Product mix optimisation model for the coconut oil industry

by Ivan Gunawan

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Abstract: Coconut can produce numerous derivatives and by-products. A coconut oil industry with five production processes: expeller-pressing, refinery, extraction, hydrogenation, and pelletising can produce up to 11 products. A product mix problem often arises in the determination of the quantity of each product to be produced. As such, product mix decisions can significantly affect profit generation. This research aims to develop a mathematical model based on linear programming (LP) to maximise profits. The optimisation model developed in this study estimates that the industry can increase profits by 43.9% by applying the best product mix decision. A sensitivity analysis shows that changes in capacity affect the model. Three production flow scenarios were tested in the LP model. Scenario 1 (adding refinery 2, using it like refinery 1 plus using refinery 2 to produce refined bleached deodorised hydrogenised coconut oil super) can increase the industry's profit by 28%.

Keywords: coconut oil industry; linear programming; maximising profit; product mix.

Reference to this paper should be made as follows: Gunawan, I., Hartanti, L.P.S., Klau, B.T.N. and Chofifah, N. (2025) 'Product mix optimisation model for the coconut oil industry', *Int. J. Industrial and Systems Engineering*, Vol. 49, No. 1, pp.1–17.

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1 Introduction

Indonesia is the largest coconut producer in the world. As of 2021, the country had 3.3 million hectares of coconut land, ranking third after oil palm and rubber (Badan Pusat Statistik, 2023). Therefore, coconut and its derivatives are among the most valuable commodities for the country. The flesh can be consumed directly or processed into various food and non-food products. The processing industries in Indonesia are categorised into upstream, intermediate, and downstream. The upstream industry processes fresh coconut into copra (dried coconut); the intermediate industry produces coconut meal, coconut shell, and coconut flour; and the downstream industry processes coconut into final products, such as activated carbon, coconut milk, and coconut oil. Despite the large production of coconut, certain industries, like coconut oil, face challenges in finding raw materials (Gunawan et al., 2022, 2021). In this case, the strategic decision is to optimise profits from limited raw materials.

Coconut oil's market is the largest among other derivative products. The two variants are virgin coconut oil (VCO), derived from fresh coconut, and crude coconut oil (CCNO), derived from dried coconut (copra). This study focuses on a specific industry processing copra into refined bleached deodorised coconut oil (RBDCNO), commonly known as coconut cooking oil. Value can be added to RBDCNO by solidifying it through a hydrogenation process. The industrial name of solid coconut oil is refined bleached deodorised hydrogenised coconut oil (RBDHCNO). Processing copra into RBDCNO or RBDHCNO requires several production stages, each generating by-products. Such by-products and the by-product of the whole production process can be directly sold or processed further. Under certain market conditions, the coconut oil industry can benefit more from selling intermediate products. However, it is important to note that each production stage requires specific resources, which requires strategic estimation of the costs. The challenge is determining the correct quantity of derivative products to maximise profits and avoid losses. This condition is known as a product mix problem.

A product mix problem is determining the appropriate products and their production quantities to maximise an industry's throughput by considering the available resources and customer demand (Chen et al., 2020; Mehdizadeh and Jalili, 2019). It is a tactical decision that equips a business with sound resource allocation plans and production schedules, hence driving profit generation. Different products require different resources and costs and generate varying profits in each stage of the production cycle (Mawgoud et al., 2022). Efficient and effective use of these resources increases an organisation's capacity to achieve its objectives and make a profit (Nitonye et al., 2023). Solutions have been proposed to solve the product mix problem. For example, fuzzy linear programming (FLP) has modelled the production processes of an in-campus bakery and informed the daily decision making (Onasanya et al., 2020). A Monte Carlo simulation has been applied to determine the product mix of paper napkins (Janekova et al., 2018). Each approach has advantages and disadvantages. Analytical hierarchy process (AHP), analytic network process (ANP), and simulations can handle complex problems but cannot provide exact optimal values. Combining AHP and mathematical programming can optimise the solution, which has been applied in a fruit-nectar product mix by Erik et al. (2022).

Linear programming (LP) is one of the most popular optimisation approaches that can provide exact optimal values. It maximises or reduces a linear objective function to constraints expressed in a linear equation or inequation (Dimina et al., 2022). LP is based on linear equations that aim to determine the optimal value of decision variables from an objective function without violating the constraint functions. The word 'programming' refers to a problem-solving strategy development rather than computer system programming (Kalwar et al., 2022). An LP model solves product mix problems by finding an optimal condition amid the existing constraints (Aregawi, 2018). LP has solved product mix problems in various contexts, such as apparel (Chanda et al., 2022; Molina, 2018; Rathi et al., 2021), textile (Woubante et al., 2019), soap (Eli and Bunonyo, 2019), guitar (Sulistiono et al., 2019), bakery (Oladejo et al., 2019; Oluwaseyi et al., 2020), washing machine (Bagalagel and ElMaraghy, 2020), ice creams (Lopes et al., 2018), leather (Kalwar et al., 2022), semiconductor (Romauch and Klemmt, 2015) and paint (Mejjaouli et al., 2022).

It is worth noting that the biggest challenge of using LP in product mix is the non-deterministic polynomial-time hardness (NP-hard) issue (Chen et al., 2020). According to the computational complexity theory, a class of problems known as NP-hard is technically defined as being “at least as hard as the hardest problems in NP” (Alam et al., 2017). The number of NP-hard’s feasible solutions grows exponentially as the number of products increases. This means obtaining an optimal solution will take a long time. This issue has yet to be overcome with the development of computer processing capability. Nonetheless, the product mix is a tactical rather than a daily operation decision, so it does not require rush processing.

This study aims to develop a linear programming model to determine the optimal product mix for the coconut oil industry. The hypothesis is that LP can accommodate the complexity of its product mix decisions. Past studies on product mix have not extensively explored the use in the coconut industry, so references that specifically discuss the development of LP models in this context are scarce. The closest application of LP to this research is the work of Liu et al. (2010) for short-term multiproduct scheduling in the edible oil industry. Although the work is limited to a small-scope production schedule, it has shown that the LP can handle the complexity of the edible oil industry characteristics. Developing such tactical decision-making models, i.e., the product mixing in the coconut oil industry, yields significant theoretical and practical benefits. It improves product identification to ease the traceability of bulk coconut oil products, which are difficult to track and trace (Gunawan et al., 2021).

The development of the LP model in the coconut oil industry involves a confirmed case of one of the largest coconut oil factories in Java, Indonesia. This coconut oil factory needs assistance determining a product mix to maximise profits because all derivative products and by-products are valuable and marketable. Besides the limited supply of raw materials, the solution includes product quality in the product mix problem. This study uses a multi-stage process flow to characterise the coconut oil industry. If a backward process occurs when processing RBDHCNO, the industry must also decide the optimal process flow. To produce RBDHCNO, RBDCNO from the refinery process goes to the hydrogenation process. After the hydrogenation process, the oil must be returned to the refinery process. Currently, the refinery plant has two refinery machines but with different capacities. Therefore, in addition to the product mix problem, the plant must determine the optimal process flow. This problem is accommodated in the proposed LP model. The development of an actual case-based model has managerial implications. The model is expected to optimise the profitability of the coconut oil industry amid the difficulty in obtaining raw materials.

2 Materials and methods

Data collection to build the model begins with observations of the coconut oil production process at the Indonesian coconut oil factory. Secondary marketing, production, and financial data were also collected and filtered. The data used in this study comprise the demand for each type of product, the raw material availability, the production capacity, the storage capacity, the process characteristics for each derivative and by-product, the selling price, and the production cost. The data were collected from January to December 2020. The development of the LP model follows the modelling-validation procedure proposed by Landry et al. (1983).

a Problem situation

The model development process begins with a thorough investigation of the problem the coconut oil factory faces.

b Conceptual model

A conceptual model is built to describe the interaction between elements involved in the system using certain agreed-upon symbols. This study uses an *influence diagram* to develop the conceptual model. The process approach and the minimal symbols in the influence diagram make the framework easy to understand.

c Formal model

A formal model is a translation of a conceptual model into mathematical symbols. The elements in the conceptual model in this study are translated into parameters and variables in the formal model, which is an LP-based optimisation model. The formal model is declared valid if it follows the conceptual model (logical validity) and produces solutions that can be proven correct (experimental validity). Therefore, the LP model development demands real case applications.

d Solution

The solution is the optimisation model output generated through the solution-search technique applied to the model. Lingo software is used to find an optimal solution value of the model, which serves as the basis for delivering problem-solving recommendations. The solution generated by the model is also a means to test the model's validity (validation by results). The validation procedure is a prediction experiment using an actual dataset.

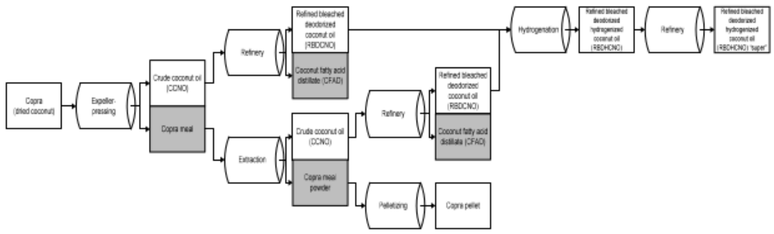
The model verification then ensures that the resulting solution does not violate the values of the constraint function and maintains the production proportion. The validation is conducted through a model sensitivity analysis. The most basic sensitivity analysis examines how the proposed solution responds to a change in a single parameter while keeping all the others constant (Lopes et al., 2018). The sensitivity analysis was conducted by trying extreme values on the model to see how much parameter changes influence the optimal solution.

3 Results

3.1 Case study

The company's first problem is that each production stage generates main products and by-products (see Figure 1). The five stages are expeller-pressing, refinery, extraction, hydrogenation, and pelletising. Both the main and the by-products can be sold directly or processed further. The RBDCNO quality grades are grouped into four: grade 1 is the best quality, followed by grades 2, 3, and 4. A particular grade can be produced through a blending process. For example, to produce grade 2, grades 1 and 3 can be mixed with a 70:30 composition. The refinery has two machines with different capacities. The model also considers using multiple machines to optimise the product mix.

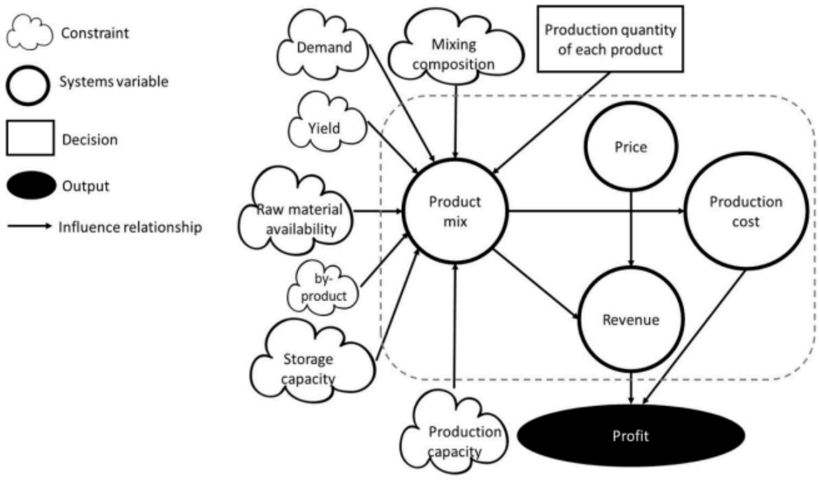
Figure 1 Coconut oil process flow



3.1.1 The conceptual model

The results of observing product mix problems in the coconut oil industry were visualised as a conceptual model. The model is used as the influence diagram, as shown in Figure 2. The influence diagram consists of five components: the clouds represent constraints; the circles represent system variables; the rectangles represent decisions; the ellipses represent the model output; and the arrows indicate the relationship between model components.

Figure 2 The influence diagram



3.1.2 The formal model

The formal model is written based on the LP approach

Indices

i products, $i = 0, 1, 2, \ldots, I$

j process, $j = 1$: expeller-pressing; 2: extraction; 3: refinery; 4: pelletising; 5: hydrogenation; 6: mixing

k	machine number, $k = 0, 1, 2, \ldots, K$
l	predecessor product, $l = 0, 1, 2, \ldots, L$
m	decisions, $m = 0$: work-in-process product; 1: finished product; 2: parent product
a	parent products, $a = 1, 2, \ldots, A$.

Parameters

P_i	price of product i
P_0	price of material
$C_{i,j,l}$	production cost of product i which follows process j from product l
D_i	demand of product i
M	material capacity
$Cap_{i,j,k,l}$	input capacity of product i process j in k^{th} machine for product l
S_i	storage capacity of product i
$Y_{i,j}$	yield of product i which follows process j
$U_{i,i',i''}$	proportion of product i' when mixed with product i'' to become product i
$U_{i,i'',i'}$	proportion of product i'' when mixed with product i' to become product i.

Variables

$x^m_{i,j,k,l}$	the amount of product i which follows process j in the k^{th} machine from product l will decide as m
$x^0_{i,j,k,l}$	the amount of product i as first mixing material which follows process j in the k^{th} machine from product l
$x^0_{i',j',k'',l'}$	the amount of product i as second mixing material which follows process j in the k^{th} machine from product l.

Objective function

$$Maximise\ profit = \left(\sum_i^I P_i x^1_{i,j,k,l}\right) - \left(\sum_a^A \sum_j^J \sum_k^K \sum_l^L C_{a,j,k,l} x^2_{a,j,k,l} + P_0 x^0_{0,0,0,0}\right) \quad (1)$$

Constraints

1 Demand constraint

$$\sum_j^J \sum_k^K \sum_l^L x^1_{i,j,k,l} \geq D_i; \qquad \forall i \quad (2)$$

2 Material capacity

$$x^0_{0,0,0,0} \leq M \quad (3)$$

3 Production capacity

$$\sum_{a}^{A} x_{a,j,k,l}^{2} \leq Cap_{j,k,l}; \qquad \forall j, k, l \tag{4}$$

4 Storage capacity

$$\sum_{j}^{J}\sum_{k}^{K}\sum_{l}^{L}\sum_{m=0}^{1} x_{i,j,k,l}^{m} \leq S_i; \qquad \forall i \tag{5}$$

5 Production characteristics

5.1 Derivative and by-product constraint

$$\sum_{a}^{A} x_{a,j,k,l=i}^{2} \leq x_{i,j,k,l}^{0}; \qquad \forall j, k \tag{6}$$

5.2 Yield constraint

$$x_{i,j,k,l=a}^{m} \leq Y_{i,j} x_{a,j,k,l}^{2}; \qquad \forall i, j, k, l \tag{7}$$

5.3 Mixing constraint

$$\begin{aligned} & x_{i,6,k,l}^{m} \leq x_{i',j',k',l'}^{0} + x_{i'',j'',k'',l''}^{0}; \qquad \forall j = 6 \\ & U_{i,i',i''} x_{i',j',k',l'}^{0} - U_{i,i',i''} x_{i'',j'',k'',l''}^{0} = 0 \end{aligned} \tag{8}$$

6 Non-negative constraint

$$x_{i,j,k,l}^{m}, x_{a,j,k,l}^{2} \geq 0; \qquad \forall a, \forall i, \forall j, \forall k, \forall l, \forall m \tag{9}$$

The objective function of this model is to maximise profit [see equation (1)] by reducing expenses through production and material costs. The first constraint function [see equation (2)] requires fulfilling all sales contracts. Excess production is also assumed to be sold, with a justification that coconut oil is a commodity with constant demand. The following constraints are the availability of copra raw materials [see equation (3)], the production input capacity of each machine [see equation (4)], and the storage facility capacity of each product type [see equation (5)]. The characteristics of the coconut oil industry are accommodated in equations (6), (7) and (8). In some production processes, the main products and by-products are called product packages. We propose an intermediate product called the parent product of product packages to accommodate product packages. The following characteristic is that the yield for each product is different. We also involve the common product mixing practices in the commodity industry to yield products of a certain quality (Chueprasert and Ongkunaruk, 2015; Thakur and Donnelly, 2010). This practice is also carried out in the coconut oil industry to fulfil certain quality requirements. Equation (9) guarantees that the decision variables do not produce negative values.

The assumptions used in the product mix optimisation model with the LP approach are:

1 all model parameters are fixed, i.e., price, production cost, production capacity, storage capacity, yield, mixing composition, and demand

2 raw materials are always available

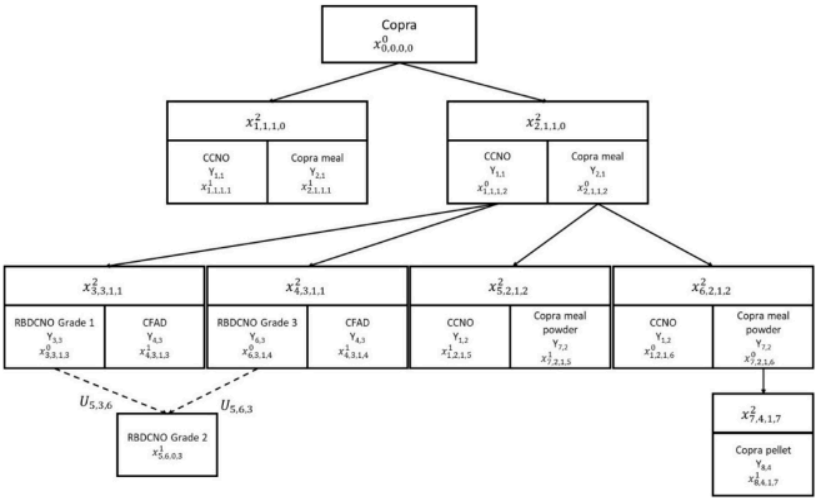
3 all products are sold

4 the product quality is fixed.

3.2 Modelling example

We use a simple case example to understand how the LP model is applied, as shown in Figure 3.

Figure 3 Case example



For the case example in Figure 3, the objective function can be written as

$$\begin{aligned}\text{Max profit} = {} & \left[P_1\left(x^1_{1,1,1,1} + x^1_{1,2,1,6}\right) + P_2 x^1_{2,1,1,1} + P_4\left(x^1_{4,3,1,3} + x^1_{4,3,1,4}\right) + P_5 x^1_{5,6,03}\right. \\ & \left. + P_7 x^1_{7,2,1,5}\right] - \left[C_{1,1,1,0} x^2_{1,1,1,0} + C_{2,1,1,0} x^2_{2,1,1,0} + C_{3,3,1,1} x^2_{3,3,1,1} + C_{4,3,1,1} x^2_{4,3,1,1}\right. \\ & \left. + C_{5,2,1,2} x^2_{5,2,1,2} + C_{6,2,1,2} x^2_{6,2,1,2} + C_{7,4,1,7} x^2_{7,4,1,7}\right] - \left[P_0 x^0_{0,0,0,0}\right]\end{aligned}$$

The demand constraints can be written as

$$x^1_{1,1,1,1} + x^1_{1,2,1,6} \ge D_1$$

$$x^1_{2,1,1,1} \ge D_2$$

$$x^1_{4,3,1,3} + x^1_{4,3,1,4} \ge D_4$$

$$x^1_{5,6,0,3} \ge D_5$$

$$x^1_{7,2,1,5} \ge D_7$$

The material capacity constraint can be written as

$$x^{0}_{0,0,0,0} \leq M$$

The production capacity constraints can be written as

$$x^{2}_{1,1,1,0} + x^{2}_{2,1,1,0} \leq Cap_{1,1,0}$$

$$x^{2}_{3,3,1,1} + x^{2}_{4,3,1,1} \leq Cap_{3,1,1}$$

$$X^{2}_{5,2,1,2} + x^{2}_{6,2,1,2} \leq Cap_{2,1,2}$$

$$x^{2}_{7,4,1,7} \leq Cap_{4,1,7}$$

The storage capacity constraints can be written as

$$x^{1}_{1,1,1,1} + x^{0}_{1,1,1,2} +^{1}_{1,2,1,5} + x^{0}_{1,2,1,6} \leq S_1$$

$$x^{1}_{2,1,1,1} + x^{0}_{2,1,1,2} \leq S_2$$

$$x^{0}_{3,3,1,3} \leq S_3$$

$$x^{1}_{4,3,1,3} + x^{1}_{4,3,1,4} \leq S_4$$

$$x^{1}_{5,6,03} \leq S_5$$

$$x^{0}_{6,3,1,4} \leq S_6$$

$$x^{1}_{7,2,1,5} + x^{0}_{7,2,1,6} \leq S_7$$

$$x^{1}_{8,4,1,7} \leq S_8$$

The derivative and by-product constraints can be written as

$$x^{2}_{1,1,1,0} + x^{2}_{2,1,1,0} \leq x^{0}_{0,0,0,0}$$

$$x^{2}_{3,3,1,1} + x^{2}_{4,3,1,1} \leq x^{0}_{1,1,1,2}$$

$$x^{2}_{5,2,1,2} + x^{2}_{6,2,1,2} \leq x^{0}_{2,1,1,2}$$

$$x^{2}_{7,4,1,7} \leq x^{0}_{7,2,1,6}$$

The yield constraints can be written as

$$x^{1}_{1,1,1,1} \leq Y_{1,1} x^{2}_{1,1,1,0}$$

$$x^{1}_{2,1,1,1} \leq Y_{2,1} x^{2}_{1,1,1,0}$$

$$x^{0}_{1,1,1,2} \leq Y_{1,1} x^{2}_{2,1,1,0}$$

$$x^{0}_{2,1,1,2} \leq Y_{2,1} x^{2}_{2,1,1,0}$$

$$x^0_{3,3,1,3} \le Y_{3,3} x^2_{3,3,1,1}$$

$$x^1_{4,3,1,3} \le Y_{4,3} x^2_{3,3,1,1}$$

$$x^0_{6,3,1,4} \le Y_{3,3} x^2_{4,3,1,1}$$

$$x^1_{4,3,1,4} \le Y_{4,3} x^2_{4,3,1,1}$$

$$x^1_{1,2,1,5} \le Y_{1,2} x^2_{5,2,1,2}$$

$$x^1_{7,2,1,5} \le Y_{7,2} x^2_{5,2,1,2}$$

$$x^0_{1,2,1,6} \le Y_{1,2} x^2_{6,2,1,2}$$

$$x^0_{7,2,1,6} \le Y_{7,2} x^2_{6,2,1,2}$$

$$x^1_{8,4,1,7} \le Y_{8,4} x^2_{7,4,1,7}$$

The mixing constraints can be written as

$$x^1_{5,6,0,3} \le x^0_{3,3,1,3} + x^0_{6,3,1,4}$$

$$U_{5,3,6} x^0_{3,3,1,3} - U_{5,6,3} x^0_{6,3,1,4} = 0$$

The non-negative constraint can be written as

$$x^1_{1,1,1,1};\ x^1_{1,2,1,6};\ x^1_{2,1,1,1};\ x^1_{4,3,1,3};\ x^1_{4,3,1,4};\ x^1_{5,6,0,3};\ x^1_{7,2,1,5};\ x^2_{1,1,1,0};\ x^2_{2,1,1,0};\ x^2_{3,3,1,1};\ x^2_{4,3,1,1};\ x^2_{5,2,1,2};$$
$$x^2_{6,2,1,2};\ x^2_{7,4,1,7};\ x^0_{0,0,0,0};\ x^0_{1,1,1,2};\ x^0_{1,2,1,6};\ x^0_{2,1,1,2};\ x^0_{3,3,1,3};\ x^0_{6,3,1,4};\ x^0_{7,2,1,6} \ge 0$$

3.2.1 Solution for the real case study

The coconut oil industry under study has parameter data in Tables 1 and 2.

Table 1 Price, capacity, and demand of each product

Product	*Price (IDR/kg)*	*Capacity (kg)*	*Demand (kg/week)*
Copra	12,000	3,000,000	-
CCNO	16,600	1,810,000	120,000
RBDCNO grade 1	18,600	1,800,000	150,000
RBDCNO grade 2	18,200	600,000	200,000
RBDCNO grade 3	17,800	350,000	300,000
RBDCNO grade 4	17,600	470,000	400,000
RBDHCNO	19,000	750,000	180,000
RBDHCNO super	19,400	350,000	40,000
CFAD	15,200	100,000	70,000
Copra meal	4,000	1,000,000	60,000
Copra meal powder	3,800	900,000	300,000
Copra pellet	4,000	500,000	400,000

Table 2 Production cost, input capacity, and yield of each process and product

Process	*Production cost (IDR/kg)*	*Process input*	*Input capacity (kg/week)*	*Product*	*Yield*
Expeller-pressing	500	Copra	2,500,000	CCNO	60%
				Copra meal	36%
Refinery	400	CCNO	560,000	RBDCNO grade 4	93.50%
				CFAD	6%
	400		560,000	RBDCNO grade 3	93.50%
				CFAD	6%
	500		550,000	RBDCNO grade 2	93.50%
				CFAD	6%
	500		550,000	RBDCNO grade 1	93.50%
				CFAD	6%
	600	RBDHCNO	300,000	RBDHCNO super	99.50%
Hydrogenation	600	RBDCNO grade 2	600,000	RBDHCNO	100%
Extraction	400	Copra meal	900,000	CCNO	11%
				Copra meal powder	89%
Pelletising	100	Copra meal	500,000	Copra pellet	100%

Table 1 shows each product's price, capacity, and demand in the coconut industry. The copra price is IDR 12,000/kg, and the factory can accommodate 3,000,000 kg of copra. Copra and product prices fluctuate with supply and demand. The prices in Table 1 are the average prices for 2020. CCNO, RBDCNO, RBDHCNO, and CFAD are stored in storage tanks. The capacity is not one storage tank but several storage tanks to store the same product. Copra, copra meal, copra meal powder, and copra pellets are stored in warehouses of 70–80 kg/sack. The demand is the average weekly demand for one year. The average demand figures are reliable since the fluctuation of commodity products is not too significant.

Table 2 shows each process's production cost, input capacity, and yield. The cost to process 1 kg of copra in expeller pressing is IDR500. The capacity of the expeller-pressing process is 2,500,000 kg/week. The expeller-pressing will produce 60% CCNO and 36% copra meal from 100% of incoming copra. The following lines are read in the same way.

The possibility of producing products through the mixing process can follow the mixing rule. RBDCNO grade 1 can be mixed with RBDCNO grade 3 to produce RBDCNO grade 2 with a composition of 70% RBDCNO grade 1 and 30% RBDCNO grade 3. RBDCNO grade 1 can be mixed with RBDCNO grade 4 to produce RBDCNO grade 2 with a composition of 80% RBDCNO grade 1 and 20% RBDCNO grade 4. RBDCNO grade 1 can be mixed with RBDCNO grade 4 to produce RBDCNO grade 3 with a composition of 25% RBDCNO grade 1 and 75% RBDCNO grade 4. RBDCNO grade 2 can be mixed with RBDCNO grade 4 to produce RBDCNO grade 3 with a composition of 35% RBDCNO grade 2 and 65% RBDCNO grade 4.

The model solution shows that, with the right product mix decision, the maximum profit for the coconut oil industry is IDR 4,451,035,000. This value is much higher than the current weekly average profit of IDR 3,092,601,210. This product mix optimisation scheme is 43.9% higher than the profit the coconut oil industry normally earns through intuition-based production mix schemes. The proposed product mix in Table 3 shows the composition to make a profit of IDR 4,451,035,000.

Table 3 The optimal product mix decision

Product	*Optimal quantity (kg)*	*Demand (kg)*	*Difference quantity (kg)*
CCNO	137,078.7	120,000	17,078.7
RBDCNO grade 1	150,000	150,000	-
RBDCNO grade 2	200,000	200,000	-
RBDCNO grade 3	300,000	300,000	-
RBDCNO grade 4	400,000	400,000	-
RBDHCNO	300,000	180,000	120,000
RBDHCNO super	298,500	40,000	258,500
CFAD	86,631	70,000	16,631
Copra meal	60,000	60,000	-
Copra meal powder	300,000	300,000	-
Copra pellet	441,853	400,000	41,853

Marketing is targeted as long as there is a difference in quantity between demand and production. It stops when the supply runs out, so the planned optimal profit has been achieved. To produce according to the optimal product mix decision, 2,482,065 kg of copra is needed. In addition, no mixing process is carried out in this production. Mixing should only be done in emergencies because it is less profitable. If production through a mixing process were more profitable, it would have been proposed in the LP model solution. This optimal solution has been verified and validated. None of the constraint equations is violated by the optimal solution.

A sensitivity analysis was conducted by changing the production capacity. The industry can still tolerate a 5% decrease in capacity, but a more than 5% decrease causes the model to produce non-feasible solutions. A 5% increase in capacity leads to an increase in profits, but an increase of more than 5% does not. Table 4 shows the effect of capacity changes on profit.

Table 4 Production capacity sensitivity analysis

Capacity changes	*Profit (IDR)*
–5%	3,305,371,000
Initial condition	4,451,035,000
+5%	4,642,948,000
+10%	4,642,948,000
+15%	4,642,948,000
+20%	4,642,948,000
+25%	4,642,948,000

3.3 The production flow decision

The next problem facing the coconut oil industry is using two refinery machines that can work in parallel. The second refinery has a smaller capacity. The production cost of refinery 2 is IDR 700/kg with an input capacity of 400,000 kg/week. Refinery 2 can result in the same product yield as refinery 1.

Three possible production flow scenarios are generated to utilise refinery 2. Scenario 1 utilises refineries 1 and 2 to process CCNO into RBDCNO. RBDCNO from refineries 1 and 2 is processed through hydrogenation into RBDHCNO. Furthermore, RBDHCNO is processed into super RBDHCNO through refinery 2. Meanwhile, scenario 2 is a serial production flow scenario. Refinery 1 is used to process CCNO into RBDCNO, and then refinery 2 continues to process RBDHCNO into super RBDHCNO. In scenario 3, refinery 1 processes CCNO into RBDCNO, which is directly sold, and refinery 2 processes CCNO into RBDHCNO.

The three scenarios were run, and the profit from each scenario was compared. The initial condition is production with a single refinery. Scenario 1, with multiple refineries, will increase profit by 28% compared to the initial condition and generates a profit of IDR 6,208,888,000. Scenario 2 generates a profit of IDR 4,451,035,000, the same as the initial condition. Refinery 2 does not impact the profits generated by the coconut oil industry in scenario 2. Scenario 3 generates the lowest profit of IDR 2,488,794,000. Scenario 3 decreases the profits. Therefore, if refinery 2 is added, the best production flow is to follow scenario 1.

4 Discussion

The general LP model needs to be adjusted so that it can be applied to determine the product mix in the coconut oil industry. The best practice in model development starts with developing a product hierarchy, as shown in Figure 3. In developing the model, we found a solution by adding a parent product to the hierarchy of derivative products and by-products so that the LP model can accommodate the specific characteristics of the coconut oil industry. The parent product bridges the calculation of production costs based on the process cost of input materials and allows the division of the yield of the main product and by-products.

The results show that the LP model can determine the product mix with optimal profits, namely 43.9% higher profit than the determination of the product mix based on an intuition that the coconut oil industry has carried out. This finding is also higher than the application of product mix in the other industry, such as the leather industry, which increases potential profits by 39% (Kalwar et al., 2022), and the textile industry, which increases potential profits by 11.8% (Woubante et al., 2019). The sensitivity analysis on the production capacity shows that, without any changes in other parameters, the capacity can only decrease by 5%, and the rest is non-feasible. Increasing production capacity by more than 5% without adding machines that adjust production flow will no longer affect profit generation.

The product mix results imply that the profitable products are RBDHCNO and super RBDHCNO. Therefore, the coconut oil industry needs to focus on these products, and the marketing department needs to be more active in marketing these products. Marketing by-products such as CFAD and copra meal derivatives, namely copra pellets, must also be improved.

The study on the possibility of adding refinery 2 shows that scenario 1 increases the potential profit of the coconut oil industry by 28%. In scenario 1, refinery 2 enhances the capacity of refinery 1 and refinery 2 also performs the task of processing RBDHCNO into super RBDHCNO. In scenario 1, RBDHCNO into super RBDHCNO is only processed by refinery 2. Refinery 1 does not do it.

5 Conclusions

This research has successfully produced an LP model to solve the product mix problem in the coconut oil industry. The LP model is proven to produce product mix decisions that maximise the profits of the coconut oil industry, namely 43.9% or IDR 4,451,035,000. This optimal profit can be increased by increasing production capacity. The sensitivity analysis shows that the capacity changes range is at ±5%. Capacity addition experiments are carried out by adding refinery 2, which can work in parallel. However, adding refinery 2 raises a new problem: determining the optimal production flow by adding refinery 2. Three production flow scenarios are proposed. The proposed production flow in scenario 1 uses refinery 2 as in refinery 1, but refinery 2 is used to produce RBDHCNO super, while refinery 1 is not. Scenario 2 only uses refinery 2 to produce super RBDHCNO. Scenario 3 focuses on refinery 2 to process CCNO to RBDHCNO, while refinery 1 only produces RBDCNO. As a result, scenario 1 is the best scenario for increasing production capacity. With scenario 1, the profit increases by 28% compared to the normal condition.

However, the LP model can only accommodate the deterministic conditions, whereas some parameters in the coconut oil industry are stochastic, such as yield. The recommendation for further research is to develop a model to support product mix decisions that accommodate the stochastic conditions in the coconut oil industry.

Acknowledgements

This study was supported by Universitas Katolik Widya Mandala Surabaya through Research Grant (2352/WM01/N/2022).

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