Production planning of crude palm oil: a study case at X Co.

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Abstract. Increasing productivity of palm oil company could be done by solving problems in the company such as non-optimal production quantity, over range of production cost, stagnation of production activity, and unplanned of production condition. Those problems can be solved by managing production planning. The purpose of this research is to focus on production planning by determining the optimal production planning, determining the best production condition, and determining criticality of crude palm oil components process. Determination of optimal production planning using goal programming shows five goals formulation: minimize the production cost of crude palm oil (CPO) and fresh fruit bunch (FFB), minimize the deficiency of FFB, maximize production to fulfill demand capacity and maximize the number of FFB processed into CPO. The result of scenario simulation shows that by increasing the productivity of palm oil plantation (11-12\%), increasing the yield of CPO (0.21-0.23\%), decreasing the effect of maturity rate of FFB (2.5\%), and fulfill the requirement of number of truck could decrease free fatty acids by 2.43\% and increase number of production by 8408247 in January 2020. The result of the analysis of the assessment of critical components of the palm oil production process results in four classifications. The four classifications of equipment criticality rating (ECR) respectively, ECR 1 at station of boiler, thrasher, and digester, ECR 2 at station of sterilizer, ECR 3 at station of clarification and engine room, and ECR 4 at receiving station, fat pit, and water treatment.

Keyword: CPO, ECR, system dynamic, goal programming, production planning

1. Introduction
Oil palm is the largest agriculture commodity in Indonesia. The most valuable product from oil palms is Crude Palm Oil (CPO). Crude palm oil is used for production in the food and non-food industry. In non-food sector CPO is commonly used as bioenergy and consumer goods while in food sector CPO is commonly used as basic ingredient to make snack, cake, and others derivative products. In 2018 palm oil production reached 47.61 million tonnes. This production increased compared to production in 2017, which is 42.04 million tonnes only. The export value of crude palm oil increase to 20.34 billion dollar with a 26\% increase compared to the export value in 2016 [1]. State-owned enterprises have a simple role while private companies have a bigger role in this competition. Based on those data, state owned enterprise has to take a role to increase crude palm oil production in Indonesia.

To solve those challenges, the industry has to increase its competitiveness by producing good quality product and being able to fulfil customer needs on time. Those strategies can be done by making good production planning. Production planning is a tool used by company management to reach out the target and increase the activity of the management system [2]. Production planning is important for
manufacture industries because the cost for energy consumption, product line maintenance and raw materials are very high [3]. Those problem can be solved by making effective management policy with optimization of production planning.

Production planning goals are to optimizing the production of crude palm oil and decrease the discrepancy between demand and production quantities. The discrepancy between demand and production quantities may cause overproduction or lack of raw material. That is why estimating or forecasting the optimum quantity of crude palm oil production is needed. The optimum production can be estimated depending on the sources of the company. A good production planning can produce a product with good quality that meets customer needs. The quality of product depends on the quality of raw materials and machine condition [4]. Demand forecasting can be done with ARIMA (Auto-Regressive Integrated Moving Average) and will be used as one of the objective constraints in goal programming.

The quality of crude palm oil depends on how the company handle and control the flow of product and raw materials. CPO quality variation is caused by supply chain activity such as transportation, production, and post-harvest. By maintaining good supply chain activity, it can improve the quality of CPO [5]. Maintaining CPO quality can be done by formulating the best production model using a dynamic system approach. The dynamic system deals with complex system by observing the change of variables from time to time [6].

2. Literature review

2.1. Production planning

Production planning is a common tool used by company management to achieve company objectives. It is related to production activity factors, such as quantity, quality, cost and time. The objective is to improve production efficiency by maximizing resources utilization. Production planning also maintains product quality to fulfill customer expectation. Production efficiency and customer satisfaction can be reached by managing good production planning policy [7]. Production activities must be well controlled and scheduled to achieve company objectives. The functions of production planning are: estimate production quantity, estimate production cost, optimizing production flow, and production scheduling [4].

2.2. Goal programming

Goal programming is one of the mathematical methods used for production optimization planning. Goal programming method can accomplish contradictory problems that make it different from linear programming. Goal programming is used to achieve objectives in various conditions or constraints. This method is used in the agriculture sector because of the complex constraint such as labourer, weathers, and electricity [8]. Mathematical model in goal programming describes the company condition more realistically than other methods [9]. That is why goal programming is the most suitable method.

2.3. System dynamic

The dynamic system is one of the significant tools of system thinking with an ability to capture interactions among wide range of variables in the system. The dynamic system can also predict trends of variable interactions over a period of time [10]. The key features of a dynamic system are the ability to deal with dynamic changes overtime, using data and testing it with different scenarios condition without implementing it [11]. Therefore, dynamic system is used as a method to arrange the best condition to produce crude palm oil.

3. Methodology

3.1. Framework
The increase of crude palm oil demand in the local and international market has made the company to increase its productivity and activity. Increasing productivity can be done by solving the identified problems in the company. The identified problems in the company consist of the poor quality of crude palm oil, the production of crude palm oil is not optimal yet, and the production machine already aged. Managing the optimal production can be done using goal programming method. The poor quality of crude palm oil can be solved by using a dynamic system approach. While to rate the criticality of production component can be done by using the ECR method. The research framework diagram can be seen in Figure 1.

**Figure 1.** Research framework.

3.2. **Analysis procedure**

3.2.1. **Demand forecasting.** Demand forecasting is measured using ARIMA (Auto-Regressive Integrated Moving Average). ARIMA is a method developed by George Box and Gwilym Jenkins and is a part of forecasting method for time series analysis. ARIMA will measure the best pattern of source data. The source data is the amount of historical data used as an input. The advantage of this method is the accuracy for the forecasted result in short time period [12]. The model formula for ARIMA consist of MA (moving average) model, AR (Auto regressive) model or combination of both models. Stages to predict ARIMA model are 1). Model identification using historical data to predict possible ARIMA model, 2). Parameter estimation measured using Minitab Software by comparing T value from models and T value from the table, 3). Model verification, this step used to choose the best ARIMA model [13].
3.2.2. Optimum production planning. The amount of optimum production planning is measured using goal programming method. This method describes the company goals into mathematical formulas. Stages to formulate goal programming formulas are: 1) Define decision variables, decision variables are a factor that can be controlled to reach optimum production and fulfill the criteria of constraints, 2) Define goal constraints, goal constraint is a constraint that detains to reach the company goal, 3) Formulate goal functions, goal function is a function measured using deviation variables [14]. The decision variables are identified based on production system in the company. The identified decision variables are 
\[ X_j = \text{The quantity of CPO production for each month in 2019, for } j = 1,2,3,4,5,6,7,8,9,10,11,12 \]
\[ X_i = \text{The quantity of FFB production for each month in 2019, for } i = 1,2,3,4,5,6,7,8,9,10,11,12 \]
The goal constraints are defined based on the problems that occur in the company. The identified constraints are: FFB production cost, CPO production cost, CPO demand target, the availability of FFB in core garden target, FFB processing target. The objective function is formulated based on the company goal constraints. The model of objective functions is to minimize deviation for each goal constraint to meet the company targets. The identified objective functions can be seen in Equation 3.1.
\[
\text{Min } Z = d_{1t} + d_{2t} + d_{3t} + d_{4t} + (d_{5t} + d_{5t}) \quad \text{for } t = 1,2,3,4,5,6,7,8,9,10,11,12 \quad (3.1)
\]
where:
\[ i = \text{Deviation variables from each goal constraints} \]
\[ d^+ = \text{Positive deviation value of goal constraints and real condition} \]
\[ d^- = \text{Negative deviation value of goal constraints and real condition} \]

3.2.3. Dynamic system. Dynamic system is a method to solve complex problems that appear caused by cause-effect relation between variables in the system. Dynamic system modelling is made using transportation and production activities. Alteration between the variables that happened time to time shows a pattern of the system [15] Storage activity does not include in modelling system because the effect is not significant [16]. Dynamic system model is simulated using an aggressive scenario, moderate scenario, slow scenario. The best simulated scenario is used as a process condition plan.

3.2.4. Criticality Value of Production Component. The criticality value of production component is a method to identify the critical value of the production component so the result can be used as an input for maintenance scheduling. The method that can be used to value the criticality is ECR (Equipment Criticality Rating). ECR can determine multi criteria problems [17]. Each criteria has its own indicators and weight based on the interview result. ECR value is obtained by multiplying indicators form each criteria with criteria weight. The ECR mathematical formula can be seen in Equation 3.2.
\[
\text{ECR} = \sum_{i=1}^{k} b_i \times N_i \quad (3.2)
\]
where:
\[ b_i : \text{weight for each criteria} \]
\[ N_i : \text{value for each indicator} \]

4. Result and discussion

4.1. Demand forecasting of crude palm oil
The accuracy of demand forecasting can minimize error in production such as overproduction or lack of production. Demand forecasting is measured using Box-Jenkins method (ARIMA). The advantage is that the forecast result of this method has a high accuracy to forecast a short time period [18]. Historical data of CPO demand in the past 5 years are used as the input for modelling the ARIMA. The stages to measure the ARIMA model are 1). Identification of the ARIMA model, 2). Estimation of the ARIMA model, and 3). Verification. Autocorrelation function, partial autocorrelation function and differencing of input data are used to identify the ARIMA model. Next step is to estimate the best ARIMA model.
The best ARIMA model can be estimated by measuring the MS (Mean Square) value from three identified models. The model identification and estimation result can be seen in Table 1.

| No | ARIMA Model       | Parameter | MS Value |
|----|-------------------|-----------|----------|
| 1  | ARIMA (1,1,0)     | Significant | 843333   |
| 2  | ARIMA (1,1,1)     | Significant | 679218   |
| 3  | ARIMA (0,1,1)     | Significant | 709135   |

The best ARIMA model is ARIMA (1,1,1) with the lowest MS value. Furthermore ARIMA (1,1,1) has a significant value of MA and AR. The last step is to forecast the CPO demand using the best ARIMA model with Minitab Software. The result for demand forecasting in 2019 can be seen in Table 2.

| Month Period | Demand forecasting (Ton) |
|--------------|--------------------------|
| January      | 5011.08                  |
| February     | 4750.63                  |
| March        | 4715.63                  |
| April        | 4712.43                  |
| Mei          | 4713.72                  |
| June         | 4715.64                  |
| July         | 4717.65                  |
| August       | 4719.68                  |
| September    | 4721.70                  |
| October      | 4723.73                  |
| November     | 4725.75                  |
| December     | 4727.78                  |

4.2. Optimum production planning
In the optimization technique, the optimal result can be measured by formulating problems based on the real constraint that happened in the company. The purpose of goal programming model is to minimize the deviation between the company objectives and formulated into objective function. Decision variables for the model consist of optimal crude palm oil and fresh fruit bunch production in 2019 with month interval.

The optimal production measured the objective function formulas with Lingo software. Based on the result of lingo software, the optimal production of CPO and FFB can be seen in Table 3.

| Month  | CPO Production Variable | CPO Production (Ton) | FFB Production Variable | FFB Production (Ton) |
|--------|--------------------------|----------------------|-------------------------|----------------------|
| January| X1                        | 5011.08              | X13                     | 12671.80             |
| February| X2                       | 4750.63              | X14                     | 13778.71             |
| March  | X3                        | 4715.63              | X15                     | 15960.29             |
| April  | X4                        | 4712.43              | X16                     | 13953.36             |
| Mei    | X5                        | 4713.72              | X17                     | 18805.68             |
The result of optimal production is not verified yet. The result can be verified using the accessibility of the objective functions. The accessibility of the result is measured by calculating the deviation value from lingo software. Deviation value of the objective function must be zero, to show that the function already fulfilled the constraint. The accessibility of the objective functions can be seen in Table 4. The objective function of minimizing FFB deficiency in core palm oil plantation has not achieved yet, with the result of deficiency is 597.69 ton. Because one function has not achieved the objectives, the sensitivity analysis used to measure allow deficiency. Sensitivity analysis is used to measure the maximum deficiency and increment of function before the function lost the optimal solution. Based on the sensitivity analysis the deficiency that can be permitted is 597.69 ton. With the result that the formulation of goal programming model can be used for all the objectives.

| Objective Functions                                    | Deviation Value | Result   | Description   |
|-------------------------------------------------------|-----------------|----------|---------------|
| Minimize CPO production cost                          | DP_{1,12}       | 0.000000 | Achieved      |
| Minimize FFB production cost                          | DP_{13,24}      | 0.000000 | Achieved      |
| Maximize CPO production to fulfil customer demand     | DM_{25,36}      | 0.000000 | Achieved      |
| Minimize FFB deficiency in core palm oil plantation   | DM_{37,48}      | 597.69   | Not achieved  |
| Maximize the processing of FFB                        | DP_{40,60}      | 0.000000 | Achieved      |
|                                                      | DM_{49,60}      | 0.000000 |               |

### 4.3. System dynamic model

The quantity and quality of FFB as raw material for the palm oil industry need to be maintained. There are three core sub-systems in post-harvest activity i.e. harvesting, transportation, and production. Those sub-system has an interconnection between them. If one of the sub-systems is delayed, it will affect the others [19]. Storehouse does not significantly affect the level of FFA in crude palm oil [20]. Therefore, the dynamic model only consists of transportation and production sub-systems. The assumptions for this model were developed based on previous research [21] i.e. 1. CPO yield rate scenario value will stop or be constant if the value of CPO yield reach 25 % each month, 2. Impact of harvesting scenario will be stop or constant if the value of FFA in CPO reach 2.16 % each month, 3. Palm oil plantation productivity rate will stop or be constant if the value of palm oil productivity reach 2500 kg/(month*ha), 4. The FFA value is a function of FFB composition and truck availability, 5. Maximum increasing of productivity rate of palm oil plantation is 2947.08 kg/(mo*ha), 6. Maximum increasing of CPO yield is 24% from total FFB used as input, 7. Maximum decreasing of FFA rate is 2.34%.

Production model only consists of one SFD (Stock Flow Diagram) i.e. amount of FFB supply. SFD has an inflow and outflow. FFB input as an inflow, CPO and CPO loss as an outflow. Flow diagram of CPO production depends on two variables i.e. amount of FFB input and expected CPO yield. Flow diagram of FFB input depends on the amount of FFB transported from oil palm plantation. Flow diagram of FFA level in CPO depends on three variables i.e. impact of the ripe criteria of FFB (Ripe fraction 1,
ripe fraction 2, ripe fraction 3, ripe fraction 4, and raw FFB), the impact of truck availability, and amount of CPO. Production diagram can be seen in figure 2.

![Diagram model of CPO production](image)

**Figure 2.** Diagram model of CPO production.

The transportation model only consists of one SFD i.e. amount of TBS trip. The inflow and outflow in SFD are actual trip and maximum trip. Amount of trip flow diagram depends on the amount of daily FFB production from each palm oil plantation. Maximum trip flow diagram depends on transportation cycle time from palm oil plantation to plant. Cycle time consist of loading time, unloading time, the velocity of truck, palm oil plantation range, and queuing time. The required number of truck depends on maximum trip availability and amount of trip from each palm oil plantation needed. Transportation diagram can be seen in Figure 3.
4.4. Analysis of system dynamic model behaviour

Analysis of dynamic model behaviour objective is to modify the value of parameters. The modification of parameters value will affect the result of the model. The difference between the model result from each parameter can be used to indicate transformation that might happen. The modification of parameters follows the company RKAP. The modification parameters are CPO yield, palm oil palm plantation productivity, the impact of harvesting criteria, and truck availability. Parameters modification can be done with three scenarios i.e. Aggressive, moderate, and slow. The policy of scenarios can be seen in Table 5.

| Scenarios   | Oil palm plantation productivity (Kg/ha) | CPO yield (%) | Impact of harvesting criteria (%) | Truck availability |
|-------------|-----------------------------------------|---------------|----------------------------------|--------------------|
| Aggressive 1 | + (11-12%)                              | + (0.21-0.23%) | -2.5%                            | Sufficient         |
| Aggressive 2 | + (11-12%)                              | Normal        | -2.5%                            | Sufficient         |
| Aggressive 3 | Normal                                  | + (0.21-0.23%) | -2.5%                            | Sufficient         |
| Moderate    | Normal                                  | Normal        | -2.0 %                           | Sufficient         |
| Slow        | - (11-12%)                              | + (0.21-0.23%) | +2.5%                            | Insufficient       |

Each scenario is simulated using Powersim Studio 10. The result of the simulation is the amount of CPO production and FFA level of CPO. The output from software can be seen in figure 4 for CPO production and figure 5 for FFA level for CPO. Aggressive 1 and aggressive 3 scenario indicate the best result value for CPO production. CPO production increased from 4146874 kg/month in April 2019 to 8408247 kg/month in January 2020 using aggressive 1 scenario. While using aggressive 3 scenario, CPO production increase from 4098717 kg/month in April 2019 to 8156446 kg/month in January 2020. The CPO production simulation increased significantly compared to previous months. Meanwhile the best result for FFA level is simulated using aggressive 1, aggressive 2, and aggressive 3 scenarios. The
FFA level decreased from 2.46% in April 2019 to 2.43% in January 2020 using aggressive 1 and 2 scenarios. While using aggressive 3 scenario the FFA level decrease from 2.46% in April 2019 to 2.40% in January 2020. The best scenario for a dynamic model is aggressive 1, because it has the highest CPO production and the difference of FFA level compared to other scenarios is just 0.03%. Therefore, the best scenario is aggressive 1.

![Figure 4. Simulation result for CPO production.](image)

![Figure 5. Simulation result for FFA level.](image)

4.5. Critically value of production component

Machine control and maintenance are measured by valuing the criticality from each production station using equipment criticality rating. Each production station is classified based on criticality rate. The classification will simplify maintenance procedure for each production station. ECR result will be used as one of the criteria to calculate maintenance index. Equipment criticality value is measured using a multicriteria approach i.e. safety, production, reliability, spare availability, frequency of failure, and
The applicability of condition monitoring technique [20]. The result of equipment criticality value can be seen in Table 6.

| Criteria                          | X<sup>a</sup> | X<sup>b</sup> | X<sup>c</sup> | X<sup>d</sup> | X<sup>e</sup> | X<sup>f</sup> | X<sup>g</sup> | X<sup>h</sup> | X<sup>i</sup> |
|----------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Safety                           | 4.09          | 13.31         | 12.29         | 16.38         | 9.22          | 9.22          | 15.36         | 6.14          | 9.22          |
| Production                       | 0.00          | 0.00          | 16.05         | 14.83         | 9.84          | 0.00          | 0.00          | 0.00          | 5.85          |
| Frequency of failure             | 0.00          | 24.98         | 24.98         | 24.98         | 24.98         | 24.98         | 24.98         | 24.98         | 0.00          |
| Spare availability               | 14.83         | 7.41          | 14.83         | 0.00          | 14.83         | 0.00          | 0.00          | 0.00          | 14.83         |
| Reliability                      | 0.00          | 0.01          | 0.03          | 0.14          | 0.21          | 0.07          | 0.44          | 0.03          | 0.00          |
| Applicability of condition       | 1.55          | 3.11          | 6.22          | 3.11          | 3.11          | 0.62          | 3.11          | 0.62          | 1.55          |
| monitoring technique             |               |               |               |               |               |               |               |               |               |
| ECR Value                        | 20.47         | 48.83         | 74.40         | 59.45         | 62.18         | 34.89         | 43.89         | 31.78         | 31.45         |

<sup>a</sup>Reception, <sup>b</sup>Sterilizer, <sup>c</sup>Thresher, <sup>d</sup>Digester, <sup>e</sup>Boiler, <sup>f</sup>Engine room, <sup>g</sup>Clarifier, <sup>h</sup>Water treatment, <sup>i</sup>Fat pit

ECR value is classified into four classification i.e. ECR 1 (Very critical), ECR 2 (Critical), ECR 3 (Quite critical), and ECR 4 (Not critical). Production station classified as ECR 1 are thresher, digester, and boiler. Those production stations are classified as ECR 1 because production activity will stop if the equipment from those station is broken and maintenance cost is high. Production station classified as ECR 2 is sterilizer. This production station is classified as ECR 2 because if the component is broken, it will impact the acceptance of palm oil. Production station classified as ECR 3 are engine room and clarifier. Those production stations are classified as ECR 3 because they have a small impact on production failure. Production stations classified as ECR 4 are reception, fat-pit, and water treatment. Those production stations are classified as ECR 4 because if the component is broken, it will not impact the production of CPO.

The higher ECR value indicates a more critical production station. If the production station is more critical indicate that the stations need intense maintenance and control system. The better maintenance and control system will reduce the risk of production failure.

### 4.6. Managerial implication

Production planning for the x company is based on problems that have been identified. Problems that are identified from the company i.e. production stagnation, non-optimal production, over range of production cost, and unplanned production condition to reach desired FFA level. Non-optimal production and over range of production cost can be solved by planning the optimal production of CPO and FFB using goal programming. Production stagnation can be solved by evaluating the criticality of CPO production using ECR. And unplanned production condition to reach desired FFA level can be solved by planning dynamic model using dynamic system.

The results from optimal production planning are the amount of FFB and CPO that will be produced each month in 2019. The improvement opportunity that can be performed based on the analysis result is the improvement of crop rotation. Improvement in a crop rotation can minimize the lack of FFB supply. Furthermore, the improvement that can be performed based on the result of a dynamic model in transportation sub-system i.e. rearrange the desired number of trucks from each oil palm plantation and change the box type for the truck from wood type to iron type. Those improvements can decrease the FFA level of FFB.
Improvement that can be performed based on the result of a dynamic model in production sub-system is rearrange the FFB composition based on company regulation. This improvement can decrease the FFA level of CPO. Improvement that can be performed based on the ECR result are compiled maintenance and control strategy for each production station. This improvement can decrease production stagnation and engine downtime.

5. Conclusions and recommendation

5.1. Conclusions
Increasing productivity of Crude Palm Oil could be done by solving problems of the company. Solving the problem of the company can be done by managing production planning. Demand forecasting to maximize production objective using ARIMA. The result for forecasting model is ARIMA (1,1,1). Determination of optimal production planning using goal programming shows five goals formulation there are minimizing the production cost of CPO and FFB, minimize the deficiency of FFB, maximize production to fulfil demand capacity, and maximize the number of FFB processed into CPO. Production condition planning uses dynamic system by arranging dynamic model from production and transportation sub system. The result of scenario simulation shows that by increasing the productivity of palm oil plantation (11-12%), it increases the yield of CPO (0.21-0.23%), decreases the effect of maturity rate of FFB (2.5%), and fulfill the required number of truck could decrease free fatty acids by 2.43% and increase the number of production by 8408247 in January 2020. The result of the analysis of the assessment of critical components of the palm oil production process results in four classifications. The four classifications of ECR respectively are: ECR 1 at the station of boiler, thrasher, and digester, ECR 2 at the station of sterilizer, ECR 3 at the station of clarification and engine room, and ECR 4 at the receiving station, fat pit, and water treatment.

5.2. Recommendations
The further research that can be conducted on a broader analysis substance including post-harvest process in a dynamic system. By including post-harvest activity in a dynamic system, it will affect the FFA level of FFB and CPO and encompass all activity in the field. By making a general dynamic model that can be used continuously from time to time. Furthermore, a broader research that can be conducted i.e. truck scheduling and maintenance schedule. Truck scheduling plan can be done based on the optimal quantity of FFB from each oil palm plantation. So that lack of truck trip will not affect the company productivity. Maintenance scheduling is a further analysis of equipment criticality value. Based on the criticality from each engine, it will be easier to make maintenance scheduling policy.

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