MATHEMATICAL MODEL FOR PRODUCTION, LOGISTICS AND PLANT CAPACITY PLANNING OF OIL PALM BUNCHES

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Abstract

We study the production planning of palm oil, the main feedstock of biodiesel production, and the capacity planning of palm oil processing plants in Thailand. As a result of Thai government promotion, the consumption of biodiesel in Thailand has been rising drastically during the past 5 years. Thailand needs a proper production planning to ensure the sufficient supply of palm oil in the next decades. As oil palm trees have long life and take years to be fully grown, the planting of oil palm tree has to be done to meet the demand using a proper planting scheduling. In addition, as the demand for biodiesel is forecasted to increase more than three times from 2008 to 2022, the total capacity of processing plants of palm oil becomes limited. The road map showing the capacity, time and suggested location is needed. Because all this planning is a very complex problem, policy makers or companies in the palm oil production industry need a decision-making tool to find optimal decisions resulting in the lowest production, logistics and facility costs. Therefore, we propose a mixed integer linear programming model for the planning of the production, logistics and facility at the same time. The numerical experiment is conducted to test the model. We found the model works well to match the demand and the supply by varying the starting time to plant oil palm trees in multiple pieces of land.

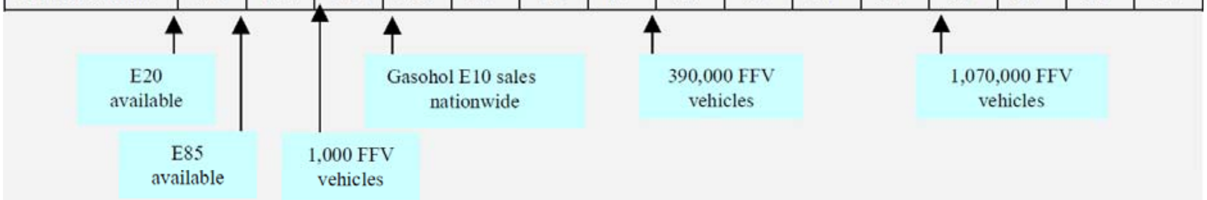
Keywords: bio-diesel, oil palm, production planning, mathematical model, optimization

Introduction

Recently, with the increase of crude oil prices, the limited fossil resources, and the growing environment concerns, there has been a renewed focus on vegetable oils and animal fats to make biodiesel fuel. Government usually promotes those vegetable oil plants to grow for the domestic consumption and renewable energy. In 2010, out of Thailand's final energy consumption of 71,166 ktoe, 64,017 ktoe came from the import (Thailand's Ministry of Energy, 2010). This is equivalent to 89.95% of total consumption. Due to the high value of the import, Ministry of Energy had established to reduce the import by creating alternative energy sources for Thailand from the materials that can be found in Thailand. Thailand, known as the agriculture country, harvests jatropha, coconut, and oil palm as the main feedstock for oil production within the country. Because the oil palm has shown the highest yield among the major oil feedstock, the oil palm has been chosen to use in the process of transesterification for biodiesel production. Thai government announced the strategic plan on biodiesel promotion and development in January 2005. The plan targets replacing 10% of diesel consumption in 2012 by increasing palm oil cultivation, and promoting community-based and commercial biodiesel production. Also, Thai government introduced a B2 mandate in February 2008, requiring the production of approximately 420,000 tons of biodiesel per year. A B5 mandate is planned to be introduced in 2011, and B10 in 2012 (National Renewable Energy Laboratory, 2008). Figure 1 shows that the demand of biodiesel is estimated to increase more than 300% from 1.35 million liters per day in 2008 to 4.5 million liters per day in 2020 (Department of Alternative Energy Development and Efficiency, 2009). Because the significant increase of the demand, the supply of palm oil will have to increase significantly as well. To ensure the stable supply of palm oil, the proper production planning of oil palm trees and the sufficient capacities of oil palm processing plants are needed.

Ethanol consumption targets

Million litres/day	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	'21	'22
Ethanol demand	1.24	1.34	2.11	2.96	3.5	4.0	4.7	5.4	6.2	7.1	8.1	8.3	8.5	8.8	9.0



Biodiesel consumption targets

Million litres/day	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	'21	'22
B100 demand	1.35	1.35	1.35	3.02	3.14	3.31	3.42	3.53	3.64	3.75	3.87	4.01	4.15	4.32	4.50

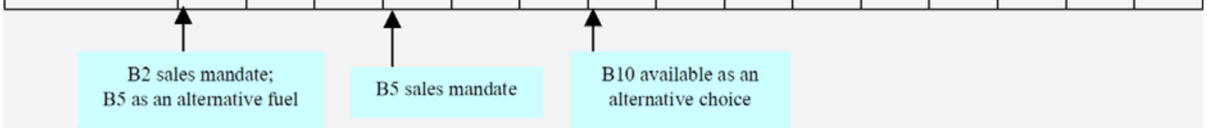


Figure 1 Thailand 15-year renewable energy plan 2008-2022. (Department of Alternative Energy Development and Efficiency, 2009)

However, the palm oil tree's yield rate depends on the age of the tree. For example, in the beginning of the life, the yield rate of palm oil is small because the plant is not fully grown. Similarly, when the tree is old, the yield rate is also low. Replacing old trees with newer ones is recommended. In addition, the operating cost is not constant and depends on the life of the tree. With the non-linear yield rate and non-linear operating costs, the production planning to meet the increasing demand is very complicated. Solving a large-scale non-linear model is a challenging task. Also, the existing capacity of oil palm processing plants will not be enough. The locations of new plants, the time to build and the new capacity to build should be determined optimally. That is, the capacity must be enough to satisfy all the demand with the minimal facility costs and logistic costs. The planner, such as the government or company manager, needs a decision model to help make the decisions that result in the optimal profit while meeting the required demand. Our research aims to develop such the model using Thai data such as planting methods, costs and revenue.

Thai National Bureau of Agricultural Commodity and Food Standards (2008) suggests that oil palm bunches shall be delivered to the collecting center (ramp) or mill within 24 hours of harvest and carefully managed to obtain optimum quality of fruits for palm oil extraction. Therefore, it is important to locate the processing plant within short driving distance from the planting areas. Several researches of the biodiesel production in Thailand are conducted. Pleanjai, Gheewala, and Garivait (2007) evaluate the environmental impact of the biodiesel production from palm oil in a life cycle perspective in order to assess the environmental implications of the proposed substitution. The study is divided into 3 stages: oil palm plantation, palm oil production and transesterification into biodiesel. Pleanjai and Gheewala (2009) investigate the energy consumption of palm methyl ester (PME) production in Thailand using a life cycle approach compared to other possible oil crops for biodiesel production including jatropha and coconut. The results help select an appropriate feedstock for biodiesel production, support policy makers in the energy sector to make informed decisions, and support the Thai Government in its policy to promote the use of indigenous and renewable sources for transportation fuels. In addition, Nanthasamroeng, Pitakaso, and Buddadee (2008) developed a heuristic algorithm for location-routing problem in ethanol production industries from bagasse and cassava in north eastern of Thailand. The research focused on choosing the plants and the transport routes for each plant by using multi-objective location-routing problems.

We organize the remaining of this paper as follows. In section 3, the assumptions and mathematical model of oil palm planting is discussed. In section 4, the model is tested and numerical results are investigated. In section 5, we conclude the research and provide the direction of future research.

Mathematical Model

We consider a decision maker such as, company or a government, who own *j* pieces of land. The size of land *j* is N_j. Each piece of land can be used to plant oil palm independently. But all the trees in the same piece of land have the same schedule. That is, they are planted initially at the same time and they are replaced by the new trees at the same time. If the oil palm trees in a piece of land are planted in period *b* and are replaced by the new set of trees in period *e*, during the period $t \in \{b, b+1, ..., e\}$, the production rate of fresh fruit bunches (FFB) (tons) per unit of land is $p_{b,e,t}$. At the same time, the total profit per land unit, excluding the transportation cost and facility cost, from planting the oil palm trees in period *b* and replacing them in period *e* is $\pi_{b,e}$. In each period, the total production of FFB from all areas must equal to or exceed the total demand of FFB, D_t. All FFB produced at land j must be transported to FFB processing plants to produce the crude palm oil (CPO). There is a transportation cost to transport FFB from the planting area to the processing plant. It costs *c* to transport one ton of FFB for one kilometer. The distance in kilometers from land *j* to plant *k* is $d_{j,k}$. We assume that the existing capacity of production facility at plant *k* is $C_{k,0}$. To build the additional capacity of palm oil production facility at plant *k*, it costs f_k per ton of FFB. We also assume that if the land *j* is assigned to grow a set of the trees from period *b* to *e*, the land *j* cannot be used to grow other sets of trees in any periods from *b* to *e*. The discussed parameters are summarized below.

Parameters:

N_j = size of land j

c = transportation cost to transport one ton of FFB for one kilometer

d_{jk} = transportation distance (km) from land j to plant k

D_t = demand of FFB in period t

$\pi_{b,e}$ = total profit per unit of land excluding transportation cost and facility cost during periods from b to e

$p_{b,e,t}$ = production rate (tons) of FFB per unit of land in period t given that the oil palm trees were planted in period b and replaced in period e.

f_k = facility cost to increase one ton of FFB processing capacity at location k

$C_{k,0}$ = existing capacity of FFB processing plant at location k

M = very large number

T = total number of planning periods

J = total number of pieces of land

K = total number of plant locations

The decision maker has to decide the following decision variables.

Decision Variables:

$x_{j,k,t}$ = quantity of FFB (tons) transported from land j to plant k in period t

$C_{k,t}$ = number of plant capacity (tons) added at plant k in period t

$z_{b,e,j}$ = 1 if the land j is assigned to plant oil palm trees for all periods from b to e

= 0 otherwise

The mathematical model to make the optimal decisions on the production planning, the logistics planning and facility planning is as follows.

$$Maximize \sum_{j=1}^{J}\sum_{b=1}^{T}\sum_{e\geq b}^{T} N_j \pi_{b,e} z_{b,e,j} - \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{k=1}^{K} N_j c d_{jk} x_{jkt} - \sum_{t=1}^{T}\sum_{k=1}^{K} f_k C_{k,t} \quad (1)$$

Subject to

$$\sum_{j=1}^{J}\sum_{b=1}^{T}\sum_{e\geq b}^{T} N_j z_{b,e,j} p_{b,e,t} \geq D_t \ , \forall\, t \in \{1,2,\ldots,T\} \quad (2)$$

$$\sum_{k=1}^{K} x_{j,k,t} = N_j \sum_{b=1}^{T}\sum_{e=b+1}^{T} z_{b,e,t} p_{b,e,t}, \ \forall j \in \{1,2,\ldots,J\}, \forall t \in \{1,2,\ldots,T\} \quad (3)$$

$$\sum_{k=1}^{K} x_{j,k,t} \leq C_{k,0} + \sum_{\tau=1}^{t} C_{k,\tau}, \ \forall k \in \{1,2,\ldots,K\}, \forall t \in \{1,2,\ldots,T\} \quad (4)$$

$$M(1-z_{b,e,j}) \geq \sum_{n=b}^{e-1} z_{b,n} + \sum_{m=b+1}^{e}\sum_{n=m}^{e} z_{m,n}, \ \forall b \in \{1,2,\ldots,T-1\}, \ \forall e \in \{b+1,b+2,\ldots,T\}, \ \forall j \in \{1,2,\ldots,J\} \quad (5)$$

$$M(1-z_{b,e,j}) \geq \sum_{m=1}^{b-1}\sum_{n=b}^{e} z_{m,n},\ \forall\ b \in \{2,3,...,T\},\ \forall e \in \{b,b+1,...,T\},\ \forall j \in \{1,2,...,J\} \quad (6)$$

$$M(1-z_{b,e,j}) \geq \sum_{m=b}^{e}\sum_{n=e+1}^{T} z_{m,n},\ \forall b \in \{1,2,...,T-1\},\ \forall e \in \{b,b+1,...,T\},\ \forall j \in \{1,2,...,J\} \quad (7)$$

$$z_{b,e},\ f_k \in \{0,1\},\ x_{j,k,t} \geq 0 \quad (8)$$

The objective function (1) is to maximize the total profit comprised of the profit from all planting areas subtracting transportation cost and the plant facility cost. The equation (2) states that the total production is equal to or more than the required demand. The equation (3) limits the total FFB transported to a plant to the total plant capacity accumulated up until period t. The equations (5), (6) and (7) prevent the land to be used more than once if it is already assigned to start planting from period *b* to *e*. The equation (8) sets up the types of variables to the desired types of decision variables. In the next section, we test the model using a small numerical example.

Results

We conduct the numerical experiment by coding the model in the IBM ILOG CPLEX version 12.4. In this section, each time period is equivalent to 4 years. As the typical life of oil palm is fewer than 32 years, we can have a total of 8 periods maximum in the experiment. The demand of FFB to be tested in the example is shown in Table 1.

Table 1 The demand of FFB in each period

Period	Total Demand of FFB (Tons)
1	0
2	56,143,147
3	66,992,657
4	77,842,167
5	88,691,678
6	99,541,188
7	110,390,699
8	121,240,209

We divide the southern of Thailand into 8 areas. There are 3 existing areas that the decision maker currently uses to plant the oil palm. The size of each land is shown in table 2. The number is specified in rai (Thai land unit measurement). One rai is equal to 1,600 meter^2. The others 5 areas are new planting sites. Each of new sites has the total area of 3,000,000 rais. Also, the total existing plant capacities (tons) during a 4-year period are shown in table 2. Also, we assume the facility cost is 199.77 baht per ton of capacity in a period.

Table 2 The total planting area in each land

Land	Province	Planting Area (rais)	Total planting area (rais)	Total existing plant capacity (tons) during 4 year period
1	Chumpon Ranong	703,339 71,033	801,372	24,528,000
2	Surathani Punga Phuket Nakornsrithamarat	911,706 101,389 1,133 146,337	1,160,565	31,360,800
3	Krabi Trang Pattalung Songkra Satool	959,205 105,082 9,414 23,992 103,991	1,259,070	35,004,960
4	New site 1	3,000,000	3,000,000	0
5	New site 2	3,000,000	3,000,000	0
6	New site 3	3,000,000	3,000,000	0
7	New site 4	3,000,000	3,000,000	0
8	New site 5	3,000,000	3,000,000	0

We use the cost of transportation is 1.3325 baht per kilometer per ton. The transportation distance is as shown in table 3.

Table 3 The transportation distance between lands

Distance (km)	**Chumpon (1)**	**Surathani (2)**	**Krabi (3)**	**New Site1 (4)**	**New Site2 (5)**	**New Site3 (6)**	**New Site4 (7)**	**New Site5 (8)**
Chumpon (1)	0	193	363	1000	1000	1000	1000	1000
Surathani (2)	193	0	211	1000	1000	1000	1000	1000
Krabi (3)	363	211	0	1000	1000	1000	1000	1000
New Site1 (4)	1000	1000	1000	800	800	800	800	800
New Site 2 (5)	1000	1000	1000	800	800	800	800	800
New Site3 (6)	1000	1000	1000	800	800	800	800	800
New Site4 (7)	1000	1000	1000	800	800	800	800	800
New Site5 (8)	1000	1000	1000	800	800	800	800	800

We assume the cumulative profit (baht) and production (tons) per rai as shown in table 4 and table 5.

Table 4 Accumulated Profit (in baht per rai) and the planting period accumulated

Planting period(s) accumulated	Accumulated Profit (baht per rai)
1	2,300
2	53,900
3	102,300
4	146,500
5	174,500
6	183,300
7	178,900
8	171,300

Table 5 Total production of FFB in each period of oil palm tree life (tons per rai)

Period	Total production in the period (tons per rai)
1	1.5
2	12
3	12
4	11.8
5	9.2
6	6
7	4
8	3.6

We use the information discussed to run numerical experiments and found the following results. Figure 2 shows the production of FFB produced from each land in each period. The production from Land 4 to Land 8 starts to be positive in period 2. This means in 8 year time, the new production sites are needed to satisfy increasing demand. Also, all 5 new planting areas become active in the future. This shows that the current planting area is not enough to satisfy the increasing demand. The total of 15 million rai of planting is used in the 5 new planting sites.

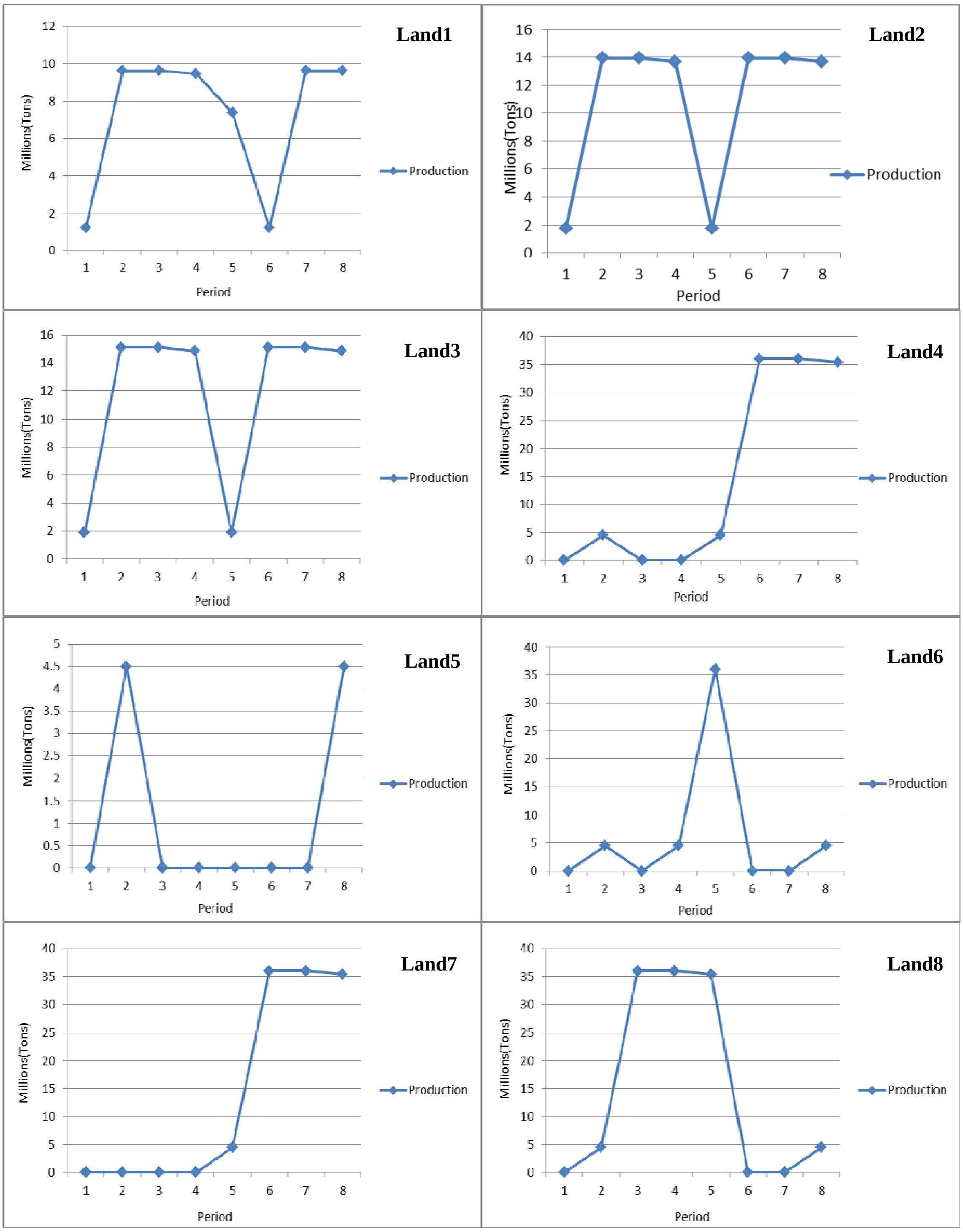


Figure 2 FFB (in million tons) produced from Land1 to Land 8

Figure 3 shows the newly installed capacity of FFB processing plant needed in each period. We found that, in period 2, 4, 5 and 6, the new production facility is needed to be installed in Land 4, 5, 6, 7, or 8.

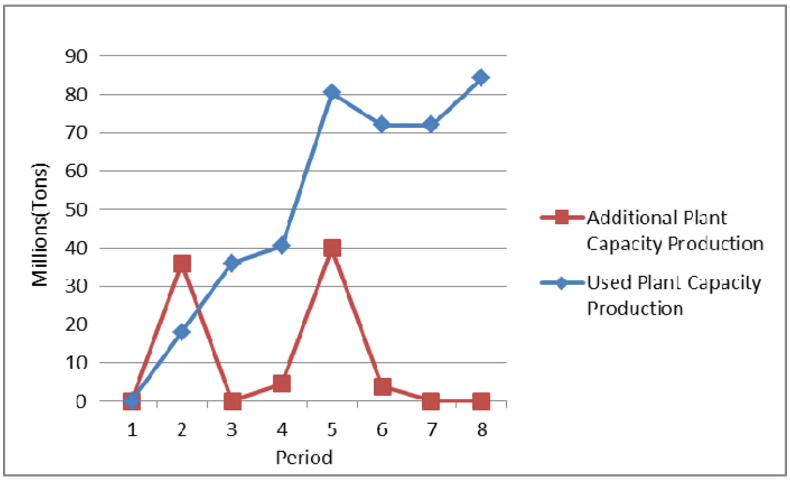


Figure 3 Additional Plant Capacities Installed in Land 4, 5, 6, 7 and 8.

Figure 4 shows the aggregate supply and demand of FFB. With the proper synchronization of all pieces of land, the supply can closely match with the increasing demand. However, the new areas of planting are needed.

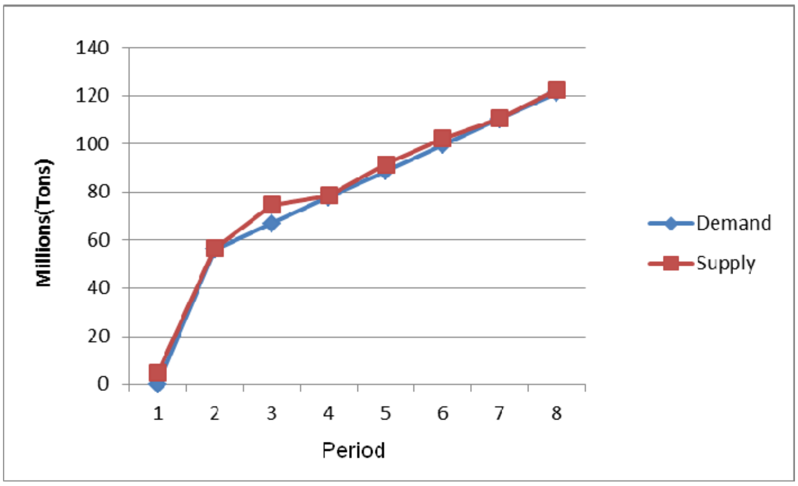


Figure 4 the total supply and demand of FFB

Discussion and Conclusion

In this research, we study the decision maker such as farmer, the company or government who wants to plan the production of oil palm bunches to meet the demand given the limited areas. The mathematical model is proposed to make the production planning of palm oil. The model takes into account the logistics cost, the facility cost, the limited area of planting and the limited capacity of processing plants. The model also suggests the timeline to install additional capacities of processing plants and to use additional planting areas. The numerical experiment is conducted using a small-scale data set. We found the model works well to match the supply and demand by varying the starting and stopping time of oil palm planting in each piece of land. However, to accurately determine the roadmap of Thailand, the more detailed data is needed. We found that the IBM ILOG CPLEX has difficulty solving large scale data sets. In the future research, the more accurate data of Thailand will be collected and the heuristic algorithm to solve the model efficiently will be proposed.

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