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Optimization of the Crude Palm Oil Supply Chain Using a Mixed Integer Linear Programming Model

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Abstract: The Crude Palm Oil (CPO) industry is a significant industry with a well-established network system, also known as a supply chain. The CPO industry is involved in the production, processing, and distribution of palm oil, which is derived from the fruit of the oil palm tree. In this paper it is considered that the CPO mill industry does not have its own oil palm plantations, so FFB (fresh fruit bunches) are supplied by nearby smallholder oil palm plantations, both private and government. Because the supply of FFB is limited, management must decide which plantations will meet the demand, therefore the Crude Palm Oil industry operates through a more complex network system. This paper addresses a discrete optimization model that is expected to be a useful planning for the Crude Palm Oil (CPO) industry incorporating selecting the oil palm plantation. An improved feasible neighborhood search approach is proposed to solve problems.

Keywords: Supply chain optimization, Crude Palm Oil, Mixed Integer Linear Programming, Feasible neighborhood search.

1 Introduction

Indonesia is home to some of the world's largest plantation lands, including palm oil plantations. Since the development of the plantation sector in Indonesia, palm oil has been predicted to be the agricultural sector's star, particularly in plantations. Furthermore, when compared to other plantation commodities such as cocoa, rubber, coffee, nutmeg, pepper, and others, this commodity has the best prospects. This can be seen in the growth of the area/producing plants, which increases year after year, as well as government policies that strive to keep this commodity in the domestic and international markets [1].

Palm oil is produced in large quantities as crude oil; in Indonesia alone, palm oil is produced by producers with 40.59% of cultivated land area by smallholder plantations, 54.43% by private large plantations, and 4.98% by large state plantations of the 14.03 million ha of total oil palm land. The crude palm oil (CPO) industry is very profitable for its producers for a variety of reasons, including high profit margins, high international demand due to an increase in the world's population of 9.6 billion by 2050, a higher productivity level than other vegetable oils, and ongoing global biofuels campaigns [2]. A mixed integer linear programming model for integrated supply chain problems is discussed in this study. The Mixed Integer Linear Programming (MILP) model approach is used to solve the mathematical programming model. [3] exhibited a model of an integrated supply chain system that includes raw material suppliers, multiple factories, distribution centers, warehouses, and customers. [4] looked into the more complicated case of an integrated supply chain. They examined a supply chain scenario that included several feed mills, plantations, and products. [5] discussed a mixed integer linear programming model that incorporates production, distribution, and marketing and includes a factory and a point of sale [27].

Furthermore, the production results from processing FFB (fresh fruit bunches) into CPO and Palm Kernel at PT Perkebunan Nusantara (PTPN) have not been properly managed. This can also complicate decisions regarding the acceptance of FFB and the distribution of CPO and Palm Kernel per day [6]. Because transportation is one of the factors influencing the smooth supply chain of CPO, we require a system that can control oil palm plantations and processing by utilizing information system technology that integrates regional mapping and information data in a complete application for companies that will facilitate decision-making both for planning and maintenance. Because this is not a finished product, the CPO industry can be a part of a business that requires a network system. The supply chain system is a network system that performs the functions of procuring materials, processing these materials into

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semi-finished products, and distributing intermediate products/semi-finished goods to customers. All of these facilities are used to meet the needs of customers. The supply chain challenge is to produce the correct product, in the correct quantity, in the correct location, at the correct time, and at the correct cost. Because of the complexity of the supply chain decision-making process, modelling techniques that can help identify and implement strategies for designing high-performance supply chain networks are required [7], [8]. The large-scale nature of the supply chain network, the hierarchical structure of decisions, the randomness of various inputs and operations, and the dynamic nature of interactions among supply chain elements are the primary reasons for using the model for decision-making [9]. As a result, the optimization model has advanced in supply chain planning and management. Because supply chain decision-making processes are complex, modelling techniques that can assist in identifying and implementing strategies for designing high-performance supply chain networks are required [7], [10], [11].

[3] presented a model of an integrated supply chain system that included raw material suppliers, several factories, distribution centers, warehouses, and customers. [4] investigated the more complex case of an integrated supply chain. They look at supply chain scenarios involving multiple feed mills, plantations, and products. So, a mixed integer linear programming model that includes factories and points of sale and integrates production, distribution, and marketing. Their research explains how to include the necessary features for supply chain management.

[12] discussed another CPO production plan that is only taken into account during the milling process. They believe the fuzzy logic approach provides a more straightforward mechanism for determining the relationship between processing variables and the amount of CPO and palm kernel loss. [13] developed a supply and demand optimization model for CPO production planning. Their model will determine which CPO market to select as well as how much demand to serve in the chosen market. [14] presented a multi-objective optimization model for planning sustainable CPO production while accounting for uncertainty in financial risk reliability.

The CPO manufacturing process can be traced back to the milling of FFB into palm oil. A series of steps is usually involved in the process of producing and consuming semi-finished products. FFB, intermediate products, and CPO end products must all be inventoried in order for people to produce and consume them at various times and levels of time. It should be noted that the time required to keep FFB in stock for palm oil is extremely short. A CPO milling company, for example, has a mill but no oil palm plantations of its own. Companies must purchase FFB from public oil palm plantations in order to produce CPO in their factories.

2 Method

Related Work

The strategic plans of palm oil supply chain incorporate interconnections between the plantation as suppliers, milling, refining, and customer, which it depicts the relationship between corporate organizations into a chain [15], [16]. The supply chain for the palm oil industry is extremely intricate. In the palm oil industry, the business operations begin with the plantation, continue via the processing industries (such as the refinery), are then dispersed to the industry of product developers (who create a variety of products), and finally reach the end users (who are the customers) [17]–[19].

The transformation of crude palm oil into intermediate or finished products is done in batches as part of the activities that take place in the refinery. The processing of palm oil refineries is utilized by a wide variety of industries. After that, the result of this processing will be disseminated to the customer both at the local market industries that produce completed goods of palm oil products and at the international market through the use of the port center as a shipping service. The handling and storage of commodities in the form of liquid or oil is necessary for distribution of crude palm oil so that it can be processed in the refinery sector. As a result of the fact that the end product of refining processes might take the form not only of a liquid but also of a solid, such as specialized fats, a storage strategy is required for both the distribution of completed goods and the logistical arrangements involved in their production. When it comes to the distribution of the product to the end user, handling procedures for solid and liquid forms of the product are distinct [20]. As a result, it requires an analysis tool that can facilitate integration throughout the supply chain. Integration will be given priority in the planning stage of supply chain operations for the palm oil industry. According to [21], the necessity for integration increases as a result of the presence of uncertainties and complicated operating characteristics.

The supply chain is one of many components of the CPO industrial system. The system’s components include raw material suppliers, CPO producers, domestic consumers, and foreign consumers. The supply chain system, which is divided into three supply chain sub-models, namely suppliers, producers, and consumers, is depicted in Figure 1 below.

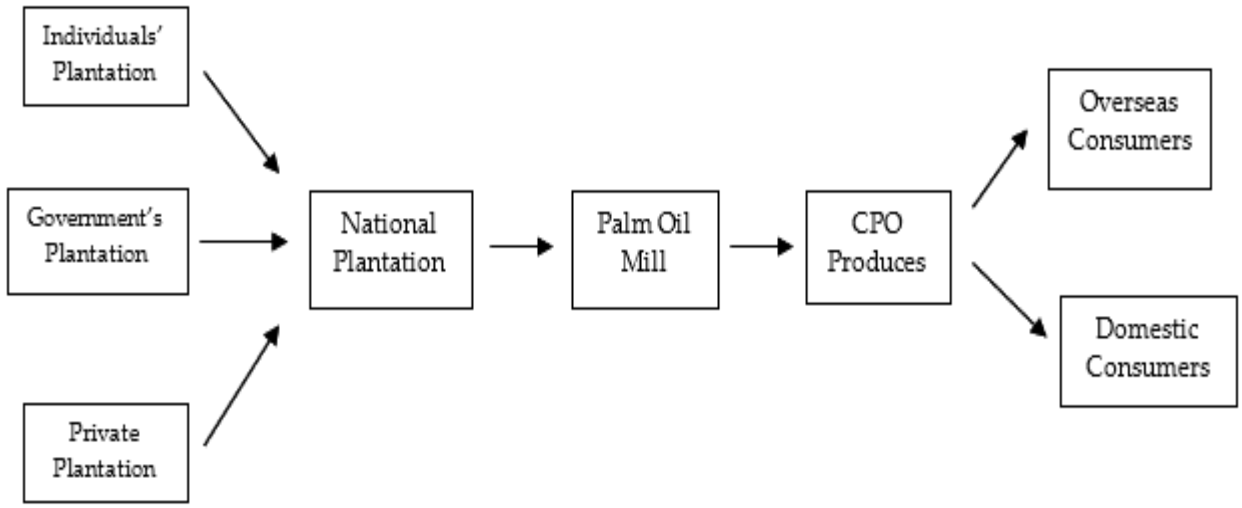

Fig. 1: CPO Supply Chain

The supply chain challenge is to produce the appropriate product, in the suitable amount, at the right location, at the exact right time, and at the cheapest rate. Because supply chain decision-making processes are complex, modelling techniques that can assist in identifying and implementing strategies for designing high-performance supply chain networks are required [7], [10], [11]. The model is used for decision making for several reasons, including the large-scale nature of the supply chain network, the structure of the decision hierarchy, the randomness of various inputs and operations, and the dynamic nature of interactions between supply chain elements [10]. In supply chain planning and management, optimization models have advanced to a high level of sophistication [6], [9], [22], [23].

Problem Description

The issue that will be raised is how to design a supply chain management system from the FFB milling process taken from oil palm plantations, both government and non-government, to the management of palm oil mills into CPO and delivery of CPO to the community (customers) using the MILP Model, which can minimize production and transportation costs [24]–[26].

In this case, the CPO enterprise must make the following optimal decision:

1. Which palm oil plantation should FFB be purchased from?
2. The quantity of FFB to be purchased from a specific oil palm plantation.
3. The amount of CPO that will be produced.
4. The amount of CPO that will be sent to each customer.
5. The amount of waste generated during the milling process is low enough to reduce overall operational costs.
6. The amount of FFB transported from the chosen oil palm plantation to the mill must be delivered on time.

There are several assumptions to consider, which are as follows:

1. FFB from palm oil plantations is always available.
2. Customer CPO demands are deterministic.
3. There is never an out-of-stock situation.

Notation:

The following are the decision variables:

x_{ij}^{t} denotes the quantity of FFB (tons) to be purchased from plantation i for mill j during time period t.

y_{j}^{t} denotes the quantity of CPO (tons) to be produced in mill j during the time period t.

z_{jk}^{t} denotes the amount of CPO (tons) to be shipped from mill j to customer k over the time period t.

v_j^t denotes the amount of liquid waste (tons) generated by the milling process in mill j over the time period t.

w_j^t denotes the amount of solid waste (tons) generated by the milling process in mill j over the time period t.

p_{ij} is a binary variable that equals 1 if FFB for mill j is obtained from plantation i and 0 otherwise.

Parameter:

α_{ij} is the cost of transportation from plantation i to mill j per kilometer (IDR).

d_{ij} is the distance (in kilometers) between plantation i and mill j (

β_j is the cost of production in the mill j (IDR)

γ_{jk} is the transportation cost to deliver CPO from mill j to customer k (IDR)

λ_j is the cost of liquid waste treatment in the mill j (IDR)

ρ_j is the transportation cost for the timely transportation of palm oil j (IDR)

τ_{ij}^t is the total cost of purchasing FFB from plantation i for milling j during time period t (IDR)

Cm_j^t is the milling capacity at mill $j \in J$ during the time period $t \in T$ (tons)

CP_j^t is the production capacity at mill $j \in J$ over time period $t \in T$ (tons)

CA_i^t is the amount of FFB available in the plantation $i \in I$ at any given time $t \in T$ (tons)

The following is the definition of the Notation or Emblem:

I representing land used for oil palm plantations

J representing a CPO milling mill

K represents number of customers

T represents multiple time periods

The objective function can be expressed mathematically as follows:

$$\sum_{i\in I}\sum_{j\in J}\sum_{t\in T}(\tau_{ij})(d_{ij})x_{ij}^t + \sum_{j\in J}\sum_{t\in T}\beta_j\, y_j^t + \sum_{j\in J}\sum_{k\in K}\sum_{t\in T}\gamma_{jk}z_{jk}^t + \sum_{j\in J}\sum_{t\in T}\lambda_j\, v_j^t + \sum_{j\in J}\sum_{t\in T}\rho_j\, w_j^t + \sum_{i\in I}\sum_{j\in J}\sum_{t\in T}\alpha_{ij}\, p_{ij}^t \quad (1)$$

Constraints:

$$\sum_{i\in I} x_{ij}^t \le Cm_j^t \qquad \forall j \in J, t \in T \quad (2)$$

$$\sum_{j\in J}\sum_{t\in T} y_j^t \le \sum_{j\in J}\sum_{t\in T} Cp_j^t \quad (3)$$

$$\sum_{i\in I} x_{ij}^t \le \sum_{i\in I} CA_i\, k_{ij}^t \qquad \forall j \in J,\ t \in T \quad (4)$$

$$\sum_{j\in J} z_{jk}^t \le \sum_{j\in J} y_j^t \qquad \forall k \in K, \mathrm{t} \in \mathrm{T} \quad (5)$$

$$v_j^t + w_j^t \le \sum_{i\in I} x_{ij}^t \qquad \forall j \in J, t \in T \quad (6)$$

$$\sum_{i\in I}\sum_{j\in J} p_{ij} = n \quad (7)$$

$$x_{ij}^t, y_j^t, z_{jk}^t, v_j^t, w_j^t \ge 0, \quad k_{ij} \in \{0,1\}, \forall i \in I, j \in J, k \in K, t \in T \quad (8)$$

Constraint (2) requires that the amount of FFB purchased from oil palm plantation $i \in I$ for milling $j \in J$ be $\le$ the milling capacity $j \in J$ in time period $t \in T$. Constraint (3) specifies that the amount of FFB to be milled must be $\le$ the production capacity of mill $j \in J$ during the time period $t \in T$. Constraint (4) states that the amount of FFB to be purchased from oil palm plantation $i \in I$ for mill $i \in I$ must be $\le$ the availability of FFB in plantation ii in time period T, if plantation is chosen. T. Equation (5) states that the amount of CPO delivered to customer $k \in K$ from mill $j \in J$

must be ≤ the amount produced at mill $j \in J$ during the time period $t \in T$. Constraint (6) states that the amount of solid and liquid waste generated by mill $j \in J$ must be ≤ the amount of FFB processed during the time period $t \in T$. The purpose of expression (7) is to ensure that only n plantations are available to supply FFB to each mill $j \in J$. The type of decision variable is specified in constraint (8).

The template details the sections that can be used in a manuscript. Note that each section has a corresponding style, which can be found in the "Styles" menu of Word. Sections that are not mandatory are listed as such. The section titles given are for articles. Review papers and other article types have a more flexible structure.

3 Result and Discussion

Using the MILP model and direct search approach, the results can be seen in Table 1 to Table 6.

Table 1: Quantity of fresh fruit bunches to be purchased (tons)

Time Period	Plantation	Mill		
		1	2	3
1	1	700	600	3,200
	2	3,300	600	600
	3	3,300	600	600
	4	600	3,300	600
	5	200	200	4,100
2	1	700	600	3,200
	2	3,300	600	600
	3	3,300	600	600
	4	600	3,300	600
	5	200	200	4,100

Table 2: Quantity of CPO to be produced (tons)

Mill	Time Period	
	1	2
1	0	0
2	0	0
3	3,500	3,500

Table 3: Quantity of CPO to be shipped (tons)

Time Period	Customer	Plantation				
		1	2	3	4	5
1	1	0	3500	3500	3500	0
	2	0	0	0	0	3500
	3	0	0	0	0	0
	4	3500	0	0	0	0
2	1	0	3500	0	0	0
	2	0	0	0	3500	0
	3	0	0	0	0	0
	4	3500	0	3500	0	3500

Table 4: Amount of liquid waste (tons)

Mill	Time Period	
	1	2
1	0	0
2	0	500
3	0	0

Table 5: Amount of solid waste (tons)

Mill	Time Period	
	1	2
1	500	500
2	500	0
3	0	500

Table 6: Plantation to be chosen (binary variable)

Time Period	Plantation	Mill		
		1	2	3
1	1	0	0	1
	2	0	1	0
	3	0	1	0
	4	0	0	1
	5	0	0	1
2	1	0	0	1
	2	0	0	1
	3	1	0	0
	4	0	1	0
	5	0	0	1

4 Conclusions

This study develops a solution model that can be used as a planning tool to reduce production and transportation costs from CPO processing to CPO delivery to consumers. This study considers the production of an integrated supply chain distribution planning faced by CPO processing industry decision makers. Due to the limited availability of FFB, this industry must purchase it from several oil palm plantations. The processing mills must decide which plantations are suitable to meet the CPO industry's production capacity. It is not easy to achieve the desired optimization, but a multi-echelon strategy is required in managing and designing the crude palm oil industry supply chain planning. In developing the Mixed Integer Linear Programming model for the integration of production planning and distribution problems in the crude palm oil industry, a direct search approach was used to solve problems.

Conflict of interest

The authors declare that there is no conflict regarding the publication of this paper.

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