential smoothing (Holt's method)
5. Trend- Seasonality Corrected exponential smoothing (Winter's method)

After all scenario and all method calculated using Computer-Aided Program Microsoft EXCEL then analyzed the error with method MSE, MAD, and MAPE. Table 5.6 shown the result of daily Forecast 2017-2019 and its error performance.

Table 5.6 Daily demand forecast and winter's seasonal factor

variabel	Parameter	daily Forecast					Winter's Method $\alpha=0.05 \beta=0.03$ (solver min MAPE)
		Moving Average (2 periode)	Moving Average (4 periode)	Exponential Smoothing $\alpha=0.1$ (solver minimize MAPE)	Holt's Method $\alpha=0.06 \beta=0.02$ (solver min MAPE)		
OPC	MSE	40751672.06	38925515.79	20483756	20395285.26	19819507	
	MAD	4996.758593	4905.975907	3597.645156	3557	3504.056662	
	MAPE	25	25	32	32	31	
PCC	MSE	40751672.06	38925515.79	31969872	32257137.71	26840236.15	
	MAD	4996.758593	4905.975907	4345	4364.644803	4001.613059	
	MAPE	25	25	24	24	20	
Winter's seasonal factor	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
OPC	0.84	0.92	1.04	0.99	1.05	0.94	1.05
PCC	0.80	0.87	1.14	1.13	1.12	1.07	1.05

Table 5.6 shown that the smallest MAPE error is far from accurate with 20% using winter's method. It means that daily demand forecast are not feasible in cement demand. Daily forecast Winter's seasonal factor will give quantitative value about how much demand in Sunday and Monday cement release. This daily seasonal factor could be taken as considerable to company how to prepare schedule for the cement loader manpower for example dispatch more loader at Tuesday to Thursday but reducer loader at Sunday and Monday.

Next, second scenario using monthly demand. The daily demand data from same month are sum together to get monthly demand. Table 5.7 shown the monthly forecast 2017-2019 and its error performance.

Table 5.7 Monthly demand forecast and winter's seasonal factor

variabel	Parameter	Moving Average (2 periode)	Moving Average (4 periode)	Exponential Smoothing $\alpha=0.89$ (solver minimize MAPE)	Holt's Method $\alpha=0.9 \beta=0.03$ (solver min MAPE)	Winter's Method $\alpha=0.3 \beta=0.38$ (solver min MAPE)						
OPC	MSE	3391821122	3291722493	2891821122	3055077827	1277476185						
	MAD	49943	48683	43768	44427.66492	28045.85805						
	MAPE	14	14	12	12	9						
PCC	MSE	6045397872	59673263044	5343798022	5664196810	7407939755						
	MAD	61576.31982	72846.82043	61576.68327	63047.63439	52834.71362						
	MAPE	11	11	9	9	8						
Winter's seasonal factor	January	February	March	April	May	June	July	August	September	October	November	December
OPC	0.88	0.80	0.97	0.83	1.05	0.55	1.05	1.12	1.13	1.26	1.18	1.01
PCC	1.03	0.88	0.89	0.87	1.00	0.69	1.10	1.08	1.12	1.25	1.16	1.00

Table 5.6 shown that the smallest MAPE error is quite accurate with 8-9% using winter's method with $\alpha= 0.3 \beta=0.38$. the winter's seasonal factor also inform that best time to do maintenance is February-April and around june when Ied al Fitri. Last scenario, 2-months demand coupled together then forecast the demand and compare the result with other 2 scenarios and make decision which scenario and method to be selected to forecast the 2020 demand. Table 5.8 shown the result of 2-month demand forecasting

Table 5.8 2-Monthly demand forecast and winter's seasonal factor

2-Months Forecast						
variabel	Parameter	Moving Average (2 periode)	Moving Average (4 periode)	Exponential Smoothing $\alpha=0.89$ (solver minimize MAPE)	Holt's Method $\alpha=1 \beta=0.02$ (solver min MAPE)	Winter's Method $\alpha=0.87 \beta=0.1$ (solver min MAPE)
OPC	MSE	28463249834	27492486924	20085249552	21579497798	7477679237
	MAD	155151	148922	122895	126120	37433.49672
	MAPE	23	18	18	18	21
PCC	MSE	44190191264	53981492719	44190191264	43043219800	4624842835
	MAD	231924	24481	171003	170540.9185	38137.52864
	MAPE	16	15	13	13	11
Winter's seasonal factor	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Des
OPC	0.83	0.89	0.79	1.08	1.19	1.09
PCC	0.96	0.88	0.85	1.10	1.20	1.10

Table 5.8 shown that the MAPE error are significantly increase above 18% for OPC. 2-monthly forecast result shown that there are shifting the MAPE error from Winter's method to Exponential Smoothing and Holt's method. It indicates that longer time-period aggregate demand, the less seasonal factor and more trend factor influence the forecasting.

After comparison within 3 scenario and 5 method. By considering that this research is intended for operational managers, it is necessary to consider selecting the shortest time-period which has the smallest error. The conclusion is to use monthly forecast using winter's method with $\alpha= 0.3$

$\beta=0.38$. the demand characteristic and forecast using winter's method shown as figure 5.3. as seen on figure 5.3, there are repetitive lowest demand on june-july from 2017-2019. This lowest demand was due to Eid al-Fitr with the governmental regulation to stop the transportation of trucks from D-7 to D+7

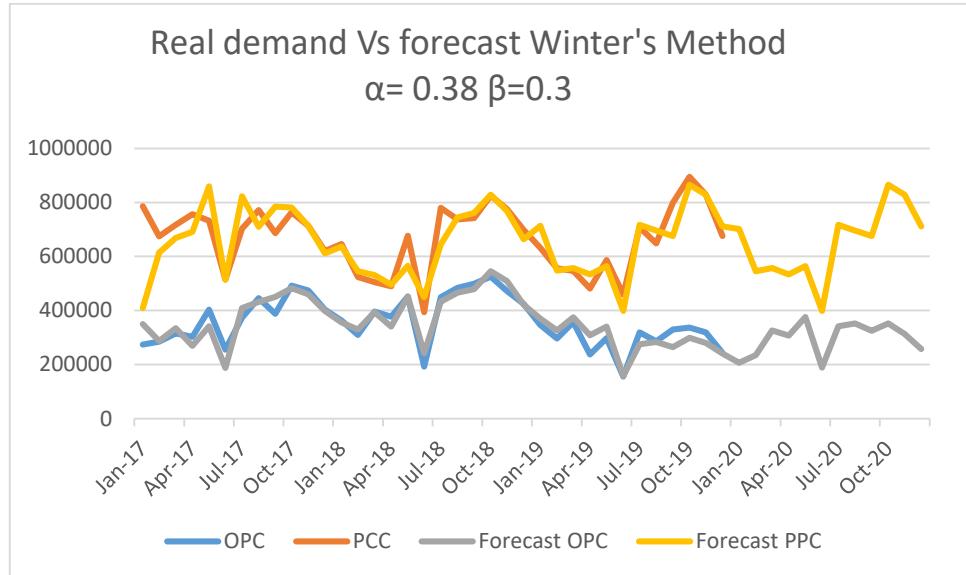


Fig. 5.3 Real demand vs forecast using winter's method

Next step is generate forecast for 2020 demand. Using monthly forecast winter's method with $\alpha= 0.3$ $\beta=0.38$ and lock the Level L January 2020 to Level L January 2019, level L February 2020 to level L February 2019 etc. then the demand 2020 as shown as Figure 5.4

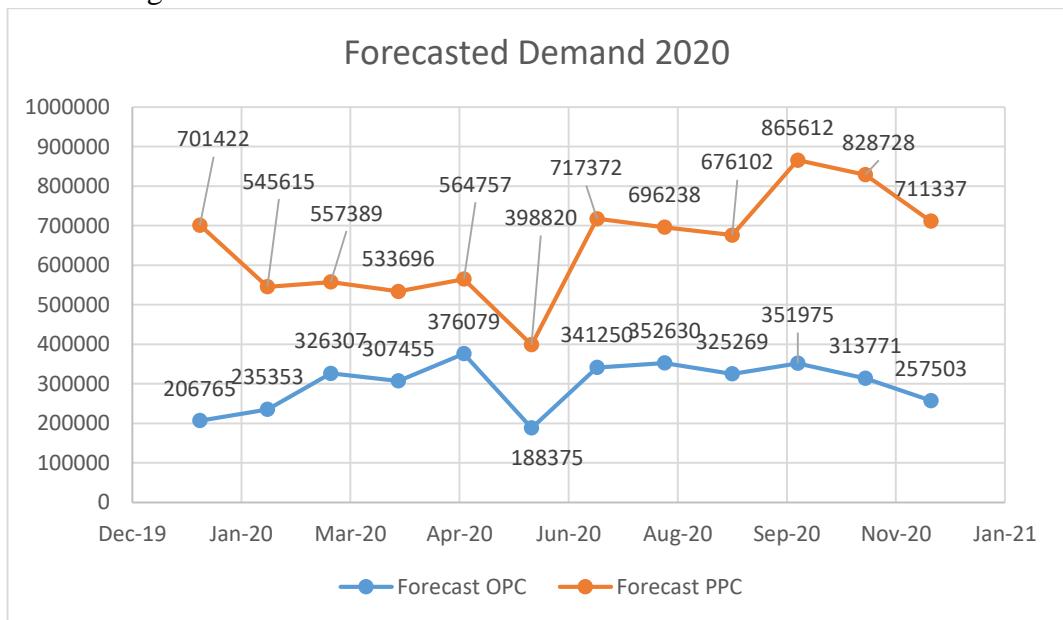


Fig. 5.4 Monthly forecast demand 2020

Forecast Demand 2020 shown in Figure 5.4 will be set as demand and applied to MILP model to give suggestion the production pattern which cost minimize while fulfilling the requested demand 2020.

5.4 Numerical experiment

Numerical experiment are conducted to enrich and give feedback how the mathematical model response using real actual data. This numerical Experiment also answer “the research question 2 : How much total production cost saving by applying Mixed Integer Linear Programming into plant model?”

There are 3 scenario tested in Numerical experiment :

1. Use model actual demand 2019 and realization production. run the MILP model to get MILP realization total production cost.
2. Use MILP LINGO, run the demand 2019 to get cost- minimized total cost production. Then compare the realization and cost-minimization to get cost-saving production cost by applying the MILP.
3. Use forecasted demand 2020. Run MILP using LINGO to get cost-minimization total production cost. compare total production cost between production policy “equally-spread within PT.XYZ plants” and cost-minimized total production cost.

5.4.1 First Scenario : Demand and Realization production 2019

This scenario are conducted to find out the production cost based on actual production realization 2019 shown in table 5.1, 5.2, and 5.3 and main equipment fixed, variable, idle-up, heating up cost from table 4.10, 4.11, 4.12 with objective function from equation 4.4. The result of production cost shown as table 5.9 below.

Table 5.9 Actual realization production cost using demand 2019

Total Cost RM	Rp473,260,700,000
Total Cost KL	Rp1,065,570,000,000
Total Cost FM	Rp787,120,400,000
Total Cost	Rp2,325,951,100,000

5.4.2 Second Scenario : Cost Minimization MILP scenario demand 2019

This scenario are conducted to find out how much potential saving can be obtained by applying optimization using the MILP model. Table 5.10 until 5.12 shown the cost optimized result from Rawmill to finishmill using 2019 demand data.

Table 5.10 Cost-optimized finish mill result data 2019

Month	Cement Type	Finish Mill								
		FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7	FM 8	FM 9
January	OPC	0	133200	0	0	133200	0	0	0	65599
	PCC	139200	6000	139200	139200	6000	0	167040	0	117361
February	OPC	0	0	133200	0	0	0	73797	144000	165600
	PCC	0	139200	6000	139200	0	0	93243	23040	15360
March	OPC	0	0	0	0	0	0	0	0	137812
	PCC	139200	139200	0	0	0	139200	167040	167040	43148
April	OPC	0	0	0	0	0	0	144000	93505	0
	PCC	0	0	0	139300	0	0	23040	75535	180690
May	OPC	0	0	90321	0	0	133200	0	144000	0
	PCC	0	139200	48879	0	6000	600	0	23040	180690
June	OPC	0	0	0	0	0	0	0	0	0
	PCC	139200	139200	139200	0	139200	0	167040	167040	180690
July	OPC	0	0	0	0	0	0	83860	144000	165600
	PCC	139200	0	0	0	139200	139200	83180	23040	15360
August	OPC	0	0	0	0	0	0	0	0	0
	PCC	0	139200	139200	139200	139200	0	167040	167040	180690
September	OPC	0	115731	0	133200	0	133200	144000	144000	165600
	PCC	0	23469	0	6000	0	6000	23040	23040	15360
October	OPC	0	6269	0	0	0	0	0	144000	0
	PCC	0	132931	139200	139200	133657	139200	167040	23040	180690
November	OPC	0	0	0	0	0	0	0	0	0
	PCC	0	139200	139200	0	0	0	167040	167040	180690
December	OPC	0	0	0	0	0	0	144000	93044	0
	PCC	0	139200	0	139200	0	0	23040	67996	180690

Table 5.11 Cost-optimized kiln result data 2019

Date	To dome clinker	FROM KILN			
		Kiln 1	Kiln 2	Kiln 3	Kiln 4
Jan	DC1	129503	33902	0	0
	DC2	129696	0	0	147590
	DC3	0	0	210485	0
	DC4	0	0	0	0
Feb	DC1	124505	0	0	0
	DC2	134694	78300	0	145349
	DC3	0	0	259200	0
	DC4	0	0	0	71394
Mar	DC1	295200	114013	0	0
	DC2	0	145186	0	0
	DC3	0	0	199056	0
	DC4	0	0	0	0
Apr	DC1	1129840	0	0	0
	DC2	0	259200	0	0
	DC3	0	0	78300	0
	DC4	0	0	0	259200
May	DC1	0	0	0	0
	DC2	0	259200	0	38731
	DC3	0	0	161393	0
	DC4	0	0	0	137376
Jun	DC1	0	173954	0	0
	DC2	0	85245	0	0
	DC3	0	0	259200	0
	DC4	0	0	0	259200
Jul	DC1	0	35952	0	0
	DC2	259200	223248	0	0
	DC3	0	0	246164	0
	DC4	0	0	0	45054
Aug	DC1	0	0	0	0
	DC2	0	0	0	0
	DC3	0	0	249885	0
	DC4	0	0	0	259200
Sep	DC1	0	0	0	0
	DC2	80759	0	0	187104
	DC3	0	0	259200	0
	DC4	0	0	0	72095
Oct	DC1	0	91733	0	0
	DC2	78300	167466	0	52817
	DC3	0	0	259200	0
	DC4	0	0	0	103782
Nov	DC1	90480	0	0	0
	DC2	168720	39384	0	0
	DC3	0	0	78300	0
	DC4	0	0	0	0
Dec	DC1	0	90480	0	0
	DC2	39384	168720	0	0
	DC3	0	0	6560	0
	DC4	0	0	0	259200

Table 5.12 Cost-optimized rawmill result data 2019

Date	To blending silo	FROM RAWMILL			
		RM 1	RM 2	RM 3	RM 4
Jan	BS1	414720	0	0	0
	BS2	0	54245	0	0
	BS3	0	0	336776	0
	BS4	0	0	0	0
Feb	BS1	414720	0	0	0
	BS2	0	125280	0	0
	BS3	0	0	414720	540000
	BS4	0	0	0	0
Mar	BS1	414720	0	0	0
	BS2	0	414720	0	0
	BS3	0	0	318489	0
	BS4	0	0	0	0
Apr	BS1	207744	0	0	0
	BS2	0	414720	0	0
	BS3	0	0	125280	0
	BS4	0	0	0	0
May	BS1	0	0	0	0
	BS2	0	414720	0	0
	BS3	0	0	258228	258228
	BS4	0	0	0	281771
Jun	BS1	0	0	0	0
	BS2	0	414720	0	0
	BS3	0	0	414720	540000
	BS4	0	0	0	0
Jul	BS1	414720	0	0	0
	BS2	0	414720	0	0
	BS3	0	0	393862	0
	BS4	0	0	0	0
Aug	BS1	0	0	0	0
	BS2	0	0	0	0
	BS3	0	0	399816	0
	BS4	0	0	0	0
Sep	BS1	129215	0	0	0
	BS2	0	0	0	0
	BS3	0	0	414720	414720
	BS4	0	0	0	125280
Oct	BS1	125280	0	0	0
	BS2	0	414720	0	0
	BS3	0	0	414720	540000
	BS4	0	0	0	0
Nov	BS1	414720	0	0	0
	BS2	0	63014	0	0
	BS3	0	0	125280	0
	BS4	0	0	0	0
Dec	BS1	63014	0	0	0
	BS2	0	414720	0	0
	BS3	0	0	10497	10497
	BS4	0	0	0	414720

Table 5.13 Comparison Total production cost actual vs cost-optimized result data 2019

Description	Actual cost 2019	MILP Cost-Minimize 2019	Cost Reduction
Total Cost RM	Rp473,260,700,000	Rp455,690,034,878.69	3.71%
Total Cost KL	Rp1,065,570,000,000	Rp1,028,089,481,778.05	3.52%
Total Cost FM	Rp787,120,400,000	Rp766,440,456,964.16	2.63%
Total Cost	Rp2,325,951,100,000	Rp2,250,219,973,621	3.29%

Table 5.10 shown data finish mill production data to fulfill 2019 demand. The finish mill production shown to be slightly under utilization because there are some finish mill shut down for 1-2 month, this shutdown can be used the maintenance to do overhaul service.

Table 5.11 shown that kiln production is quite normal and stable. Every month, at least 1 kiln shutdown for overhaul service. Another interesting thing is kiln 2 tend to higher utilization than kiln 1 due to lower production cost and there are sufficient clinker transport to supply kiln 1 from kiln 2 and vice versa.

Table 5.12 shown that rawmill 4 tend to be more often to be stopped. It is due to raw mill 4 has higher production cost than raw mill 3.

Table 5.13 shown data about cost comparison using data demand 2019. The result indicates that using the MILP cost optimization has potential cost saving by 3.29% total cost

5.4.3 Production suggestion for 2020 using MILP

This sub-section answer research question “Q3: How to select production line of the plant efficiently to fulfill near future demand?. Moreover, how to investigate the relationship between electrical energy consumption cost as well as coal price to total production cost?.”.

The Third scenario are conducted to give solution for the company’s operational manager how to operate in cost minimization to fulfill the 2020 demand. Table 5.14 until Table 5.16 shown the production

Table 5.14 Cost-optimized finish mill result data 2020

Month	Cement Type	Finish Mill						
		FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7
January	OPC	133200	0	133200	0	0	0	0
	PCC	6000	0	6000	0	0	117844	167040
February	OPC	133200	0	0	0	0	0	29940
	PCC	6000	0	139200	0	0	139200	167040
March	OPC	0	0	0	0	0	0	0
	PCC	0	0	139200	0	0	0	167040
April	OPC	0	67718.2	74135	0	0	0	0
	PCC	139200	0	65064	0	0	0	167040
May	OPC	0	0	0	0	0	0	0
	PCC	139200	0	139200	0	0	127386	23040
June	OPC	0	0	133200	0	0	0	55175
	PCC	139200	0	6000	0	0	0	111865
July	OPC	64050	0	133200	0	0	0	167040
	PCC	75150	78893	6000	139200	0	0	23040
August	OPC	75429	0	133200	0	0	0	144000
	PCC	63771	139200	6000	139200	0	0	23040
September	OPC	58868	0	133200	133200	0	0	0
	PCC	80332	139200	6000	6000	0	0	167040
October	OPC	133200	0	85574	0	0	0	0
	PCC	6000	6000	139200	53626	0	0	167040
November	OPC	0	133200	133200	0	0	0	0
	PCC	139200	6000	6000	139200	0	0	167040
December	OPC	124302	0	133200	0	0	0	0
	PCC	14898	0	6000	139200	0	0	167040

Table 5.15 Cost-optimized kiln result data 2020

Date	To dome clinker	FROM KILN			
		Kiln 1	Kiln 2	Kiln 3	Kiln 4
Jan	DC1	0	202606	0	0
	DC2	259200	56594	0	0
	DC3	0	0	259200	0
	DC4	0	0	0	185644
Feb	DC1	0	0	0	0
	DC2	0	259200	0	0
	DC3	0	0	0	0
	DC4	0	0	0	242664
Mar	DC1	0	150815	0	0
	DC2	0	108385	0	0
	DC3	0	0	0	0
	DC4	0	0	0	259200
Apr	DC1	0	87705	0	0
	DC2	0	171494	0	84556
	DC3	0	0	0	0
	DC4	0	0	0	174643
May	DC1	0	0	0	0
	DC2	0	259200	0	19016
	DC3	0	0	0	0
	DC4	0	0	0	240183
Jun	DC1	0	92461	0	0
	DC2	0	166738	0	31013
	DC3	0	0	0	0
	DC4	0	0	0	228187
Jul	DC1	0	206424	0	0
	DC2	259200	52776	0	13248
	DC3	0	0	0	0
	DC4	0	0	0	245952
Aug	DC1	0	206424	0	0
	DC2	259200	52776	0	13248
	DC3	0	0	0	0
	DC4	0	0	0	245952
Sep	DC1	0	128520	0	0
	DC2	259200	130679	0	42048
	DC3	0	0	0	0
	DC4	0	0	0	217152
Oct	DC1	23564	259200	0	0
	DC2	235635	0	0	0
	DC3	0	0	0	0
	DC4	0	0	0	259200
Nov	DC1	259200	2046	0	0
	DC2	0	257154	0	77544
	DC3	0	0	0	0
	DC4	0	0	0	181656
Dec	DC1	13169	0	0	
	DC2	2466030	79193	0	0
	DC3	0	0	0	0
	DC4	0	0	0	210600

Table 5.16 Cost-optimized raw mill result data 2020

Date	To blending silo	FROM RAWMILL			
		RM 1	RM 2	RM 3	RM 4
Jan	BS1	540000	139547	0	0
	BS2	0	400453	0	0
	BS3	0	0	119784	278767
	BS4	0	0	420216	0
Feb	BS1	0	0	0	0
	BS2	540000	0	0	0
	BS3	0	0	0	0
	BS4	0	0	540000	0
Mar	BS1	0	0	0	0
	BS2	540000	0	0	0
	BS3	0	0	0	0
	BS4	0	0	540000	0
Apr	BS1	0	0	0	0
	BS2	540000	0	0	0
	BS3	0	0	0	0
	BS4	0	0	0	0
May	BS1	359770	540000	0	0
	BS2	180230	0	0	0
	BS3	0	0	0	0
	BS4	0	0	540000	0
Jun	BS1	0	0	0	0
	BS2	540000	0	0	0
	BS3	0	0	0	0
	BS4	0	0	540000	0
Jul	BS1	391910	0	0	0
	BS2	148090	0	0	0
	BS3	0	0	0	0
	BS4	0	0	5400000	0
Aug	BS1	125280	0	0	0
	BS2	414720	0	0	0
	BS3	0	0	0	0
	BS4	0	0	540000	0
Sep	BS1	0	0	0	0
	BS2	540000	0	0	0
	BS3	0	0	0	0
	BS4	0	0	0	0
Oct	BS1	250560	0	0	0
	BS2	289440	0	0	0
	BS3	0	0	0	0
	BS4	0	0	540000	0
Nov	BS1	125280	0	0	0
	BS2	414720	0	0	0
	BS3	0	0	0	0
	BS4	0	0	540000	0
Dec	BS1	413290	0	0	0
	BS2	126710	0	0	0
	BS3	0	0	0	0
	BS4	0	0	0	0

According to 5.13 and 5.14, Finish Mill (FM) 5 & FM 6 are recommended to close down for a years. Then next step is investigated why FM5 & FM6 from Tuban 3 plant are closed down. It is not because the FM5&FM6 fixed cost, Idle up cost and variable cost, but it is because the MILP Program decide to shutdown the kiln 3 for entire year. Then continue investigate the cost structure for kiln 3 from table 4.11. table 4.11 indicates that Kiln 3 has the highest fixed cost with almost 11.2% higher than any other kiln. Eventhough kiln 3 has lowest variable cost but it does not change the decision that 1 kiln has to be temporarily closed down.

Table 5.17 shown the cost-minimized total production cost for demand 2020 scenario

Table 5.17 Cost-minimized Total production cost result data 2020

Cost-minimized Total Production cost 2020	
Total Cost RM	Rp475,334,380,000
Total Cost KL	Rp1,045,946,000,000
Total Cost FM	Rp770,592,100,000
Total Cost	Rp2,291,872,480,000

Table 5.18 show the recommendation how to operate the plant 1 – 4 to fulfill demand 2020

Table 5.18 Plant operational recommendation for demand 2020

Plant	Plant Operational Recommendation
Finish Mill	
FM1	Run Max capacity, Stop to OVH on MARCH 2020
FM2	Stop for first half year, do OVH between January - June 2020, Preferable January 2020, and backup For FM3, FM7, FM8, FM9
FM3	Run Max capacity, Stop to OVH when the FM2 or FM4 ready, preferable April 2020
FM4	Stop for first half year, do OVH between January - June 2020, Preferable February 2020, and backup For FM3, FM7, FM8, FM9
FM5	stop entire years
FM6	stop entire years
FM7	Run Max capacity, Stop to OVH when the FM2 or FM4 ready, preferable May 2020
FM8	Run Max capacity, Stop to OVH when the FM2 or FM4 ready, preferable July 2020
FM9	Run Max capacity, Stop to OVH when the FM2 or FM4 ready, preferable June 2020
Kiln	
KL1	Stop Kiln 1 from February to June 2020, do OVH then ready to backup KL2
KL2	Run Max Capacity, supply both dome clinker plant 1 DC1& Plant 2 DC2, OVH only when KILN 1 ready to operation.
KL3	stop entire years, then OVH, ready to Backup incase other Plant KL4 shutdown
KL4	Run Max Capacity, OVH only when KILN 3 ready to operation.
Raw mill	
RM1	Rawmill 1 and Rawmill 2 alternately operate to meet the demand for Kiln 1&2
RM2	Rawmill 1 and Rawmill 2 alternately operate to meet the demand for Kiln 1&2
RM3	Rawmill 1 and Rawmill 2 alternately operate to meet the demand for Kiln 4
RM4	Rawmill 1 and Rawmill 2 alternately operate to meet the demand for Kiln 4

Table 5.19 shown the calculation of % utilization of the plant in PT. XYZ to verify that decision to shut down the kiln 3 for entire years is right decision. The 2020 cement demand converted into clinker demand using clinker-to-cement ratio then analyzed

Table 5.19 Plant utilization data 2020

Cement Type	Total Demand	Clinker Needed
OPC (85% clinker)	3,582,732	3,045,322
PPC (65% Clinker)	7,797,087	5,068,106
Total Clinker needed :	8,113,428	
Annual 1 Plant Capacity	3,000,000	
Total 4 Plant	12,000,000	
%Utilization	67.61%	

Table 5.19 shown that the plant utilization only 67.61%. it also inform the management that realization demand are only need 3 plants instead of 4 plants. The top management has to create new market or do some marketing and sales strategy to increase the demand. there are several demand and revenue management theory can be applied, for example pricing management, special price for volume contract, broken bag on delivery warranty, product diversification like home solution and cement-based construction product.

After give production suggestion for 2020 demand to production manager, this research also calculate how much potential cost saving by comparing cost-minimized MILP with current “production policy” equally-spread the production within all plant to maintain all plant has to keep running. Table 5.20 until 5.22 shown the production of finish mill, kiln, and rawmill using equally-spread demand production policy.

Table 5.20 Equally-spread policy demand finish mill result data 2020

Cement Type	Finish Mill								
	FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7	FM 8	FM 9
OPC	68,922		68,922		68,922		68,922		68,922
PCC		116,904		116,904		116,904		116,904	116,904
OPC	78,451		78,451		78,451		78,451		78,451
PCC		90,936		90,936		90,936		90,936	90,936
OPC	108,769		108,769		108,769		108,769		108,769
PCC		92,898		92,898		92,898		92,898	92,898
OPC	102,485		102,485		102,485		102,485		102,485
PCC		88,949		88,949		88,949		88,949	88,949
OPC	125,360		125,360		125,360		125,360		125,360
PCC		94,126		94,126		94,126		94,126	94,126
OPC	62,792		62,792		62,792		62,792		62,792
PCC		66,470		66,470		66,470		66,470	66,470
OPC	113,750		113,750		113,750		113,750		113,750
PCC		119,562		119,562		119,562		119,562	119,562
OPC	117,543		117,543		117,543		117,543		117,543
PCC		116,040		116,040		116,040		116,040	116,040
OPC	108,423		108,423		108,423		108,423		108,423
PCC		112,684		112,684		112,684		112,684	112,684
OPC	117,325		117,325		117,325		117,325		117,325
PCC		144,269		144,269		144,269		144,269	144,269
OPC	104,590		104,590		104,590		104,590		104,590
PCC		138,121		138,121		138,121		138,121	138,121
OPC	85,834		85,834		85,834		85,834		85,834
PCC		118,556		118,556		118,556		118,556	118,556

Table 5.21 Equally-spread policy demand kiln result data 2020

Date	To dome clinker	FROM KILN			
		Kiln 1	Kiln 2	Kiln 3	Kiln 4
Jan	DC1	134,571	210,558	134,571	151,975
	DC2				
	DC3				
	DC4				
Feb	DC1	125,792	184,900	125,792	118,217
	DC2				
	DC3				
	DC4				
Mar	DC1	152,838	213,221	152,838	120,768
	DC2				
	DC3				
	DC4				
Apr	DC1	144,929	202,746	144,929	115,634
	DC2				
	DC3				
	DC4				
May	DC1	167,738	228,920	167,738	122,364
	DC2				
	DC3				
	DC4				
Jun	DC1	96,578	139,784	96,578	86,411
	DC2				
	DC3				
	DC4				
Jul	DC1	174,403	252,118	174,403	155,431
	DC2				
	DC3				
	DC4				
Aug	DC1	175,337	250,763	175,337	150,852
	DC2				
	DC3				
	DC4				
Sep	DC1	165,404	238,648	165,404	146,489
	DC2				
	DC3				
	DC4				
Oct	DC1	193,501	287,276	193,501	187,549
	DC2				
	DC3				
	DC4				
Nov	DC1	178,681	268,459	178,681	179,558
	DC2				
	DC3				
	DC4				
Dec	DC1	150,021	227,082	150,021	154,123
	DC2				
	DC3				
	DC4				

Table 5.22 Equally-spread policy demand rawmill result data 2020

Date	To blending silo	FROM RAWMILL			
		RM 1	RM 2	RM 3	RM 4
Jan	BS1	207,032	0	0	0
	BS2	0	323,935	0	0
	BS3	0	0	207,032	0
	BS4	0	0	0	233,807
Feb	BS1	193,526	0	0	0
	BS2	0	284,462	0	0
	BS3	0	0	193,526	0
	BS4	0	0	0	181,872
Mar	BS1	235,135	0	0	0
	BS2	0	328,033	0	0
	BS3	0	0	235,135	0
	BS4	0	0	0	185,796
Apr	BS1	222,968	0	0	0
	BS2	0	311,917	0	0
	BS3	0	0	222,968	0
	BS4	0	0	0	177,899
May	BS1	258,058	0	0	0
	BS2	0	352,184	0	0
	BS3	0	0	258,058	0
	BS4	0	0	0	188,252
Jun	BS1	148,582	0	0	0
	BS2	0	215,052	0	0
	BS3	0	0	148,582	0
	BS4	0	0	0	132,940
Jul	BS1	268,312	0	0	0
	BS2	0	387,874	0	0
	BS3	0	0	268,312	0
	BS4	0	0	0	239,124
Aug	BS1	269,750	0	0	0
	BS2	0	385,790	0	0
	BS3	0	0	269,750	0
	BS4	0	0	0	232,079
Sep	BS1	254,467	0	0	0
	BS2	0	367,151	0	0
	BS3	0	0	254,467	0
	BS4	0	0	0	225,367
Oct	BS1	297,694	0	0	0
	BS2	0	441,962	0	0
	BS3	0	0	297,694	0
	BS4	0	0	0	288,537
Nov	BS1	274,893	0	0	0
	BS2	0	413,014	0	0
	BS3	0	0	274,893	0
	BS4	0	0	0	276,243
Dec	BS1	230,801	0	0	0
	BS2	0	349,357	0	0
	BS3	0	0	230,801	0
	BS4	0	0	0	237,112

Equally-spread production policy demand 2020 have total production cost then compared with cost-minimized total production cost MILP shown at table 5.23

Table 5.23 comparison Total production cost demand comparison 2020

Description	Equally-spread demand Total production cost 2020	Cost-minimized Total Production cost 2020	Cost Reduction
Total Cost RM	Rp533,566,660,767	Rp475,334,380,000	10.91%
Total Cost KL	Rp1,287,716,111,578	Rp1,045,946,000,000	18.78%
Total Cost FM	Rp778,043,121,432	Rp770,592,100,000	0.96%
Total Cost	Rp2,599,325,893,777	Rp2,291,872,480,000	11.83%

Table 5.23 indicates that potential cost saving using forecasted demand 2020 with current equally-spread policy and cost minimized MILP will reduce total production cost by 11.83%. the biggest cost saving is in kiln equipment by 18.78%. this savings was caused by the production decision to shut down the kiln 3 for entire years and maximized production in other kiln.

5.5 Sensitivity analysis

Sensitivity analysis provides users of mathematical and simulation models with tools to appreciate the dependency of the model output from model input and to investigate how important is each model input in determining its output [7]. Sensitivity analysis are done energy price parameter, namely electricity price/KWh and Coal price/Ton cost. To conduct analysis, the aforementioned parameter are mapped into an interval of [+10%, +20%, +30%, +50%] coefficients. This interval based on experience that government policy to increase the “PLN” electrical price/kWH by step of 10% or 30% as shown in table 5.25.. The result of sensitivity analysis are illustrated in table 5.16 and figure 5.6. as expected that any increment in cost parameter will lead to a boost in objective function value. table 5.24 and figure 5.6 shown that coal price are slightly higher impact on total production cost than electricity price. If electricity price rise up to 50%, then total production cost will be impacted by 17.95%, but if coal price rise up to 50% then total production cost will be impacted by 22%. This sensitivity analysis result are important to management to make strategic decision that secure coal supply chain and price are more crucial than build corporate-owned powerplant.

Table 5.24 Impact of electricity price and coal price to total production cost

No.	Scenario	Electric Price Rp/kWh	Coal Price Rp/Ton	Total Production Cost	%Total Cost Impact
1	Current electricity & current coal Price	Rp 977	Rp 680,000	Rp 2,250,219,973,621	0.00%
2	electricity price +10%	Rp 1,075	Rp 680,000	Rp 2,367,001,000,000	5.19%
3	electricity price +20%	Rp 1,172	Rp 680,000	Rp 2,438,400,000,000	8.36%
4	electricity price +30%	Rp 1,270	Rp 680,000	Rp 2,529,990,000,000	12.43%
5	electricity price +50%	Rp 1,466	Rp 680,000	Rp 2,654,080,000,000	17.95%
6	Coal Price +10%	Rp 977	Rp 748,000	Rp 2,383,582,000,000	5.93%
7	Coal Price +20%	Rp 977	Rp 816,000	Rp 2,491,642,000,000	10.73%
8	Coal Price +30%	Rp 977	Rp 884,000	Rp 2,562,714,000,000	13.89%
9	Coal Price +50%	Rp 977	Rp 1,020,000	Rp 2,745,280,000,000	22.00%

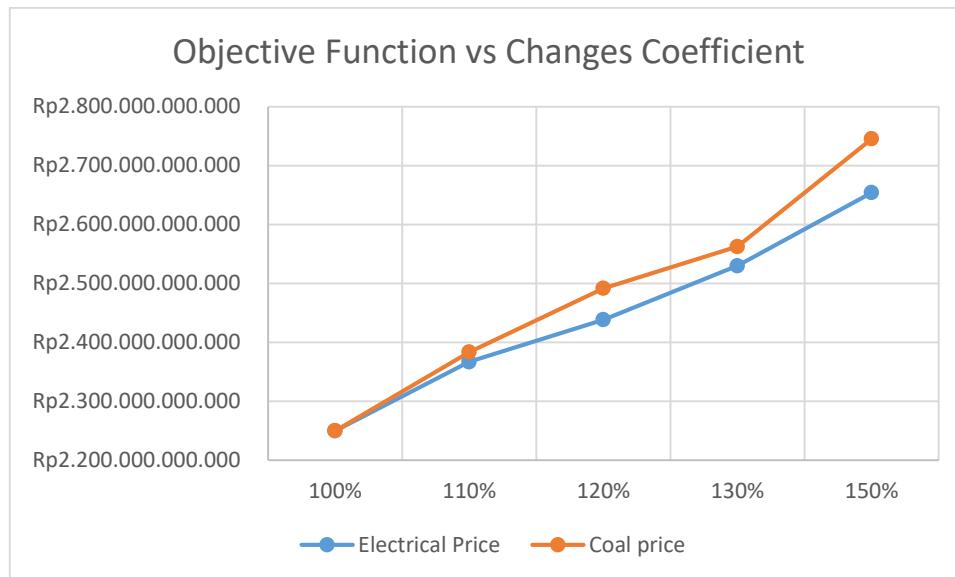


Fig. 5.6 Impact chart of electricity price and coal price to total production cost

Table 5.25 Historical data of increasing electrical tariff

Date	Price (Rp/kWh)	%Difference
before 1 january 2017	Rp605	
01-Jan-17	Rp791	30.7%
01-Mar-17	Rp1,034	30.7%
01-May-17	Rp1,352	30.8%
01-Jul-17	Rp1,467	8.5%

CHAPTER 6 CONCLUSION AND SUGGESTION

This research concern about the issue of production planning to minimize the total production cost in a cement company in Indonesia which is more focused on operational scale and provides holistic solutions for operational managers. As for the methods used are Mixed Integer Linear Programming, Demand Forecast, and sensitivity analysis. This optimization of total production cost uses the LINGO 11.0 computer aided program and cost savings are obtained Rp 75.731.126.379,00 or equal 3.29% cost reduction comparing existing condition. Based on research that has been done, the conclusions and suggestions as follow:

6.1 Conclusion

The following is the conclusion of this research that has been conducted.

1. There are 3 major main equipment in cement plant, Rawmill, Kiln, and Finish Mill. Every types of main equipment has its own unique characteristic. Each of this unique characteristic is shown in cost function in objective function. Raw mill and Finish mill cost function just consist of Idle up cost, fixed cost, and variable cost and only affected by electrical energy price. Cost function of kiln use thermal unit characteristic function, which consist of idle up cost, fixed cost, variable cost, and heating up cost and affected by electrical, coal, and industrial diesel oil price as kiln is thermal unit plant.
2. A Mathematical model of cement plant has been successfully developed. This model converted into MILP program using Computer-Aided Software LINGO 11. The MILP also has been successfully running using Computer-Aided Software LINGO 11 and successfully verified and validated.
3. In this study conducted several experiments for demand forecast using the method Moving Average, Exponential Smoothing, trend-correction exponential smoothing (Holt's Method), Seasonal & Trend- Correction exponential smoothing (winters's method). Also conducted experiment about period of forecasting, daily, monthly, and 2-monthly. Experiment use data from 2017-2019. The best result that reflected the cement demand is using monthly forecast using winter's method with $\alpha=0.38$ and $\beta=0.3$ with MAPE 8%.
4. According to demand 2019 experiment, after comparing data realization production cost vs MILP cost minimization. The MILP application can reduce total production cost by 3.29%.
5. MILP program also can release recommendation to operational manager about Which plan has to run? what type cement has to produce? How much cement, clinker, and kiln feed to produce? When to do annual overhaul for main equipment?. Using forecasted demand 2020, the significant recommendation is to shutdown kiln 3 for entire year and maximized

production capacity in finish mill FM1, FM3, FM4, FM7, FM8, FM9. the potential total production cost saving is 11.83% using forecasted 2020 demand.

6. Sensitivity analysis has been carried out with a scenario of changing the price of the electricity energy price and the coal price. As for the steps used are + 10%, 20%, 30%, 50%. the result is that the impact of rising coal prices is greater than electricity price increases. a 50% increase in coal prices would impact a 22% increase in production costs while a 50% increase in the electricity energy consumption cost would impact 17% of the total production cost. it show that increase coal price is higher impact than increase electricity price to total production cost. It indicates that secure coal supply chain and price are more crucial than build corporate-owned powerplant.

6.2 Suggestion

The following are some suggestion from researchers for further research for the MILP model :

1. Consider to add independent rawmill silo, clinker op cement silo and packer machine to increase model accuracy and reflected real plant complexity.
2. Consider to use Heuristic approach to support more production complexity and faster calculation.
3. Consider to apply the stochastic and uncertain demand to increase accuracy of the future demand which is a force-majeur pandemic occur during middle of this research which drop the 2020 demand by 30% and has not been researched yet in this thesis.
4. Consider to apply dynamic optimization which can support situation equipment cost changing after getting serviced and overhauled.

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Appendix 1

MILP program in LINGO:

```
MODEL:  
SETS:  
Prod/1..2/:;  
Time/1..12/:;  
CS/1..2/:CICS,IICS;  
FM/1..9/:AFM,EFM,MYYFM;  
DC/1..4/:CICD,IICD;  
KL/1..4/:AKL,CKL,EKL;  
BS/1..4/:CIBS,IIIBS;  
RM/1..4/:ARM,ERM;  
ProdTime(Prod,Time):D;  
CSTime(CS,Time):ICS;  
CSProd(CS,Prod):YCS;  
CSProdTime(CS,Prod,Time):RCS;  
FMTIME(FM,Time):FFM;  
FMCS(FM,CS):BFM,YFM,YYFM,YYYFM;  
FMCSTime(FM,CS,Time):RFM;  
DCTime(DC,Time):ICD;  
DCFMD(CD,FM):YCD,YYCD;  
DCFMTIME(DC,FM,Time):RCD;  
KLTime(KL,Time):FKL,G;  
KLDC(KL,DC):BKL,YKL,YYKL;  
KLDCTime(KL,DC,Time):RKL;  
BSTime(BS,Time):IBS;  
BSKL(BS,KL):YBS;  
BSKLTime(BS,KL,Time):RBS;  
RMTIME(RM,Time):FRM;  
RMBS(RM,BS):BRM,YRM;  
RMBSTime(RM,BS,Time):RRM;  
ENDSETS  
  
DATA:  
!capacity inventory Cement Silo OPC PPC;  
CICS = 1920000  
6000000;  
  
!initial inventory Cement Silo t=0;  
IICS = 36484  
157000;  
  
!idle cost Finishmill 1..9;  
EFM = 494661206  
305542080  
631136880  
425031120  
699531840  
704319120  
593526960  
699042960  
599586160;
```

```

!Fixed cost Finishmill 1..9;
AFM = 1960839000
1627548480
2462040000
1973173680
2389400640
2234810880
1978424640
1767392640
3090915360;

!Max Production rate finishmill 1..9 for operatioanal day 29 days
due to 1 day for service;
MYYFM = 139200
139200
139200
139200
139200
139200
167040
167040
180960;

!Max capacity Clinker dome 1..4;
CICD = 1950000
1950000
1950000
2100000;

!initial inventory clinker dome 1..4;
IICD = 60884
63063
19930
63008;

!idle up cost kiln 1..4;
EKL = 140688000
140688000
140688000
140688000;

!Heating up cost Kiln 1..4;
CKL = 1218162227
1343323102
1226948710
1173386658;

!Fixed cost Kiln 1..4;
AKL = 26105616000
25843536000
29396232000
26105616000;

```

```

!max capacity blending silo from rawmill 1..4;
CIBS = 1200000
1200000
1200000
1200000;
1200000;

!initial inventory blending silo 1..4;
IIBS = 35403
32267
34169
32518;

!idle up cost rawmill 1..4;
ERM = 234479520
259179120
476699040
322124400;

!Fixed cost rawmill 1..4;
ARM = 4474405440
1653084000
1653084000
1793772000;

!Monthly demand 1..12 OPC & PCC;
D = 206764 235353 326307 307454 376079 188375 341250 352629 325268
351974 313770 257502
701421 545614 557389 533695 564757 398819 717371 696238 676102
865612 828727 711336      ;

!connectivity matric clinker dome to demand;
YCS = 1      0
0      1;

!Variable cost producing OPC PPC finish mill 1..9;
BFM = 57664 57664
61981 61981
52359 52359
59809 59809
52965 52965
50565 50565
51291 51921
51947 51947
43131 43131;

!connectivity matric finish mill producing OPC PPC;
YFM = 1      1
1      1
1      1
1      1
1      1
1      1

```

```

1      1
1      1
1      1;

!connectivity matrix max production rate producing OPC PPC
finishmill 1..9;
YYFM = 133200      144000
133200      144000
133200      144000
133200      144000
133200      144000
133200      144000
144000      172800
144000      172800
165600      187200;

!connectivity matrix clinker factor when producing OPC PCC
finishmill 1..9;
YYYFM = 0.85      0.65
0.85  0.65
0.85  0.65
0.85  0.65
0.85  0.65
0.85  0.65
0.85  0.65
0.85  0.65
0.85  0.65;

!connectivity matrix row clinker dome 1..4 could supply column
finish mill 1..9;
YCD = 1      1      0      0      0      0      0      0      0
0      0      1      1      0      0      0      0      1
0      0      0      0      1      1      1      1      0
0      0      0      0      0      0      1      1      0;

!connectivity maximum rate matrix row clinker dome 1..4 could
supply column finish mill 1..9;
YYCD = 180000      180000      0      0      0      0      0      0      0
          0
0      0      180000      180000      0      0      0      0      180000
0      0      0      0      180000      180000      30000  30000  0
0      0      0      0      0      0      180000      180000      0;

!variable cost row kiln 1..4 and transported to column clinker
dome 1..4;
BKL = 24240 24240 24240 24240
24276 24276 24276 24276
20651 20651 20651 20651
29101 29101 29101 29101;

!connectivity matrix row kiln 1..4 to store at column clinker come
1..4;
YKL = 1      1      0      0

```

```

1      1      0      0
0      0      1      0
0      1      0      1;

!connectivity matrix ratio kiln feed to clinker output in ton;
YYKL = 1.6  1.6  0      0
1.6   1.6  0      0
0      0      1.6  0
0      1.6  0      1.6;

!connectivity matrix blending silo;
YBS = 1      0      0      0
0      1      0      0
0      0      1      0
0      0      0      1;

!variable cost row raw mill 1..4 to column blending silo 1..4;
BRM = 27219 27219 27219 27219
35950 35950 35950 35950
34788 34788 34788 34788
35274 35274 35274 35274;

!connectivity matric row rawmill 1..4 to column blending silo
1..4;
YRM = 1      1      0      0
1      1      0      0
0      0      1      1
0      0      1      1;

ENDDATA

MIN = TotalCostRM + TotalCostKL + TotalCostFM;
TotalCostRM = @SUM(RMTIME(k,t) : ARM(k)*FRM(k,t) + ERM(k)*(1-
FRM(k,t))) + @SUM(RMBSTIME(k,l,t) : BRM(k,l)*RRM(k,l,t));
TotalCostKL = @SUM(KLTIME(m,t) : AKL(m)*FKL(m,t) + EKL(m)*(1-
FKL(m,t)) + CKL(m)*G(m,t)) + @SUM(KLDCTIME(m,n,t) : BKL(m, n) *
RKL(m, n, t));
TotalCostFM = @SUM(FMTIME(o,t) : AFM(o)*FFM(o,t) + EFM(o)*(1-
FFM(o,t))) + @SUM(FMCSTIME(o,p,t) : BFM(o,p)*RFM(o,p,t));

@FOR(ProdTime(q,t) : @SUM(CS(p) : YCS(p,q)*RCS(p,q,t)) >= D(q,t));

@FOR(CSTime(p,t) | t #EQ# 1: ICS(p,t) = IICS(p) + @SUM(FM(o) :
YFM(o,p)*RFM(o,p,t)) - @SUM(Prod(q) : YCS(p,q)*RCS(p,q,t)));
@FOR(CSTime(p,t) | t #GE# 2: ICS(p,t) = ICS(p,t-1) + @SUM(FM(o) :
YFM(o,p)*RFM(o,p,t)) - @SUM(Prod(q) : YCS(p,q)*RCS(p,q,t)));
@FOR(CSTime(p,t) : ICS(p,t) <= CICS(p));

@FOR(FMTIME(o,t) : @SUM(CS(p) : YFM(o,p)*RFM(o,p,t)) <=
FFM(o,t)*MYYFM(o));
@FOR(FMCSTIME(o,p,t) : RFM(o,p,t) <= YYFM(o,p));

```

```

@FOR (FMTIME(o,t): @SUM(DC(n): YCD(n,o)*RCD(n,o,t)) >= @SUM(CS(p):
YYYFM(o,p)*RFM(o,p,t)));;

@FOR (DCTIME(n,t) | t #EQ# 1: ICD(n,t) = IICD(n) + @SUM(KL(m):
YKL(m,n)*RKL(m,n,t)) - @SUM(FM(o): YCD(n,o)*RCD(n,o,t)));
@FOR (DCTIME(n,t) | t #GE# 2: ICD(n,t) = ICD(n,t-1) + @SUM(KL(m):
YKL(m,n)*RKL(m,n,t)) - @SUM(FM(o): YCD(n,o)*RCD(n,o,t)));
@FOR (DCTIME(n,t): ICD(n,t) <= CICD(n));
@FOR (DCFMTIME(n,o,t): RCD(n,o,t) <= YYCD(n,o));

@FOR (KLTIME(m,t): @SUM(DC(n): YKL(m,n)*RKL(m,n,t)) <=
FKL(m,t)*360*24*30);
@FOR (KLTIME(m,t): @SUM(BS(l): YBS(l,m)*RBS(l,m,t)) >= @SUM(DC(n):
YYKL(m,n)*RKL(m,n,t)));
!@FOR (KLTIME(m,t) | t #LE# 11 : FKL(m,t) + FKL(m,t+1) <= 2*(1-
G(m,t));
@FOR (KLTIME(m,t) | t #LE# 11 #AND# t #GE# 2: FKL(m,t+1) - FKL(m,t)
= G(m,t));

@FOR (BSTIME(l,t) | t #EQ# 1: IBS(l,t) = IIIBS(l) + @SUM(RM(k):
YRM(k,l)*RRM(k,l,t)) - @SUM(KL(m):YBS(l,m)*RBS(l,m,t)));
@FOR (BSTIME(l,t) | t #GE# 2: IBS(l,t) = IBS(l,t-1) + @SUM(RM(k):
YRM(k,l)*RRM(k,l,t)) - @SUM(KL(m):YBS(l,m)*RBS(l,m,t)));
@FOR (BSTIME(l,t): IBS(l,t) <= CIBS(l));

@FOR (BSTIME(l,t): IBS(l,t) >= 0.015*CIBS(l));
@FOR (DCTIME(n,t): ICD(n,t) >= 0.015*CICD(n));
@FOR (CSTIME(p,t): ICS(p,t) >= 0.015*CICS(p));

@FOR (RMTIME(k,t): @SUM(BS(l): YRM(k,l)*RRM(k,l,t)) <=
FRM(k,t)*750*24*30);

@FOR (FMTIME(o,t): @BIN(FFM(o,t)));
@FOR (KLTIME(m,t): @BIN(FKL(m,t)));
@FOR (RMTIME(k,t): @BIN(FRM(k,t)));
@FOR (KLTIME(m,t): @BIN(G(m,t)));

```

Appendix 2

Monthly demand forecast Seasonality & trend-corrected exponential smoothing
(Winter's method) $\alpha=0.3$ $\beta=0.38$

data	day	OPC	Total Demand	Tuban	L0=	397879.78	T0=	-1886.84	$\alpha=$	0.30	$\beta=$	0.38		
			PCC	Level L	Trend T	Seasonal Factor	Forecast	Error	Abs Error	MSE	MAD	%error	MAPE	
			397880	-1886.8394										
1	Jan-17	1	273764	786398	370024	-11713	0.88	350005	76241	76241	5812721293	76241	28	28
2	Feb-17	1	284928	674128	357283	-12102	0.80	287668	2740	2740	2910114093	39491	1	14
3	Mar-17	1	315659	717699	339289	-14332	0.97	334634	18975	18975	2060091093	32652	6	12
4	Apr-17	1	302597	756190	336855	-9830	0.83	269788	-32810	32810	1814184571	32691	11	11
5	Mei 17	1	403000	732056	344518	-3211	1.05	342199	-60801	60801	2190689100	38313	15	12
6	Jun-17	1	255240	514576	378377	10816	0.55	187572	-67668	67668	2588724307	43206	27	15
7	Jul-17	1	373822	703346	379040	6974	1.05	409285	35463	35463	2398568798	42100	9	14
8	Aug-17	1	445513	771925	389634	8344	1.12	432056	-13457	13457	2121384955	38519	3	12
9	Sep-17	1	387389	686757	381224	2004	1.13	450364	62975	62975	2326326909	41237	16	13
10	Oct-17	1	492138	763385	385430	2838	1.26	482919	-9219	9219	2102192837	38035	2	12
11	Nov-17	1	474560	713759	391986	4244	1.18	459934	-14627	14627	1930533001	35907	3	11
12	Des 17	1	403555	620020	397773	4828	1.01	398403	-5152	5152	1771867421	33344	1	10
13	Jan-18	1	363058	645550	405057	5758	0.88	355846	-7212	7212	1639570967	31334	2	10
14	Feb-18	1	309972	524631	403372	2941	0.80	329821	19849	19849	1550599003	30513	6	9
15	Mar-18	1	396555	505715	407139	3254	0.97	393897	-2658	2658	1447696875	28656	1	9
16	Apr-18	1	377662	489739	423789	8323	0.83	340718	-36944	36944	1442521183	29174	10	9
17	Mei 18	1	451457	676781	431909	8246	1.05	452162	705	705	1357696263	27500	0	8
18	Jun-18	1	192979	394359	413358	-1893	0.55	241895	48916	48916	1415200236	28690	25	9
19	Jul-18	1	449894	780302	416385	-32	1.05	432707	-17187	17187	1356263052	28084	4	9
20	Aug-18	1	484357	737449	421287	1835	1.12	466014	-18343	18343	1305273316	27597	4	9
21	Sep-18	1	499639	742150	428662	3931	1.13	478819	-20820	20820	1263759433	27274	4	8
22	Oct-18	1	525048	824617	427796	2116	1.26	545125	20077	20077	1224637969	26947	4	8
23	Nov-18	1	472449	775140	420556	-1424	1.18	509264	36815	36815	1230322056	27376	8	8
24	Des 18	1	424662	698742	420099	-1058	1.01	421430	-3232	3232	1179493776	26370	1	8
25	Jan-19	1	346443	632226	410889	-4143	0.88	370377	23934	23934	1155227174	26273	7	8
26	Feb-19	1	296883	555620	395620	-8353	0.80	326554	29671	29671	1144656395	26403	10	8
27	Mar-19	1	357526	546883	381706	-10457	0.97	375433	17907	17907	1114137487	26089	5	8
28	Apr-19	1	237505	481343	345606	-20160	0.83	308220	70715	70715	1252939145	27683	30	9
29	Mei 19	1	297721	587416	313125	-24822	1.05	340547	42826	42826	1272978937	28205	14	9
30	Jun-19	1	156350	459157	287156	-25256	0.55	158442	2092	2092	1230692231	27334	1	9
31	Jul-19	1	319155	707209	274421	-20518	1.05	275421	-43734	43734	1252690834	27863	14	9
32	Aug-19	1	286555	648517	254539	-20277	1.12	284187	-2368	2368	1213719551	27067	1	9
33	Sep-19	1	329980	799286	251523	-13746	1.13	265098	-64881	64881	1304503618	28213	20	9
34	Oct-19	1	336597	894819	246609	-10404	1.26	299631	-36966	36966	1306327140	28470	11	9
35	Nov-19	1	319423	828728	246274	-6594	1.18	279802	-39621	39621	1313855535	28789	12	9
36	Des 19	1	243044	675517	240294	-6362	1.01	240994	-2049	2049	1277476185	28046	1	9
	Jan-20			281508	11640	0.88	206765							
	Feb-20			316222	20371	0.80	235353							
	Mar-20			346288	24039	0.97	326307							
	Apr-20			344962	14441	0.83	307455							
	May-20			336858	5911	1.05	376079							
	Jun-20			325225	-727	0.55	188375							
	Jul-20			318173	-3121	1.05	341250							
	Aug-20			297279	-9846	1.12	352630							
	Sep-20			288687	-9371	1.13	325269							
	Oct-20			275642	-10762	1.26	351975							
	Nov-20			266317	-10218	1.18	313771							
	Dec-20			251769	-11856	1.01	257503							

data	day	Total Demand Tuban		L0=	397879.78	T0=	-1886.84	$\alpha=$	0.83	$\beta=$	0.00			
		PCC	PCC											
		397880	#####											
1	Jan-17	1	786398	786398	699396	-1887	1.03	409725	-376673	376673	141882528852	376673	48	48
2	Feb-17	1	674128	674128	754916	-1887	0.88	613537	-60590	60590	72776846550	218632	9	28
3	Mar-17	1	717699	717699	799232	-1887	0.89	668486	-49214	49214	49325227602	162159	7	21
4	Apr-17	1	756190	756190	860393	-1887	0.87	690663	-65528	65528	38067396454	138001	9	18
5	Mei	1	732056	732056	752167	-1887	1.00	859849	127794	127794	33720160264	135960	17	18
6	Jun-17	1	514576	514576	749572	-1887	0.69	515160	584	584	28100190338	113397	0	15
7	Jul-17	1	703346	703346	657474	-1887	1.10	822408	119061	119061	26110964127	114206	17	15
8	Aug-17	1	771925	771925	702988	-1887	1.08	710303	-61623	61623	23321761459	107633	8	14
9	Sep-17	1	686757	686757	628118	-1887	1.12	784780	98023	98023	21798067664	106565	14	14
10	Oct-17	1	763385	763385	614287	-1887	1.25	781264	17880	17880	19650229079	97697	2	13
11	Nov-17	1	713759	713759	612704	-1887	1.16	713335	-424	424	17863860988	88854	0	12
12	Des 17	1	620020	620020	617209	-1887	1.00	612330	-7689	7689	16380132843	82090	1	11
13	Jan-18	1	645550	645550	622483	-1887	1.03	636661	-8889	8889	15126201256	76459	1	10
14	Feb-18	1	524631	524631	600459	-1887	0.88	545884	21253	21253	14078020860	72516	4	10
15	Mar-18	1	505715	505715	574488	-1887	0.89	531370	256555	256555	13183363630	69392	5	10
16	Apr-18	1	489739	489739	566588	-1887	0.87	495988	6249	6249	12361843998	65445	1	9
17	Mei 18	1	676781	676781	657229	-1887	1.00	565585	-111196	111196	12361996726	68137	16	9
18	Jun-18	1	394359	394359	587839	-1887	0.69	449972	55614	55614	11847045011	67441	14	10
19	Jul-18	1	780302	780302	688840	-1887	1.10	644511	-135791	135791	12194002435	71038	17	10
20	Aug-18	1	737449	737449	681693	-1887	1.08	744286	6838	6838	11586640104	67828	1	10
21	Sep-18	1	742150	742150	665814	-1887	1.12	760943	18793	18793	11051713330	65493	3	9
22	Oct-18	1	824617	824617	661471	-1887	1.25	828292	3676	3676	10549976856	62683	0	9
23	Nov-18	1	775140	775140	664481	-1887	1.16	768296	-6843	6843	10093318334	60256	1	9
24	Des 18	1	698742	698742	691280	-1887	1.00	664236	-34506	34506	9722373192	59183	5	8
25	Jan-19	1	632226	632226	624089	-1887	1.03	713301	81075	81075	9596403158	60058	13	9
26	Feb-19	1	555620	555620	630088	-1887	0.88	547297	-8323	8323	9229974782	58068	1	8
27	Mar-19	1	546883	546883	618073	-1887	0.89	557672	10789	10789	8892434835	56317	2	8
28	Apr-19	1	481343	481343	565770	-1887	0.87	533742	52399	52399	8672907273	56177	11	8
29	Mei 19	1	587416	587416	582731	-1887	1.00	564766	-22651	22651	8391532746	55021	4	8
30	Jun-19	1	459157	459157	654080	-1887	0.69	398821	-60336	60336	8233163734	55199	13	8
31	Jul-19	1	707209	707209	644492	-1887	1.10	717372	10163	10163	7970909532	53746	1	8
32	Aug-19	1	648517	648517	605898	-1887	1.08	696238	47721	47721	7792983088	53557	7	8
33	Sep-19	1	799286	799286	695728	-1887	1.12	676102	-123184	123184	8016658445	55667	15	8
34	Oct-19	1	894819	894819	713352	-1887	1.25	865612	-29207	29207	7805964163	54889	3	8
35	Nov-19	1	828728	828728	711465	-1887	1.16	828728	0	0	7582936615	53321	0	8
36	Des 19	1	675517	675517	679800	-1887	1.00	711337	35820	35820	7407939755	52835	5	8
	Jan-20				622177	-1887	1.03	701422						
	Feb-20				629769	-1887	0.88	545615						
	Mar-20				618020	-1887	0.89	557389						
	Apr-20				565761	-1887	0.87	533696						
	May-20				582730	-1887	1.00	564757						
	Jun-20				654079	-1887	0.69	398820						
	Jul-20				644492	-1887	1.10	717372						
	Aug-20				605898	-1887	1.08	696238						
	Sep-20				695728	-1887	1.12	676102						
	Oct-20				713352	-1887	1.25	865612						
	Nov-20				711465	-1887	1.16	828728						
	Dec-20				679800	-1887	1.00	711337						

Appendix 3

Cost data Finish Mill 1-9

(FINISH MILL 1)				
JAM KE	FEEDRATE (t/h)	AKUMULASI DAYA (MWh)	KONSUMSI DAYA (MWh)	KET
0	189.4	172265.4		
1	182.2	172272.8	7.4	
2	188.4	172279.1	6.3	
3	189.1	172286.0	6.8	
4	167.3	172289.8	3.8	
5	72.0	172291.0	1.2	
6	0.0	172291.9	0.8	
7	0.0	172292.6	0.8	
8	0.0	172293.2	0.6	
9	0.0	172294.1	0.9	
10	0.0	172294.8	0.7	
11	0.0	172295.5	0.7	
12	0.0	172296.0	0.5	
13	0.0	172296.7	0.7	
14	4.5	172297.4	0.7	FIXED COST
15	4.1	172302.2	4.9	
16	159.9	172309.8	7.6	
17	162.3	172317.5	7.7	
18	186.3	172325.1	7.7	
19	179.4	172332.5	7.4	
20	188.4	172341.1	8.6	
21	198.1	172348.6	7.6	
22	192.7	172355.2	6.6	
23	178.4	172362.8	7.6	
KETERANGAN		AVG TONASE	AVG KWH	COST
IDLE COST				Rp 687,029.45
FIXED COST		4.3	2.8	Rp 2,723,387.50
RUNNING		183.6	7.6	Rp 26,038.07
JUMLAH VAR.COST				
electric price 100%				

(FINISH MILL 2)				
JAM KE	FEEDRATE (t/h)	AKUMULASI DAYA (MWh)	KONSUMSI DAYA (MWh)	KET
0	182.5652	152321.8		
1	189.8336	152329.5	7.7	
2	179.3677	152336.2	6.7	
3	192.3542	152339.3	3.1	
4	85.5930	152341.7	2.4	
5	0.0000	152342.2	0.5	
6	0.0000	152343.0	0.8	
7	0.0000	152343.2	0.2	
8	0.0000	152343.5	0.3	
9	0.0000	152343.9	0.4	
10	0.0000	152344.3	0.4	
11	4.1538	152345.5	1.2	
12	4.3047	152348.9	3.5	FIXED COST
13	181.3278	152356.3	7.4	
14	181.4513	152363.9	7.6	
15	186.1423	152371.1	7.2	
16	182.5652	152377.8	6.7	
17	189.8336	152385.8	8.0	
18	181.1424	152394.2	8.4	
19	170.1239	152401.8	7.6	
20	168.5169	152410.0	8.1	
21	170.2120	152418.5	8.5	
22	182.4389	152425.1	6.7	
23	171.3569	152433.6	8.4	
KETERANGAN		AVG TONASE	AVG KWH	COST
IDLE COST				Rp 424,364.84
FIXED COST		4.2	2.3	Rp 2,260,484.90
RUNNING		178.4	7.7	Rp 30,355.88
JUMLAH VAR.COST				

(FINISH MILL 3)					
JAM KE	FEEDRATE (t/h)	AKUMULASI DAYA (MWh)		KONSUMSI DAYA (MWh)	KET
0	3.1538	162214.9			
1	4.1211	162222.0		7.1	
2	171.1913	162229.1		7.1	
3	169.1448	162235.9		6.8	
4	176.9265	162243.1		7.2	
5	172.5652	162250.2		7.1	
6	169.5381	162256.2		6.0	
7	170.1239	162261.0		4.8	
8	168.5169	162267.6		6.6	
9	170.2120	162273.9		6.2	
10	0.0	162275.9		2.0	
11	0.0	162276.5		0.7	
12	0.0	162277.3		0.7	
13	0.0	162278.1		0.9	
14	0.0	162278.8		0.6	
15	0.0	162279.5		0.8	
16	0.0	162280.3		0.8	
17	0.0	162281.0		0.8	
18	4.5	162283.9		2.9	
19	4.1	162288.0		4.1	FIXED COST
20	159.9	162294.4		6.4	
21	162.3	162301.7		7.2	
22	176.3	162308.3		6.7	
23	179.4	162315.6		7.3	RUNNING
KETERANGAN		AVG TONASE	AVG KWH	COST	JUMLAH VAR.COST
IDLE COST				Rp 876,579.67	
FIXED COST		4.3	3.5	Rp 3,419,500.00	Rp 20,733.39
RUNNING		172.7	7.1	Rp 20,733.39	

(FINISH MILL 4)					
JAM KE	FEEDRATE (t/h)	AKUMULASI DAYA (MWh)		KONSUMSI DAYA (MWh)	KET
0	181.3	152229.3			
1	181.5	152236.5		7.2	
2	186.1	152243.0		6.5	
3	182.6	152249.3		6.3	
4	179.0	152257.1		7.8	
5	64.1	152264.3		7.2	
6	0.0	152265.3		1.0	
7	0.0	152266.3		1.0	
8	0.0	152266.6		0.3	
9	0.0	152267.1		0.5	
10	0.0	152267.5		0.4	
11	0.0	152268.0		0.5	
12	0.0	152268.5		0.5	
13	0.0	152269.1		0.7	
14	0.0	152269.9		0.7	
15	0.0	152270.7		0.9	
16	4.2	152272.3		1.6	
17	4.3	152276.3		4.0	FIXED COST
18	179.4	152284.2		7.8	
19	177.1	152292.1		7.9	
20	181.3	152300.6		8.5	
21	181.5	152308.7		8.1	
22	186.1	152316.5		7.9	
23	182.6	152323.8		7.3	RUNNING
KETERANGAN		AVG TONASE	AVG KWH	COST	JUMLAH VAR.COST
IDLE COST				Rp 590,321.85	
FIXED COST		4.2	2.8	Rp 2,740,519.19	Rp 28,183.01
RUNNING		181.7	7.9	Rp 28,183.01	

545 GROUP (FINISH MILL 5)					
JAM KE	FEEDRATE (t/h)	AKUMULASI DAYA (MWh)		KONSUMSI DAYA (MWh)	KET
0	192.4	162265.4		5.4	
1	85.6	162270.8		2.0	
2	0.0	162272.8		0.5	
3	0.0	162273.3		0.7	
4	0.0	162274.0		1.2	
5	0.0	162275.1		0.7	
6	0.0	162275.9		1.8	
7	0.0	162276.5		0.7	
8	0.0	162277.3		0.7	
9	0.0	162278.9		1.7	
10	0.0	162280.8		1.0	
11	0.0	162281.7		2.6	
12	4.2	162284.3		3.8	
13	4.3	162288.2		3.9	
14	179.4	162292.1		7.1	
15	190.5	162299.2		7.9	
16	199.2	162307.1		7.5	
17	192.3	162314.7		7.5	
18	196.8	162322.1		7.7	
19	197.7	162329.8		8.0	
20	198.1	162337.8		7.2	
21	198.1	162345.0		6.9	
22	192.7	162351.9		6.6	
23	200.5	162358.6			
KETERANGAN		AVG TONASE	AVG KWH	COST	JUMLAH VAR.COST
IDLE COST				Rp 971,572.22	
FIXED COST		4.2	3.2	Rp 3,138,612.50	Rp 21,339.22
RUNNING		196.9	7.4	Rp 21,339.22	

546 GROUP (FINISH MILL 6)					
JAM KE	FEEDRATE (t/h)	AKUMULASI DAYA (MWh)		KONSUMSI DAYA (MWh)	KET
0	189.4	162265.4		5.4	
1	182.2	162270.8		2.0	
2	188.4	162272.8		0.5	
3	189.1	162273.3		0.7	
4	167.3	162274.0		1.2	
5	72.0	162275.1		0.7	
6	0.0	162275.9		0.7	
7	0.0	162276.5		0.7	
8	0.0	162277.3		0.7	
9	0.0	162278.9		1.7	
10	0.0	162280.8		1.8	
11	0.0	162281.7		1.0	
12	0.0	162282.5		0.8	
13	0.0	162283.2		0.6	
14	4.5	162285.6		2.4	
15	4.1	162289.5		3.9	
16	159.9	162295.4		5.9	
17	162.3	162301.7		6.2	
18	186.3	162308.3		6.7	
19	179.4	162315.6		7.3	
20	188.4	162320.8		5.2	
21	198.1	162327.0		6.2	
22	192.7	162334.1		7.1	
23	178.4	162342.0		7.9	
KETERANGAN		AVG TONASE	AVG KWH	COST	JUMLAH VAR.COST
IDLE COST				Rp 978,221.25	
FIXED COST		4.3	3.2	Rp 3,103,904.57	Rp 18,939.44
RUNNING		183.6	6.7	Rp 18,939.44	

547 GROUP (FINISH MILL 7)					
JAM KE	FEEDRATE (t/h)	AKUMULASI DAYA (MWh)	KONSUMSI DAYA (MWh)	KET	
0	245.0	162258.0			
1	246.4	162265.4	7.5		
2	85.6	162271.8	6.4		
3	0.0	162275.8	4.0		
4	0.0	162277.0	1.2		
5	0.0	162278.2	1.2		
6	0.0	162278.9	0.7		
7	0.0	162279.5	0.7		
8	0.0	162280.3	0.7		
9	0.0	162281.0	0.8		
10	0.0	162281.8	0.8		
11	0.0	162282.5	0.8		
12	4.2	162284.3	1.8		
13	4.3	162288.2	3.8	FIXED COST	
14	169.6	162293.1	4.9		
15	197.9	162300.1	7.0		
16	226.9	162307.3	7.3		
17	231.3	162314.7	7.3		
18	229.6	162321.9	7.3		
19	228.8	162329.2	7.3		
20	227.2	162336.5	7.3		
21	224.5	162343.8	7.3		
22	226.0	162351.1	7.3		
23	226.5	162358.6	7.4		
KETERANGAN		AVG TONASE	AVG KWH	COST	JUMLAH VAR.COST
IDLE COST				Rp 824,343.75	
FIXED COST		4.2	2.8	Rp 2,747,812.50	Rp 19,665.85
RUNNING		227.6	7.3	Rp 19,665.85	

548 GROUP (FINISH MILL 8)					
JAM KE	FEEDRATE (t/h)	AKUMULASI DAYA (MWh)	KONSUMSI DAYA (MWh)	KET	
0	230.0	162257.9			
1	97.7	162264.4	6.6		
2	0.0	162268.9	4.4		
3	0.0	162270.0	1.1		
4	0.0	162272.0	2.0		
5	0.0	162272.4	0.4		
6	0.0	162273.5	1.2		
7	0.0	162274.2	0.6		
8	0.0	162275.1	1.0		
9	0.0	162276.0	0.8		
10	0.0	162276.8	0.9		
11	4.5	162278.1	1.3		
12	4.9	162281.9	3.7	FIXED COST	
13	165.9	162285.2	3.3		
14	189.8	162291.2	6.0		
15	230.9	162297.9	6.8		
16	227.6	162304.7	6.7		
17	233.6	162311.9	7.3		
18	229.4	162318.2	6.296875		
19	231.8	162326.1	7.9		
20	224.4	162333.8	7.7		
21	225.7	162341.1	7.3		
22	226.1	162348.6	7.4		
23	228.3	162355.7	7.2		
KETERANGAN		AVG TONASE	AVG KWH	COST	JUMLAH VAR.COST
IDLE COST				Rp 970,893.75	
FIXED COST		4.7	2.5	Rp 2,454,712.50	Rp 20,321.40
RUNNING		228.6	7.2	Rp 20,321.40	

(FINISH MILL 9)				
JAM KE	FEEDRATE (t/h)	AKUMULASI DAYA (MWh)	KONSUMSI DAYA (MWh)	KET
0	297.1	173113.3		IDLE COST
1	293.9	173120.1	6.8	
2	295.1	173128.0	7.9	
3	295.1	173134.3	6.3	
4	295.1	173141.9	7.6	
5	179.0	173148.3	6.4	
6	97.6	173155.1	6.8	
7	0.0	173159.9	4.8	
8	0.0	173160.6	0.7	
9	0.0	173161.1	0.5	
10	0.0	173161.9	0.8	
11	0.0	173162.7	0.8	
12	0.0	173163.6	0.9	
13	0.0	173164.5	0.9	
14	0.0	173165.4	0.9	
15	0.0	173166.3	0.9	
16	6.2	173171.2	4.9	
17	6.1	173175.1	3.9	FIXED COST
18	179.0	173181.8	6.7	
19	217.9	173188.9	7.1	
20	253.0	173196.2	7.3	
21	255.0	173203.0	6.8	
22	255.0	173210.5	7.5	
23	255.0	173218.1	7.6	RUNNING
KETERANGAN		AVG TONASE	AVG KWH	COST
IDLE COST				Rp 777,203.50
FIXED COST		6.1	4.4	Rp 4,292,938.00
RUNNING		254.5	7.3	Rp 11,505.87
JUMLAH VAR.COST				

Appendix 4

Cost Data Kiln 1-4

KILN 1							
Bulan	Tanggal	Feedrate (t/h)	MWh	Batubara (t/h)	IDO (kg/j)	Status	Keterangan
Feb-19	1	0	0.2	0	0	OVH	IDLE COST
	2	0	0.2	0	0	OVH	
	3	0	0.2	0	0	OVH	
	4	0	0.2	0	0	OVH	
	5	0	0.2	0	0	OVH	
	6	0	0.2	0	0	OVH	
	7	0	0.2	0	0	OVH	
	8	0	0.2	0	0	OVH	
	9	0	0.2	0	0	OVH	
	10	0	0.2	0	0	OVH	
	11	0	0.2	0	0	OVH	
	12	0	0.2	0	0	OVH	
	13	0	0.2	0	0	OVH	
	14	0	0.2	0	0	OVH	
	15	0	0.2	0	0	OVH	Trans. IDLE COST TO HEATING UP COST
	16	0	3.6	0	5026	Heating Up	HEATING UP COST
	17	0	13.1	0	35040	Heating Up	
	18	0	19.7	128	65664	Heating Up	
	19	0	4.5	118.4	11088	Heating Up	
	20	160	3	49.01	0	RUNNING	FIXED COST
	21					RUNNING	
	22					RUNNING	
	23	570	5.4	58	0	RUNNING	STEADY STATE
TOTAL COST			KET				
IDLE COST		Rp 195,400	Rp/Jam				
HEATING UP COST		Rp 1,218,162,227					
FIXED COST		Rp 36,257,800	Rp/Jam				
VARIABLE COST		Rp 20,629					

KILN 2							
Bulan	Tanggal	Feedrate (t/h)	MWh	Batubara (t/h)	IDO (kg/j)	Status	Keterangan
Jul-19	1	0	0.2	0	0	OVH	IDLE COST
	2	0	0.2	0	0	OVH	
	3	0	0.2	0	0	OVH	
	4	0	0.2	0	0	OVH	
	5	0	0.2	0	0	OVH	
	6	0	0.2	0	0	OVH	
	7	0	0.2	0	0	OVH	
	8	0	0.2	0	0	OVH	
	9	0	0.2	0	0	OVH	
	10	0	0.2	0	0	OVH	
	11	0	0.2	0	0	OVH	
	12	0	0.2	0	0	OVH	
	13	0	0.2	0	0	OVH	
	14	0	0.2	0	0	OVH	Trans. IDLE COST TO HEATING UP COST
	15	0	4.1	0	6319	Heating Up	HEATING UP COST
	16	0	16.1	0	47900	Heating Up	
	17	0	19.4	127.3	62917	Heating Up	
	18	0	4.7	119.1	13765	Heating Up	
	19	163	3.4	47.9	0	RUNNING	FIXED COST
	20					RUNNING	
	21					RUNNING	
	22	593	4.7	59.1	0	RUNNING	STEADY STATE
TOTAL COST			KET				
IDLE COST		Rp 195,400	Rp/Jam				
HEATING UP COST		Rp 1,343,323,102					
FIXED COST		Rp 35,893,800	Rp/Jam				
VARIABLE COST		Rp 20,665					

KILN 3								
Bulan	Tanggal	Feedrate (t/h)	MWh	Batubara (t/h)	IDO (kg/j)	Status	Keterangan	
Apr-20	1	0	0.2	0	0	OVH	IDLE COST	
	2	0	0.2	0	0	OVH		
	3	0	0.2	0	0	OVH		
	4	0	0.2	0	0	OVH		
	5	0	0.2	0	0	OVH		
	6	0	0.2	0	0	OVH		
	7	0	0.2	0	0	OVH		
	8	0	0.2	0	0	OVH		
	9	0	0.2	0	0	OVH		
	10	0	0.2	0	0	OVH		
	11	0	0.2	0	0	OVH		
	12	0	0.2	0	0	OVH		
	13	0	0.2	0	0	OVH		
	14	0	0.2	0	0	OVH		
	15	0	0.2	0	0	OVH		
	16	0	0.2	0	0	OVH	Trans. IDLE COST TO	
	17	0	4.3	0	3173	Heating Up	HEATING UP COST	
	18	0	17.3	0	41722	Heating Up		
	19	0	21.7	132	61194	Heating Up		
	20	0	4.5	118.4	10651	Heating Up		
	21	157	3.3	55.3	0	RUNNING	FIXED COST	
	22					RUNNING		
	23					RUNNING		
	24	549	6.1	61.1	0	RUNNING	STEADY STATE	
TOTAL COST			KET					
IDLE COST	Rp 195,400		Rp/Jam					
HEATING UP COST	Rp 1,226,948,710							
FIXED COST	Rp 40,828,100		Rp/Jam					
VARIABLE COST	Rp 17,040							

KILN 4								
Bulan	Tanggal	Feedrate (t/h)	MWh	Batubara (t/h)	IDO (kg/j)	Status	Keterangan	
Feb-20	1	0	0.2	0	0	OVH	IDLE COST	
	2	0	0.2	0	0	OVH		
	3	0	0.2	0	0	OVH		
	4	0	0.2	0	0	OVH		
	5	0	0.2	0	0	OVH		
	6	0	0.2	0	0	OVH		
	7	0	0.2	0	0	OVH		
	8	0	0.2	0	0	OVH		
	9	0	0.2	0	0	OVH		
	10	0	0.2	0	0	OVH		
	11	0	0.2	0	0	OVH		
	12	0	0.2	0	0	OVH		
	13	0	0.2	0	0	OVH	Trans. IDLE COST TO HEATING UP COST	
	14	0	2.9	0	7213	Heating Up	HEATING UP COST	
		0	11.3	0	35040	Heating Up		
	15	0	18	120	59664	Heating Up		
	16	0	4.5	115.1	11088	Heating Up		
	17	160	3	49.01	0	RUNNING	FIXED COST	
	18					RUNNING		
	19					RUNNING		
	20	570	5.7	60.5	0	RUNNING	STEADY STATE	
	21	570	5.7	60.5	0	RUNNING	STEADY STATE	
	22	570	5.7	60.5	0	RUNNING	STEADY STATE	
	23	570	5.7	60.5	0	RUNNING	STEADY STATE	
TOTAL COST			KET					
IDLE COST	Rp 195,400		Rp/Jam					
HEATING UP COST	Rp 1,173,386,658							
FIXED COST	Rp 36,257,800		Rp/Jam					
VARIABLE COST	Rp 25,490							

Appendix 5

Cost data Rawmill 1-4

RAW MILL 1					
TANGGAL	JAM KE	FEEDRATE (t/h)	Akumulasi Daya (MWh)	Konsumsi Daya (MWh)	Keterangan
	0	634	3412332.2		
	1	620	3412341.2	9.0	
	2	634	3412351.1	10.0	
	3	635	3412360.2	9.1	
	4	633	3412371.1	10.9	
	5	628	3412380.3	9.2	
	6	634	3412389.3	9.0	
	7	620	3412399.6	10.3	
	8	620	3412410.0	10.4	
	9	631	3412419.2	9.2	
	10	627	3412428.4	9.2	
	11	0.0	3412428.6	0.2	
	12	0.0	3412428.8	0.2	
	13	0.0	3412429.1	0.3	IDLE COST
	14	0.0	3412429.5	0.3	
	15	0.0	3412429.9	0.4	
	16	0.0	3412430.4	0.5	
	17	66	3412434.9	4.5	FIXED COST
	18	65	3412443.1	8.2	
	19	620	3412452.8	9.7	
	20	634	3412462.1	9.3	RUNNING COST
	21	635	3412472.3	10.2	
	22	633	3412481.9	9.6	
	23	628	3412491.3	9.4	
KETERANGAN		AVG TONASE	AVG KWH	COST	JUMLAH VAR.COST
	IDLE COST			Rp 325,666.67	
	FIXED COST	65.3	6.4	Rp 6,214,452.75	Rp 5,631.27
	RUNNING	632.5	9.6	Rp 5,631.27	

RAW MILL 2					
TANGGAL	JAM KE	FEEDRATE (t/h)	Akumulasi Daya (MWh)	Konsumsi Daya (MWh)	Keterangan
	0	631	2169232.2		
	1	643	2169241.8	9.6	
	2	0.0	2169242.3	0.5	IDLE COST
	3	0.0	2169242.7	0.4	
	4	0.0	2169243.0	0.3	
	5	0.0	2169243.4	0.4	
	6	0.0	2169243.8	0.4	
	7	0.0	2169243.9	0.1	
	8	0.0	2169244.2	0.3	
	9	0.0	2169244.6	0.4	
	10	0.0	2169244.9	0.3	
	11	0.0	2169245.4	0.5	
	12	0.0	2169245.8	0.4	
	13	0.0	2169246.2	0.4	
	14	95.6	2169248.5	2.3	FIXED COST
	15	120.6	2169250.9	2.4	
	16	633	2169261.4	10.5	
	17	628	2169271.0	9.6	
	18	630	2169280.7	9.7	RUNNING COST
	19	634	2169290.8	10.1	
	20	629	2169301.3	10.5	
	21	634	2169311.6	10.3	
	22	653	2169322.1	10.5	
	23	654	2169331.9	9.8	
KETERANGAN		AVG TONASE	AVG KWH	COST	JUMLAH VAR.COST
	IDLE COST			Rp 359,971.58	
	FIXED COST	108.1	2.4	Rp 2,295,950.00	Rp 14,362.85
	RUNNING	639.0	10.2	Rp 14,362.85	

RAW MILL 3					
TANGGAL	JAM KE	FEEDRATE (t/h)	Akumulasi Daya (MWh)	Konsumsi Daya (MWh)	Keterangan
	0	631	2319232.2		
	1	643	2319205.4	-26.8	
	2	655	2319215.0	9.6	
	3	657	231924.6	9.6	
	4	631	2319234.2	9.6	
	5	643	2319240.8	6.6	
	6	0.0	2319243.9	3.1	
	7	0.0	2319243.9	0.0	
	8	0.0	2319244.2	0.3	
	9	0.0	2319244.6	0.4	
	10	0.0	2319244.9	0.3	
	11	0.0	2319245.4	0.5	
	12	0.0	2319245.8	0.4	
	13	0.0	2319246.2	0.4	
	14	55.6	2319248.5	2.3	
	15	67.1	2319250.9	2.4	
	16	633	2319261.4	10.5	
	17	628	2319271.0	9.6	
	18	630	2319280.7	9.7	
	19	634	2319290.8	10.1	
	20	629	2319301.3	10.5	
	21	634	2319311.6	10.3	
	22	653	2319322.1	10.5	
	23	654	2319331.9	9.8	
KETERANGAN					
	AVG TONASE	AVG KWH	COST	JUMLAH VAR.COST	
IDLE COST			Rp 662,082.37		
FIXED COST	61.4	2.4	Rp 2,295,950.00	Rp 13,200.44	
RUNNING	639.0	10.2	Rp 13,200.44		
RAW MILL 4					
TANGGAL	JAM KE	FEEDRATE (t/h)	Akumulasi Daya (MWh)	Konsumsi Daya (MWh)	Keterangan
	0	634	1162335.2		
	1	620	1162341.8	6.6	
	2	0.0	1162342.3	0.5	
	3	0.0	1162342.7	0.4	
	4	0.0	1162343.0	0.3	
	5	0.0	1162343.4	0.4	
	6	0.0	1162343.8	0.4	
	7	0.0	1162343.9	0.1	
	8	0.0	1162344.2	0.3	
	9	0.0	1162344.6	0.4	
	10	0.0	1162345.9	1.3	
	11	65.6	1162348.5	2.6	
	12	124	1162351.0	2.5	
	13	620	1162357.5	6.5	
	14	634	1162367.3	9.8	
	15	635	1162368.0	10.5	
	16	633	1162378.4	10.4	
	17	628	1162388.0	9.6	
	18	630	1162397.7	9.7	
	19	631	1162407.8	10.1	
	20	629	1162418.3	10.5	
	21	634	1162428.4	10.1	
	22	633	1162438.9	10.5	
	23	634	1162448.5	9.5	
KETERANGAN					
	AVG TONASE	AVG KWH	COST	JUMLAH VAR.COST	
IDLE COST			Rp 447,395.44		
FIXED COST	94.8	2.6	Rp 2,491,350.00	Rp 13,686.12	
RUNNING	632.1	10.1	Rp 13,686.12		