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Optimization of Packaged Palm Cooking Oil Supply Chain Network to Fulfill Domestic Mandatory Requirements, Export Demands, and Maximize Profit

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Abstract

This study addresses palm oil supply chain network design challenges in Central Kalimantan, Indonesia, focusing on balancing export demands with Domestic Market Obligation (DMO) and biodiesel-35 policy requirements. The research aims to determine optimal facility numbers, locations, and capacities that maximize profitability while meeting both export and domestic cooking oil demands. A Mixed Integer Linear Programming (MILP) model was developed to optimize this multi-level, multi-product, multi-capacity, multi-destination supply chain with transshipment distribution. The model incorporated DMO policy constraints connecting export quantities with domestic demand requirements, with robustness assessed through sensitivity analysis of demand variations, export price fluctuations, and government policy changes. The optimal network configuration requires five palm oil mills, two refinery and fractionation units, five distribution centers with packaging facilities, and two internal packaging plants, generating USD 66,423 thousand monthly profit. Sensitivity analysis revealed that facility decisions are primarily influenced by demand quantities, while price fluctuations mainly affect profitability without changing infrastructure decisions. This model provides strategic guidance for stakeholders to optimize packaged cooking oil supply chains under regulatory constraints. The research demonstrates that DMO policy creates new connections between export-bulk and domestic packaged cooking oil networks. Five strategically located distribution centers with packaging capabilities enable simultaneous fulfillment of export demands while prioritizing domestic requirements. The model's novelty lies in addressing DMO policy's constant ratio element linking export and domestic volumes, contributing to both economic and social welfare considerations.

Keywords: Crude Palm Oil, Domestic Market Obligation, Supply Chain Network Design, Mixed Integer Linear Programming

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1. Introduction

Indonesia and Malaysia are the world's largest palm oil producers, supplying 84% of palm oil globally with 57% from Indonesia and 27% from Malaysia (Ritchie & Roser, 2021). The versatile CPO characteristic is utilized in several sectors, including food, oleochemicals, and energy. The most well-known and consumed CPO derivative product in the food sector is cooking oil, which is one of the nine staple foods for society in Indonesia. In this regard, the price of cooking oil is highly significant with Indonesia's food security. Cooking oil price is highly related to the processing cost and CPO price as its raw material. In Indonesia, CPO price determined by PT. Kharisma Pemasaran Bersama Nusantara (KPBN) through auctions that correlate with international CPO price, meaning that the fluctuation of international price will directly affect domestic cooking oil prices (Amanta & Nafisah, 2022; Irawan & Soesilo, 2021; Novindra et al., 2011).

Between June 2021 and April 2022, global CPO price increased by 67.5% (Arndt et al., 2023), reaching a record value of USD 1,776.96 per metric ton in April 2022. This surge in CPO prices was influenced by several factors: 1. The conflict between Ukraine and Russia, that are both major producers of vegetable oil from sunflower seeds. Supply disruptions due to the conflict led buyers to seek alternative vegetable oil sources, including palm oil. 2. Implementation of the Biodiesel-35 (B35) policy by the Indonesian government, and 3. Global logistics disruptions caused by the COVID-19 pandemic. (Andriessa, 2022). In response to the rising cooking oil prices, the government gradually issued policy instruments from January to November 2022, including establishment of cooking oil Domestic Market Obligation (DMO) and Domestic Price Obligation (DPO) policy (Amir et al., 2022). The DMO policy regulates that export activities can only occur once a certain quantity of domestic cooking oil demand has been met. Not only for securing food national security, DMO also serves as a prerequisite for issuing Export Permit (EP), creates the regulation to act as CPO exports control mechanism. This regulation has introduced changes to CPO supply chain and its derivative products, particularly for export market.

Palm oil commodity businesses face challenges such as lack of a robust domestic distribution network which hindering efficient product distribution and unavailaibility of packaging facilities to convert bulk cooking oil into packaged forms. This discrepancy highlights the conflict between government policy and the existing distribution system for packaged cooking oil in the domestic market. Minyak Goreng Rakyat (MGR) program, established through Permendag No. 49/2022, addresses these challenges. The regulation allows bulk cooking oil from palm oil refineries to be submitted through distributors which listed in Pelaku Usaha Jasa Logistik dan Eceran (PUJLE) platform (Tata Kelola Program MGR, 2022), and retailed as unbranded single plastic package cooking oil. However, the distribution of cooking oil without appropriate packaging gave rise to

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questions about adulteration and hygiene level. The program faces limitations due to imbalanced packaging facilities provided by the government compared to production capacities in palm oil mills and refinery-fractionation plants. This would increase the risk of failure to meet DMO requirements which results in delayed or canceled exports and financial losses such as penalties, stockpiling, and potential quality degradation. The uneven distribution of packaged cooking oil also affects availability and average prices in the market. From October 2022 to April 2023, average prices for packaged cooking oil in 34 Indonesian provinces tended to increase and remained above the Harga Eceran Tertinggi (HET) set by the government (Sistem Pemantauan Pasar Kebutuhan Pokok, 2023) while DMO policy continues to play a crucial role in maintaining domestic cooking oil supply.

However, existing studies have largely focused on macroeconomic implications of CPO price fluctuations (Amanta & Nafisah, 2022; Irawan & Soesilo, 2021; Novindra et al., 2011), biodiesel policy effects (Arndt et al., 2023), or general trade disruptions. Few have examined the direct supply chain impact of the DMO policy, especially in relation to packaging constraints and domestic distribution bottlenecks that affect export readiness and price stability. This study aims to fill this gap by analyzing the intersection between regulatory enforcement, logistical limitations, and their downstream consequences on both domestic availability and international trade performance. Unlike previous works, this research highlights the structural vulnerabilities within the MGR program and provides a systems-level evaluation of policy-induced risk in palm oil supply chains.

2. Literature Review

Research related to supply chain network design has been conducted with various purpose to solve various problem. Supply chain network for palm oil commodities involved selecting markets, plantation locations, processing facility locations, and distribution route choices to balance supply and demand presented by Suksa-ard and Raweewan (2013). The objective was to maximize profit based on multi-product sales revenue (Suksa-ard & Raweewan, 2013). Escobar (2017) focused on determining the expansion capacity value of central distribution centers to enhance supply chain performance, considering three different demand scenarios for each product type at various demand locations over a specific time horizon. Broader scope applied to optimize the supply chain network for bio-ethanol to assess the impact of Brazil's policy on substituting fossil fuels with plant-based fuels (Kostin et al., 2018). Their model included decision variables related to production plant facilities, inventory, inventory expansion, product quantity, and vehicle requirements, aiming to maximize overall supply chain profit. Building upon Kostin et.al (2018) work, Peña González et.al (2021) optimized the palm oil supply chain network in Colombia, adding power generation facilities to improve value chains and reduce

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logistics costs. Model with combining transshipment and Facility Location Problem (FLP) aspects to optimize supply chain network (Hidayat et al., 2021) and integrated strategic-tactical level model investment decisions associated to location, technology, and capacity of the facilities also conducted. The research object and echelon in the Tesfamichael et al. model is biofuel from biomass or the biofuel-to-biomass supply chain (BBSC) system with palm oil as raw material (Tesfamichael et al., 2021). In this study, the application of mass balance in model creation to determine physical flow rate and binary decision variables. Tesfamichael et al.'s (2021) research is basic model for the formation of supply chain network design (SCND), Peña González et al.'s (2021) research fills weaknesses in the details of transportation units' calculation and limitations of the number of delivery quantities. However, none of these studies mentioned policy interventions as a parameter directly affecting demand values in supply chain network design.

3. Materials and Methods

3.1 Problem Statement

The main contribution of this paper is to come up with the optimization model as method for designing packaged palm cooking oil supply chain, considering policies related with tactical and strategic decision. Particularly, this research has considered the static logistic infrastructure in Central Kalimantan, and the product demand variation at each destination zone. The DMO policy restricts palm oil product export by applying precedence element in multi-type demand, which also affects quantity. In this study, the palm cooking oil supply chain comprised five major echelons, palm oil mill, processing plant, fractionation plant, packaging plant or distribution center, and market as demand zones. The problem is described as follows. CPO produced from palm oil mill installed at candidate location o. Each mill has different capacities and capable to produce according to its maximum capacity. CPO produced from mill will be sent to two ports located at n as an export product. Apart from delivered as export product, CPO will be transported to the respective processing plant with capacity c and technology f that are installed at candidate location i. Similar with CPO, the processed products u are delivered to port n to fulfill export demands except for u= FAME which will be delivered to the domestic fuel terminal h. Part of the u= RBDPO will be delivered to an installed fractionation plant with capacity e in candidate location j to produce v. Fractionation product v also delivered to port n as export products, while part of v = RBDPOL will be delivered to the packaging facility with capacity a' located at j', the same location with fractionation plant j, or to distribution center with capacity a located at k. Both will produce packaged cooking oil z and deliver it to respective demand zone m. Superstructure of this problem is shown on Figure 1.

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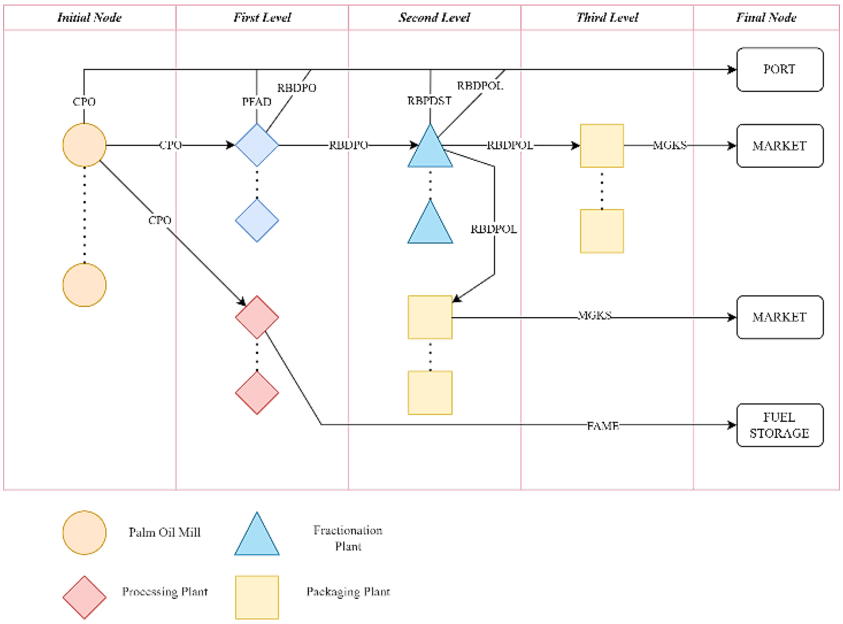

Figure 1. Model Superstructure

In this study, the mixed-integer linear programming (MILP) is selected as the primary optimization approach in supply chain network design, which is justified by its strong capacity to address large-scale, complex systems involving both strategic and tactical decision-making. MILP models allow for the inclusion of both continuous and binary decision variables, making them particularly suitable for problems that require facility location planning, capacity determination, production allocation, transportation mode selection, and demand fulfillment.

MILP enables the formulation of models with various objective functions including minimization of total costs – such as transportation, production, and storage costs; maximization of profit or Net Present Value (NPV); and multi-objective trade-offs involving economic and environmental considerations.

The effectiveness of MILP is supported by a wide range of previous studies. García-Cáceres et al. (2015) and Peña González et al. (2021) demonstrated the use of MILP in designing globally integrated supply chains that simultaneously optimize profitability and sustainability. Kostin et al. (2018) applied MILP to optimize the Brazilian bioethanol supply chain, integrating technology selection, transportation configuration, and facility capacity planning to enhance system-wide profitability. Escobar (2017) employed a scenario-based MILP framework to incorporate financial criteria such as NPV and Present Equivalent Cost (PEC), allowing for investment decision-making under demand uncertainty. Furthermore, the linear and deterministic structure of MILP allows the use of standard solution techniques such as branch-and-bound, and

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it can be extended with metaheuristic algorithms (e.g., Ant Colony Optimization, Genetic Algorithm) to handle large-scale or nonlinear supply chain problems.

3.2 Model Constraint and Mass Balance

To address behaviour palm cooking oil supply chain, the design incorporates as multi-level, multi-product, multi-capacity, multi-destination, multi-type vehicle, along with transshipment in the product distribution system which also involves DMO policy that connect export demand quantities with domestic demand and their impact on location selection, capacity decisions, and overall supply chain profitability.

Indices	
$TBS,CPO,u,v,z \in COM$	Set of Commodity
$a,a',d,c,e \in CAP$	Set of capacity facilities
$a \in A$	Set of distribution center capacity
$a' \in A'$	Set of internal packaging plant capacity
$d \in D$	Set of mill capacity
$c \in C$	Set of processing plant capacity
$e \in E$	Set of fractionation plant capacity
$f \in F$	Set of processing plant techology
$i \in I$	Set candidate locations for processing plant
$j \in J$	Set candidate locations for fractionation plant
$k \in K$	Set candidate locations for internal packaging plant
$h \in H$	Set candidate locations for fuel tank stations
$m \in M$	Set candidate locations for domestic market
$n \in N$	Set candidate locations for port
$o \in O$	Set candidate locations for palm oil mill
$u \in U$	Set of processing plant product
$v \in V$	Set of fractionation plant product
$z \in Z$	Set of packaging plant product
Variables	
$Y_{o,d}$	Binary variable of palm oil mill at o with capacity d
$WCPOo_{o}$	CPO production at mill o
$SCPOo_{o}$	CPO stock at mill o
$QCPOoi_{o,i}$	CPO delivered from mill o to processing plant i
$QCPOon_{o,n}$	CPO delivered from mill o to port n
$WCPOifu_{i,f,u}$	CPO at processing plant i with technology f to produce u
$SCPOi_{i}$	Stock of CPO at processing plant i

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$Wifu_{i,f,u}$	Product u at processing plant i with technology f
$Qinu_{i,n,u}$	Product u from processing plant i delivered to port n
$Qiju_{i,j,u}$	Product u from processing plant i delivered to fractionation plant j
$Qihu_{i,h,u}$	Product u from processing plant i delivered to fuel tank stations h
$SIU_{i,u}$	Stock of product u at processing plant i
$Wju_{j,u}$	Product u at fractionation plant j
$SJU_{j,u}$	Stock of product u at fractionation plant j
$Wjv_{j,v}$	Product v at fractionation plant j
$Qjnv_{j,n,v}$	Product v from fractionation plant j delivered to port n
$Qjkv_{j,k,v}$	Product v from fractionation plant j delivered to distribution center k
$Qjj^{'}v_{j,j^{'},v}$	Product v from fractionation plant j delivered to internal packaging plant j’
$SJV_{j,v}$	Stock of product v at fractionation plant j
$Qkmz_{k,m,z}$	Product z delivered from distribution center k to market m
$SKV_{k,v}$	Stock of product v at distribution center k
$Qjmz_{j,m,z}$	Product z delivered from internal packaging plant j to market m
$SJ^{'}V_{j,v}$	Product v at internal packaging plant j
$B_{i,c,f}$	Binary variable of processing plant at i with technology f and capacity c
$R_{j,e}$	Binary variable of fractionation plant at j with capacity e
$P_{k,a}$	Binary variable of distribution center at k with capacity a
$P^{'}_{j',a'}$	Binary variable of internal packaging plant at j’ with capacity a’
$DmdMGKS_{m,z}$	Packaged cooking oil demand at m
nTB	Number of box trucks
nTT	Number of tank trucks
$Eloi_{o,i}$	Travel distance from palm oil mill o to processing plant i
$Elon_{o,n}$	Travel distance from palm oil mill o to port n
$Elin_{i,n}$	Travel distance from processing plant i to port n
$Elij_{i,j}$	Travel distance from processing plant i to fractionation plant j
$Eljn_{j,n}$	Travel distance from fractionation plant j to port n
$Eljk_{j,k}$	Travel distance from fractionation plant j to packaging plant k
$Elkm_{k,m}$	Travel distance from packaging plant k to market m
$Eljm_{j,m}$	Travel distance from fractionation plant j to market m
Parameters	
$\propto_u$	CPO processing conversion constant
γ_v	Fractionation conversion constant

lCPOi	Maximum CPO stock at processing plant
lui	Maximum product u stock at processing plant
luj	Maximum product u stock at fractionation plant
lvj	Maximum product v stock at processing plant
lvk	Maximum product v stock at distribution center
lvj'	Maximum product v stock at internal packaging plant
$DmdE_{COM,n}$	Commodity export demand at each port n
$DmdFAME_h$	FAME demand at each fuel tank station h
DMO	Domestic market constant
δ_m	Market distribution constant
PF	Fuel price
PD	Delivery price
ConF	Fuel consumption
Fl_{COM}	Fleet capacity
Sp	Fleet speed
WH	Driver’s working hour
UPC_{COM}	Variable cost
SC_{COM}	Storage cost of commodity
$PriceU_u$	Price of product u
$PriceV_v$	Price of product v
PriceCPO	Price of CPO
HET_z	Price of packaged cooking oil
FC_{CAP}	Fixed cost of facilities
RM_{COM}	Raw material price

3.2.1 General Constraint and Mass Balance

Palm Oil Mill

$WCPOo_o \le d \times Y_{o,d}, \forall\ o \in O,\ d \in D$	(1)
$SCPOo_o = WCPOo_o - \sum_{i\in I} QCPOoi_{o,i} - \sum_{n\in N} QCPOon_{o,n}, \forall\ o\in O$	(2)
$\sum_{d\in D} Y_{o,d} \le 1, \forall\ o\in O$	(3)

The total amount of CPO from palm oil mill o should not excel the chosen capacity d (1) CPO mass balance represents in (2) While decision variable $Y_{o,d}$ can only chose one capacity from set D (3).

Processing and Fractionation Plant

$\sum_{f\in F} SCPOi_{i,f} = \sum_{o\in O} QCPOoi_{o,i} - \sum_{f\in F} \sum_{u\in U} WCPOif_{i,f,u}, \forall\ i\in I, f\in F, u\in U$	(4)
$Wifu_{i,f,u} = \propto_f \times \sum_{u\in U} WCPOif_{i,f,u}, \forall\ u \neq PFAD, f\in F, i\in I$	(5)

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$$\mathrm{Wifu}_{i,f,\mathrm{PFAD}}=\sum_{u\in U}\mathrm{WCPOif}_{i,f,u}-\mathrm{Wifu}_{i,f,\mathrm{RBDPO}},\forall\ u\neq \mathrm{FAME},f=\mathrm{Refining},i\in I \tag{6}$$

CPO as raw material stored at processing plant i should equals with amount of CPO delivered from mill o to refining plant i reduced by amount of CPO processed at i through production technology f to produce total products of u (4). The refining conversion factor links between the processing plant product u at i with technology f and CPO as input except for u=PFAD (5) which produced as side product from RBDPO (6).

$$\mathrm{Wifu}_{i,f,u}=\sum_{n\in N}\mathrm{Qinu}_{i,n,u}+\sum_{j\in J}\mathrm{Qiju}_{i,j,u}+\mathrm{SUI}_{u,i},\forall\ u=\mathrm{RBDPO},f=\mathrm{Refining},j\in J,n\in N,i\in I \tag{7}$$

$$\mathrm{Wifu}_{i,f,u}=\sum_{n\in N}\mathrm{Qinu}_{i,n,u}+\mathrm{SUI}_{u,i},\forall,\ u=\mathrm{PFAD},f=\mathrm{Refining},n\in N,i\in I \tag{8}$$

$$\mathrm{Wifu}_{i,f,u}=\sum_{h\in H}\mathrm{Qihu}_{i,h,u}+\mathrm{SUI}_{u,i},\forall\ u=\mathrm{FAME},f=\mathrm{Bioplant},h\in H,\ i\in I \tag{9}$$

The amount of each product u produced at processing plant i through technology f is equal with the amount delivered to their specific destination and product excess (7), (8), and (9).

$$\sum_{c\in C}\sum_{f\in F}\left(B_{i,c,f}\times C_f\right)\geq \mathrm{WCPOif}_{i,f,u},\forall\ u\in U,f\in F,i\in I \tag{10}$$

$$\sum_{c\in C}B_{i,c,f}\leq 1,\forall\ B\in\{0,1\} \tag{11}$$

CPO processed in processing plant i through technology f to produce u cannot exceed the chosen capacity from C (10), each location i can only choose one capacity from set C (11).

$$\sum_{i\in I}\mathrm{Qiju}_{i,j,u}=\mathrm{Wju}_{j,u}+\mathrm{SJU}_{j,u},\forall\ u=\mathrm{RBDPO},\ v\in V,\ j\in J,\ i\in I \tag{12}$$

$$\mathrm{Wjv}_{j,v}=\gamma_v^{\mathrm{FRAK}}\times \mathrm{Wju}_{j,u},\forall\ u\in U,v\in V,j\in J \tag{13}$$

$$\mathrm{Wjv}_{j,v}=\sum_{n\in N}\mathrm{Qjnv}_{j,n,v}+\mathrm{SJV}_{j,v},\forall\ \ v=\mathrm{RBDPST},j\in J,n\in N \tag{14}$$

$$\mathrm{Wjv}_{j,v}=\sum_{n\in N}\mathrm{Qjnv}_{j,n,v}+\sum_{k\in K}\mathrm{Qjkv}_{j,k,v}+\sum_{j'\in J}\mathrm{Qjj'v}_{j,j',v}+\mathrm{SJV}_{j,v},\forall\ v=\mathrm{RBDPOL},j\in J,j'\in J,k\in K,n\in N \tag{15}$$

RBDPO delivered from processing plant i to fractionation plant j equals with RBDPO processed as raw material and excess (12). Similar with processing plant, the fractionation conversion factor links between the product v and RBDPO as input (13). The amount of each product v produced at fractionation plant j equals the amount delivered to their specific destination and excess. (14) and (15)

$$\sum_{e\in E}\left(R_{j,e}\times E_e\right)\geq \mathrm{Wju}_{j,u},\forall\ j\in J,e\in E \tag{16}$$

$$\sum_{e\in E}R_{j,e}\leq 1,\forall\ R\in\{0,1\} \tag{17}$$

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RBDPO processed in fractionation plant j cannot exceed the capacity e (16), each location i can only chose one capacity from set E (17).

Packaging Plant

$\sum_{j\in J} Qjkv_{j,k,v} = \sum_{m\in M} Qkmz_{k,m,z} + SKV_{k,v}, \forall\ v=RBDPOL, j\in J, k\in K, m\in M, z=MGKZ$	(18)
$\sum_{j\in J} Qjj^{'}v_{j,j^{'},v} = \sum_{m\in M} Qjmz_{j,m,z} + SJ'V_{j^{'},v}, \forall\ v=RBDPOL, j\in J, j'\in J, m\in M, z=MGKZ$	(19)
$\sum_{a\in A} P_{k,a} \leq 1, P\in\{0,1\}$	(20)
$\sum_{a'\in A'} P'_{j,a} \leq 1, \forall\ P\in\{0,1\}$	(21)
$\sum_{a\in A}\left(P_{k,a}\times A_a\right) \geq \sum_{j\in J} Qjkv_{j,k,v}$	(22)
$\sum_{a'\in A'}\left(P'_{j,a'}\times A_{a'}\right) \geq \sum_{j^{'}\in J'} Qjj^{'}v_{j,j^{'},v}$	(23)
$P'_{j^{'},a'} \leq R_{j,e}, \forall\ v=RBDPO, j^{'}\in J, j\in J, e\in E$	(24)

RBDPOL packaged at distribution center k or internal packaging plant j' to fulfill DMO of cooking oil. No conversion process in this location, hence the RBDPOL sent from fractionation plant j to k or j' equals with amount delivered to market and RBDPOL stock as raw material at packaging facility (18)(19). There is only one capacity chosen from set for each location of packaging facility (20)(21) and the RBDPOL packaged cannot exceed the capacity (22) and (23). Internal packaging plants can only be built in operating fractionation plant (24).

3.2.2 Export and Domestic Demand Constraint

$\left(DmdE_{COM,n}\right)\times DMO\times \delta_m = DmdMGKS_{m,z}$ $\forall\ u,v,CPO\in COM, n\in N, m\in M, u\neq FAME, z=MGKS$	(25)
$\sum_{j\in J} Qjmz_{j,m,z} + \sum_{k\in K} Qkmz_{k,m,z} = DmdMGKS_{m,z}$	(26)
$\sum_{i\in I} Qihu_{i,h,u} = DmdFAME_{u,h}$	(27)
$\sum_{o\in O} QCPOon_{o,n} + \sum_{i\in I}\sum_{u\in U} Qinu_{i,n,u} + \sum_{j\in J}\sum_{v\in V} Qjnv_{j,n,v} = DmdE_{COM,n}$	(28)

Cooking oil demand for each market obtained by calculating all export demand multiplied by DMO and market distribution constant ratio (25), both can be supplied from distribution center or internal packaging plant (26) while biodiesel demand will be fulfilled directly from bioplant (27) and export demands fulfilled from mill, processing, and fractionation plant (28).

3.2.3 Transportation Unit

$\sum_{o\in O}\sum_{i\in I} \frac{QCPOoi_{o,i}}{Fl_{CPO}} \times \left(\frac{2*ELoi_{o,i}}{Sp\times WH}\right) \leq nTT, \forall\ o\in O, i\in I$	(29)

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$$
\begin{aligned}
&\sum_{o\in O}\sum_{n\in N}\frac{QCPOon_{o,n}}{Fl_{CPO}}\times\left(\frac{2{*}ELon_{o,n}}{Sp\times WH}\right)\leq nTT,\forall\ o\in O,n\in N\\
&\sum_{u\in U}\sum_{i\in I}\sum_{n\in N}\frac{Qinu_{i,n,u}}{Fl_{u}}\times\left(\frac{2{*}ELin_{i,n}}{Sp\times WH}\right)\leq nTT,\forall\ u\neq FAME,i\in I,n\in N\\
&\sum_{u\in U}\sum_{i\in I}\sum_{h\in H}\frac{Qihu_{i,h,FAME}}{Fl_{FAME}}\times\left(\frac{2{*}ELih_{i,h}}{Sp\times WH}\right)\leq nTT,\forall\ \ i\in I,h\in H\\
&\sum_{u\in U}\sum_{i\in I}\sum_{j\in J}\frac{Qiju_{i,j,RBDPO}}{Fl_{RBDPO}}\times\left(\frac{2{*}ELij_{i,j}}{Sp\times WH}\right)\leq nTT,\ \forall\ i\in I,j\in J\\
&\sum_{v\in V}\sum_{j\in J}\sum_{n\in N}\frac{Qjnv_{j,n,v}}{Fl_{v}}\times\left(\frac{2{*}ELjn_{j,n}}{Sp\times WH}\right)\leq nTT,\forall\ v\in V,j\in J,n\in N\\
&\sum_{j\in J}\sum_{k\in K}\frac{Qjkv_{j,k,RBDPOL}}{Fl_{RBDPPOL}}\times\left(\frac{2{*}ELjk_{j,k}}{Sp\times WH}\right)\leq nTT,\forall\ \ j\in J,k\in K\\
&\sum_{k\in K}\sum_{m\in M}\frac{Qzkm_{k,m,MGKS}}{Fl_{MGKS}}\times\left(\frac{2{*}ELkm_{k,m}}{Sp\times WH}\right)\leq nTB,\forall\ \ k\in K,m\in M\\
&\sum_{j\in J}\sum_{m\in M}\frac{Qjmz_{j,m,MGKS}}{Fl_{MGKS}}\times\left(\frac{2{*}ELjm_{k,m}}{Sp\times WH}\right)\leq nTB,\ \forall\ j\in J,m\in M
\end{aligned}
$$

Number of trucks required (29) to deliver bulk or packaged product from source to destination point adapted from Peña González., et al. (2021) model. Number of transportations calculated by the quantity(Q), traveled distance (El), fleet capacity (Fl), maximum vehicle speed (Sp), and the driver's working hours (WH). Packaged cooking oil delivered from location *k* (Qkmz) or *j* (Qjmz) will use box truck unit (nTB), while all bulk products will use tank trucks (nTT).

3.3 Objective Function

$$
\begin{aligned}
\text{Fixed Cost}=&\sum_{o\in O}\left(Y_{o,d}\times FC_{d}\right)+\\
&\sum_{f\in F}\sum_{c\in C}\sum_{i\in I}\left(B_{i,c,f}\times FC_{c}\right)+\sum_{e\in E}\sum_{j\in J}\left(R_{j,e}\times FC_{e}\right)+\sum_{a\in A}\sum_{k\in K}\left(P_{k,a}\times FC_{a}\right)+\\
&\sum_{a'\in A'}\sum_{j'\in J}\left(P'_{j',a'}\times FC_{a'}\right)
\end{aligned}
\tag{30}
$$

$$
\text{Variable Cost}= UPC_{COM}\times\left(\begin{array}{c}
\sum_{o\in O} WCPOo_{o}+\\
\sum_{i\in I}\sum_{f\in F}\sum_{u\in U} WCPOifu_{i,f,u}+\\
\sum_{j\in J}\sum_{u\in U} Wju_{j,u}+\\
\sum_{j\in J}\sum_{k\in K}\sum_{v\in V} Qjkv_{j,k,v}+\\
\sum_{j\in J}\sum_{j'\in J}\sum_{v\in V} Qjj'v_{j,j',v}
\end{array}\right)
\tag{31}
$$

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$\text{Inventory Cost}=\mathrm{USC_{COM}}\times\left(\begin{array}{c}\sum_{o\in O}\mathrm{SCPOo}_{o}+\\ \sum_{i\in I}\mathrm{SCPOi}_{i}+\\ \sum_{i\in I}\mathrm{SIU}_{i,u}+\\ \sum_{j\in J}\sum_{u=RBDPO}\mathrm{SJU}_{j,u}+\\ \sum_{v\in V}\mathrm{SJV}_{j,v}+\\ \sum_{k\in K}\sum_{v=RBDPOL}\mathrm{SKV}_{k,v}+\\ \sum_{j'\in J}\sum_{v=RBDPOL}\mathrm{SJ'V}_{j',v}\end{array}\right)$	(32)
$\text{Delivery Cost}=\mathrm{PD}\times\left(\begin{array}{c}\sum_{o\in O}\sum_{n\in N}\frac{2\mathrm{ELon}_{o,n}\times\mathrm{QCPOon}_{o,n}}{\mathrm{Fl_{CPO}}}+\\ \sum_{o\in O}\sum_{i\in I}\frac{2\mathrm{ELoi}_{o,i}\times\mathrm{QCPOoi}_{o,i}}{\mathrm{Fl_{CPO}}}+\\ \sum_{i\in I}\sum_{n\in N}\sum_{u\in U}\frac{2\mathrm{ELinu}_{i,n,u}\times\mathrm{Qinu}_{i,n,u}}{\mathrm{Fl}_{u}}+\\ \sum_{i\in I}\sum_{j\in J}\frac{2\mathrm{ELij}_{i,j}\times\mathrm{Qiju}_{i,j,RBDPO}}{\mathrm{Fl_{RBDPO}}}+\\ \sum_{j\in J}\sum_{n\in N}\sum_{v\in V}\frac{2\mathrm{ELvjn}_{j,n}\times\mathrm{Qjnv}_{j,n,v}}{\mathrm{Fl}_{v}}+\\ \sum_{j\in J}\sum_{k\in K}\frac{2\mathrm{ELjk}_{j,k}\times\mathrm{Qjkv}_{j,k,RBDPO}}{\mathrm{Fl_{RBDPOL}}}+\\ \sum_{j\in J}\sum_{m\in M}\frac{2\mathrm{ELjm}_{j,m}\times\mathrm{Qjmz}_{j,m,MGKS}}{\mathrm{Fl_{MGKS}}}+\\ \sum_{k\in K}\sum_{m\in M}\frac{2\mathrm{ELkm}_{k,m}\times\mathrm{Qkmz}_{k,m,MGKS}}{\mathrm{Fl_{MGKS}}}\end{array}\right)$	(33)
$\text{Fuel Cost}=\mathrm{PF}\times\left(\begin{array}{c}\sum_{o\in O}\sum_{n\in N}\left(\frac{2\mathrm{ELon}_{o,n}}{\mathrm{ConF}}\times\frac{\mathrm{QCPOon}_{o,n}}{\mathrm{Fl_{CPO}}}\right)+\\ \sum_{o\in O}\sum_{i\in I}\left(\frac{2\mathrm{ELoi}_{o,i}}{\mathrm{ConF}}\times\frac{\mathrm{QCPOoi}_{o,i}}{\mathrm{Fl_{CPO}}}\right)+\\ \sum_{i\in I}\sum_{n\in N}\sum_{u\in U}\left(\frac{2\mathrm{ELinu}_{i,n,u}}{\mathrm{ConF}}\times\frac{\mathrm{Qinu}_{i,n,u}}{\mathrm{Fl}_{u}}\right)+\\ \sum_{i\in I}\sum_{j\in J}\sum_{u=RBDPO}\left(\frac{2\mathrm{ELij}_{i,j}}{\mathrm{ConF}}\times\frac{\mathrm{Qiju}_{i,j,RBDPO}}{\mathrm{Fl_{RBDPO}}}\right)+\\ \sum_{j\in J}\sum_{n\in N}\sum_{v\in V}\left(\frac{2\mathrm{ELjn}_{j,n,v}}{\mathrm{ConF}}\times\frac{\mathrm{Qjnv}_{j,n,v}}{\mathrm{Fl}_{v}}\right)+\\ \sum_{j\in J}\sum_{k\in K}\left(\frac{2\mathrm{ELjk}_{j,k}}{\mathrm{ConF}}\times\frac{\mathrm{Qjkv}_{j,k,RBDPOL}}{\mathrm{Fl_{RBDPOL}}}\right)+\\ \sum_{j\in J}\sum_{m\in M}\left(\frac{2\mathrm{ELjm}_{j,m}}{\mathrm{ConF}}\times\frac{\mathrm{Qjmz}_{j,m,MGKS}}{\mathrm{Fl_{MGKS}}}\right)+\\ \sum_{k\in K}\sum_{m\in M}\left(\frac{2\mathrm{ELkm}_{k,m}}{\mathrm{ConF}}\times\frac{\mathrm{Qkmz}_{k,m,MGKS}}{\mathrm{Fl_{MGKS}}}\right)\end{array}\right)$	(34)

Total fixed cost calculated by multiplying binary variable from each facility with fixed cost (30) while total variable cost obtained by multiplying quantity of raw material processed at each facility with unit price cost (31). Total inventory cost obtained by multiplying stock of each

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commodity at each facility with storage cost (32). Delivery cost is defined as the function of delivery cost per distance unit multiplied by total distance needed to deliver product quantity, with each trip containing maximum product quantity per fleet capacity(33), while fuel cost, similar with delivery cost, considers the value of fleet's fuel consumption(34). Parameter used related to transportation, both unit fleet needed, and fuel or delivery cost presented in Table 1

Description	**Tank truck**	**Box Truck**	**Source**
Capacity (L)	5,000	6,000	
Fuel Price (Rp/L)	9,600	9,600	(PT. Pertamina (Persero), 2024)
Fuel Consumption (km/L)	8	8	
Speed (km/h)	60	60	(Lalu Lintas dan Angkutan Jalan, 2009)
Working Hour (hour/month)	168	168	(Upah Minimum Provinsi tahun 2022, 2021)
Price Delivery (Rp/km)	302	302	

Table 1 Parameter used to calculate cost and unit needed

$$\text{Raw Material Purchase}=\sum_{o\in O} WCPOo_{o}\times RM_{TBS}+\sum_{i\in I}\sum_{f\in F}\sum_{u\in U} WCPOifu_{i,f,u}\times RM_{CPO}+\sum_{j\in J}\sum_{u\in U} Wju_{j,u}\times RM_{RPO}+\begin{pmatrix}\sum_{j\in J} Qjj'v_{j,j',v}\\ +\sum_{j\in J} Qjkv_{j,k,v}\end{pmatrix}\times RM_{ROL} \tag{35}$$

$$\begin{aligned}\text{Revenue}=&\sum_{n\in N}\sum_{o\in O} QCPOon_{o,n}\times PrCPO_{CPO}+\sum_{n\in N,}\sum_{i\in I}\sum_{u\in U} Qinu_{i,n,u}\times PrU_{u}+\\&\sum_{n\in N}\sum_{j\in J}\sum_{v\in V} Qjnv_{j,n,v}\times PrV_{v}+HET\times\begin{pmatrix}\sum_{m\in M}\sum_{k\in K}\sum_{v\in V} Qkmz_{k,m,z}+\\ \sum_{m\in M}\sum_{j\in J} Qjmz_{j,m,z}\end{pmatrix}+\\&\sum_{o\in O}\sum_{i\in I} QCPOoi_{o,i}\times RM_{CPO}+\sum_{j\in J}\sum_{u\in U} Qiju_{j,u}\times RM_{RPO}+\\&\sum_{h\in H}\sum_{u\in U} Qihu_{h,u}\times PrU_{FAME}+\begin{pmatrix}\sum_{j\in J} Qjj'v_{j,j',v}+\\ \sum_{j\in J} Qjkv_{j,k,v}\end{pmatrix}\times RM_{ROL}\end{aligned} \tag{36}$$

Similar with production cost, raw material purchased calculated using quantity of raw material processed at each facility multiplied by raw material cost (35) while revenue calculated by multiplied product quantity sold for export product, local product, and raw material for derivative facility (36).

$$\text{Profit}=\text{Revenue}-\begin{pmatrix}\text{Raw Material Purchase+ Fixed Cost+}\\ \text{Variable Cost+Inventory Cost+}\\ \text{Transportation Cost}\end{pmatrix} \tag{37}$$

$$\text{Max Profit} \tag{38}$$

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Finally, profit as an objective function calculated by reducing revenue by all cost component described in (37) and (38).

4. Case Study

To employ the mathematical model, Central Kalimantan province chosen as scope of the research. Indonesia Statistics Bureau data shown Central Kalimantan potential in palm oil commodity by state this province as the second largest CPO producer with total production value of 8.36 million tons or 17.86% of Indonesia's total CPO production. Palm oil production in Central Kalimantan show increasing trend throughout 2018–2022 (Direktorat Statistik Tanaman Pangan, Hortikultura, dan Perkebunan, 2023), supported by biophysical conditions such as soil quality, climate, and proper infrastructure (Xin et al., 2021) which strengthen potential of development along with proven comparative advantage. The increasing trend in oil palm plantation productivity shows that plantations are potentially able to supply fresh fruit bunch to palm oil mill continuously. Central Kalimantan palm oil industry's upstream potential has not been used to its fullest advantage downstream, shown by only having one biodiesel plant and two refinery-fractionation plant operating until 2024. Since 2013, there has been no discernible shift in the number of CPO processing plant, suggesting that down streaming CPO products as a value chain strategy is still being explored. The high risk of developing downstream palm oil products is influenced by a number of down streaming-related challenges, including the possibility of adverse effects on the environment and society such as sustainability requirements with global standards, exchange rate volatility, and access to international markets (Glenday et al., 2015).

Cooking oil distribution map by Indonesian Central Bureau of Statistics show that most of cooking oil distributed in Central Kalimantan come from outside the province, stated position as an importer from other provinces. One of the main cause is the majority packaged cooking oil plants in Indonesia are located in East Java province (Direktorat Statistik Distribusi, 2023). This becomes an obstacle when the DMO policy which stated packaging form is ratified as the main requirement for issuing export permits. Based on this disparity, this study accommodates the number of packaging plants needed, in accordance with available candidate location plant facility in Central Kalimantan province to meet cooking oil demand.

There are 64 potential locations for palm oil mills, four potential locations for processing plants, three potential locations for fractionation plants (j), and five potential locations for packaging plants (k) which also roles as distribution centers for cooking oil. The potential locations for fractionation plants are also potential locations for internal packaging plants (j’). The destinations are divided into three, namely two export port locations (n) to meet the demand for CPO and export processed products, 14 demand location spread across each city/district (m) as cooking oil end point, and three fuel storage (h) to as biodiesel end point.

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4.1 Input Parameter

4.1.1 Candidate Location

In this study, palm oil mill, refinery and fractionation plants, and packaging plants data obtained refer to the Indonesian Standard Industrial Classification (KBLI) number which will be used to determine number and location of facilities in Central Kalimantan province. Data was obtained from the National Industrial Information System (SIINas) portal managed by the Ministry of Industry, consisting of columns of company names and addresses that have been categorized based on the KBLI number. This addresses converted to coordinates by geocoding using Google Maps Geocoding API tool (Google Developers, 2012) which has advantages in terms of accuracy and completeness of the database. The coordinate shown as latitude and longitude presented in Table 2. The calculation between distances with input data in the form of coordinate points is carried out using the Harvesine formula. Distance calculation is not using existing transportation routes, but shortest distance from the source point to the destination point. Results of distance calculation using harvesine method and distance by plotting destination and source points on Google Maps provide certain deviation. To overcome this gap, the output of the distance calculation using the Harvesine method will be increased by 40%.

4.1.2 Demand Location and Quantity

The end point for packaged cooking oil is a central market located in each city or district in Central Kalimantan. For export product demand, the end point is two export port units, namely Kumai and Sampit port, while fuel storage location for biodiesel product is the delivery point stated in the Decree of the Minister of Energy and Mineral Resources no. 146.K/HK/02/DJE/2021 (Penetapan BU BBM dan BU BBN Jenis Biodiesel serta Alokasi Volume BBN, 2023). In this study, domestic demand data refers to the average consumption of cooking oil per capita per week in each district/city in Central Kalimantan province in percent of total district/city unit, while export demand is obtained from national export-import annual reports.

Code	Longitude	Latitude	Code	Longitude	Latitude
PKS_1	112.7867174	-1.59912	PKS_17	112.7615378	-1.732979
PKS_2	112.1787896	-2.06839	PKS_18	114.1288804	-1.114518
PKS_3	112.32056	-2.28306	PKS_19	111.712691	-2.667392
PKS_4	112.36452428	-2.420117	PKS_20	111.1863623	-2.298740
PKS_5	113.2876784	-1.769790	PKS_21	113.91667	-1.58333
PKS_6	112.5663074	-2.416477	PKS_22	112.9658247	-2.528004
PKS_7	113.33690507	-1.859557	PKS_23	112.8952909	-1.389000
PKS_8	111.75186045	-2.715707	PKS_24	112.2996577	-2.243413
PKS_9	114.04556	-0.90667	PKS_25	112.4311648	-2.673936
PKS_10	111.7211904	-2.745307	PKS_26	111.5968466	-1.882764
PKS_11	112.15333	-2.09056	PKS_27	112.610027	-2.4340182

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PKS_12	112.610027	-2.434018	PKS_28	112.6415521	-2.1331259
PKS_13	114.5220587	-2.581123	PKS_29	114.1606	-2.9439
PKS_14	112.634607	-2.602926	PKS_30	111.4401749	-2.2678146
PKS_15	111.8673509	-2.496877	PKS_31	111.5120185	-1.9863042
PKS_16	111.7327267	-2.491847	PKS_32	111.7860876	-2.237445
Code	**Longitude**	**Latitude**	**Code**	**Longitude**	**Latitude**
PKS_33	112.3163974	-2.342616	PKS_49	111.15056	-1.9975
PKS_34	112.610027	-2.434018	PKS_50	111.5250399	-1.8614925
PKS_35	113.5178283	-1.518578	PKS_51	111.6032146	-2.4025065
PKS_36	114.8830863	-0.754399	PKS_52	112.5663074	-2.4164777
PKS_37	112.5663074	-2.416477	PKS_53	111.34472	-2.23417
PKS_38	112.7500251	-2.108664	PKS_54	111.4661256	-2.2106368
PKS_39	111.4398348	-2.490402	PKS_55	111.1714146	-2.7105638
PKS_40	113.245	-1.68028	PKS_56	112.07639	-2.51167
PKS_41	113.0341244	-2.002161	PKS_57	111.7327267	-2.491847
PKS_42	112.1894441	-2.396500	PKS_58	111.9193382	-2.1886888
PKS_43	113.0548591	-1.975221	PKS_59	112.8451367	-1.9991599
PKS_44	113.0914340	-1.349176	PKS_60	111.6285457	-1.9818979
PKS_45	111.3835203	-1.931785	PKS_61	113.42528	-1.41278
PKS_46	112.5541485	-3.342699	PKS_62	112.1458854	-2.4496396
PKS_47	112.5541485	-3.342698	PKS_63	112.6121057	-1.6448733
PKS_48	112.5541485	-3.342698	PKS_64	112.7973297	-2.024911
Code	**Longitude**	**Latitude**	**Code**	**Longitude**	**Latitude**
PRO_1	111.6389357945	-2.672324	FRAK_3	112.9212167	-2.7247162
PRO_2	111.7974995861	-2.648041	PACK_1	111.6567726905	-2.665543
PRO_3	112.9212167	-2.724716	PACK_2	111.7072637440	-2.7418064
PRO_4	111.8673509	-2.496877	PACK_3	111.6245438055	-2.6796298
FRAK_1	111.6389357945	-2.672323	PACK_4	111.6909941083	-2.745594
FRAK_2	111.7974995861	-2.648041	PACK_5	112.9406984797	-2.538893

Table 2 Code and coordinate location of facilities

Produk	Kumai Port	Sampit Port
CPO	0	4.652
RBDPO	14.250	15.341
PFAD	4.000	0
RBDPOL	18.000	0
RBDPST	5.000	0
Total	41.250	19.993

Table 3 Export demand for each product

(Direktorat Statistik Tanaman Pangan, Hortikultura, dan Perkebunan, 2023)

4.1.3 Cost, Capacity Facility, and Product Price

Parameter related with cost obtained from private companies in the agribusiness sector while the capacity values for each facility are mean of industry data and confronted with Indonesian ministry of industry data, when available. Fixed costs are associated with the capacity selected from the available set, presented in Table 4 and Table 5. using assumption of 330 operating days per year. The value of variable costs depends on the amount of raw materials used for production and inventory cost expressed in USD per MT of product, not related to the location of the facility. Variable cost and inventory cost shown in Table 6.

Maximum storage tank presented in Table 7 obtained using supply chain management approach (Simchi-Levi et al., 2000), with terms storaged value not exceed twice the average product inventory. The average product inventory value obtained from personal communication with palm oil refinery practicioner.

Palm Oil Mill		CPO Processing Plant			Fractionation Plant	
		Capacity	Refinery Plant	Biodiesel Plant		
Capacity	Cost		Cost	Cost	Capacity	Cost
5.800	84.679	42.000	154.982	-	44.800	64.403
17.400	146.010	56.000	-	164.988	50.400	69.335
26.100	192.626	61.600	202.650	569.191	56.000	75.253
34.800	315.124				61.600	93.007
52.200	756.050					

Table 4. Capacity (MT/month) and Fixed Cost (USD/month) for facilities

Capacity	Internal Packing	Distribution Center
252	7.179	-
189	10.091	-
2.016	-	25.005
4.032	-	95.132

Table 5. Capacity (MT/year) and and Fixed Cost (USD/month) for packaging plant

Facility	Variable Cost	Commodity	Storage Cost
Palm Oil Mill	2,91	CPO	1,50
Refinery Plant	11,04	RPO	1,70
Biodiesel Plant	65,97	PFAD	1,00

Fractionation Plant	2,03	FAME	1,50
Internal Packing Plant	111,21	ROL	1,50
Distribution Center	22,19	RST	1,00

Table 6. Variable Cost (USD/MT) and Storage Cost (USD/MT)

Product	lcpof		lu, lui	luj	lvj	lvk	lvj'
	Refinery	Bioplant					
CPO	23.067	28.000					
RBDPO			32.597	10.866			
PFAD			5.880	5.880			
FAME			4.200				
RBDPOL					28.189	1.500	500
RBDPST					14.781		

Lcpof = CPO in processing plant
lu, lui = product u in processing plant
luj = product u in fractionation plant
lvj = product v in fractionation plant
lvk = product v in packing plant k
lvj’ = product v in internal packing plant j

Table 7. Maximum product quantity in storage tank (MT/month)

Product price for both local and export market presented at Table 8 in unit USD/MT. Product export price obtained by forecasting product prices from 2011 to 2021 using 2-month interval moving average method. Local CPO price in this research is final price auction from Belawan and Dumai Port (PT. Kharisma Pemasaran Bersama Nusantara, 2021), while the selling prices of RBDPO and RBDPOL are obtained from private agribusiness company. The price of fresh fruit bunches is calculated based on the Regulation of the Minister of Agriculture no.1 2018

Product	**Export Price**	**Domestic Price**
FFB	-	210,71
CPO	911,95	771,00
RBDPO	1.059,43	745,00
PFAD	912,32	-
FAME	-	1.100,00
RBDPOL	1.055,98	825,00
RBDPST	911,95	-
MGKS	-	940,00

Table 8. Product Price (USD/MT)

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4.2 Model Verification and Validation

The verification and validation of the MILP model are conducted through a combination of structural and numerical procedures:

4.2.1 Model Formulation Verification

The model is developed using a mass balance approach and structured into multiple subsystems according to the hierarchical levels in the supply chain (e.g., plantation, mill, refinery, storage, and export terminals). The logical consistency of variables, constraints, and objectives is verified by reviewing the mathematical formulation—ensuring that key constraints such as capacity limits, product flow balances, and expansion decisions are correctly modeled (e.g., Peña González et al., 2021).

4.2.2 Numerical Validation via Case Studies

Case studies are implemented using empirical or historical data. The performance of the optimized supply chain configuration is compared with the existing configuration in terms of profitability and resource efficiency.

4.2.3 Sensitivity Analysis

Sensitivity tests are conducted to examine the responsiveness of the model outcomes to changes in key parameters (e.g., transportation costs, demand levels, processing capacities). This step is critical for evaluating the robustness of the model and identifying key drivers of supply chain performance.

This systematic verification and validation process ensures that the MILP model is not only mathematically sound but also relevant and applicable for supporting real-world decision-making in complex supply chain systems.

5. Result and Discussion

To solve the MILP model MATLAB R2024a is used to obtain the global optimal solution, with three cases used to test the validity of the model namely change in export demand, product price, and DMO ratio value. The case test is carried out continuously, so that the parameters that have been changed will be applied for test in the next case.

5.1 Location and Capacity

Table 9 shows that changes in quantity of export demand affect the selection of the location points of the palm oil mill, processing plants, and fractionation plant facility. The changes in export demand made in case 2 are -8.80% at the Kumai port and +55.15% at the Sampit port.

Case	1		2		3		4	
Key Parameter changed	Base		Export Product Demand		Export Product Price		DMO Ratio	
Facility	L	K	L	K	L	K	L	K
Palm oil mill	PKS_8	17.400	PKS_8	26.100	PKS_8	26.100	PKS_10	26.100
	PKS_10	26.100	PKS_14	26.100	PKS_14	26.100	PKS_14	26.100
	PKS_19	17.400	PKS_19	26.100	PKS_19	26.100	PKS_19	26.100
	PKS_22	26.100	PKS_22	26.100	PKS_22	26.100	PKS_22	26.100
	87.000		104.400		104.400		104.400	
Processing Plant	PRO_1	61.600	PRO_2	56.000	PRO_2	56.000	PRO_1	56.000
	PRO_3*	56.000	PRO_3*	56.000	PRO_3*	56.000	PRO_3*	56.000
	117.600		112.000		112.000		112.000	
Fractionation Plant	FRAK_1	44.800	FRAK_2	44.800	FRAK_2	44.800	FRAK_1	44.800
	FRAK_2	44.800	FRAK_3	44.800	FRAK_3	44.800	FRAK_3	44.800
	89.600		89.600		89.600		89.600	
Distribution Center	PACK_1	4.032	PACK_1	4.032	PACK_1	4.032	PACK_1	2.016
	PACK_2	4.032	PACK_2	4.032	PACK_2	4.032	PACK_2	4.032
	PACK_3	4.032	PACK_3	4.032	PACK_3	4.032	PACK_3	4.032
	PACK_4	4.032	PACK_4	4.032	PACK_4	4.032	PACK_4	2.016
	PACK_5	2.016	PACK_5	4.032	PACK_5	4.032	PACK_5	2.016
	18.144		20.160		20.160		14.112	
Internal Packaging Plant	FRAK_2	252	FRAK_2	252	FRAK_2	252	-	-
			FRAK_3	252	FRAK_3	252		
	252		504		504		0	

L = Location, K = Capacity
* Plant has refinery and bioplant technology in one location

Table 9 Capacity and location chosen, based on changed parameter

This change of location indicates that the model will try to find the shortest route to the destination port, minimize transportation cost component and maximize profit from export sales. The location of PKS_10 which is closer to the port of Kumai (PORT_1) is replaced with the

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location of PKS_14 which is closer to the port of Sampit (PORT_2) as shown on Figure 2 so that fulfillment of export demand at Sampit port can be met more easily and efficient in its operations. In capacity selection, models also gives decision to increase production quantity. Related with decision to build packaging plant, model shows that increase in export quantity affects addition of packaging facility needed. In case 1, the five packaging plant units which also act as distribution centers and one internal packaging plant unit have been operating with full utility according to the largest capacity choice. Increase in export demand will impact packaged cooking oil, gives model a decision to add a new packaging facility, namely located in FRAK_3. Change in the location decision of processing plant PRO_1 to PRO_2 is respond of model to minimize costs, namely moving from a processing plant to a fractionation plant in same location will provide lower total cost.

Figure 2 Model Output of palm oil mill, processing plant and fractionation plant, and port

The increase in export prices did not change the decision of facility location. In fact, the results were the same as case 2, both in terms of location point selection and capacity. Case 4 is an example of decreasing value of DMO ratio that can occur when the quantity of packaged cooking oil has been fulfilled or there has been an oversupply of CPO and processed products. Results showed that all packaged cooking oil were supplied from distribution centers and no internal packaging factories were built. It also implies decreased necessity of packaged cooking oil to be distributed to the market, as seen from the change in total capacity of distribution center. Based on this case, it is known that decrease in DMO parameter from 30% to 20% is sensitive to a decrease in total production capacity of packaging plants by 30%.

Validation of location conducted by comparing it to the existing system. In the development of the supply chain network design along with case that have been carried out, five packaging plants, namely PACK_1 to PACK_5, were still decided to be built and operated as distribution centers

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to meet the DMO. This shows that there will be an additional chain in the cooking oil supply chain which will change the main pattern of cooking oil distribution. The results of this solution are in accordance with the 2023 cooking oil trade distribution report which shows the addition of one intermediary facility unit due to activities carried out by the government to control and maintain price stability (Direktorat Statistik Distribusi, 2023).

5.2 Profit Value

The increase in export demand affects revenue and related costs. In relation with utilization and selected production capacity, results of case 2 show that average utilization of processing plant increases from 68% to 76%, which can reduce the proportion of fixed costs from total supply chain costs by 0.05%. Variable cost calculated based on the number of product units produced, so the value will be proportional to raw material quantity converted into products. In case 2 at the fractionation plant facility, the average utility increases from 51% to 68% and increase total production cost to 67,334 USD. Similar to variable costs, the cost of purchasing raw materials will increase in proportion to the amount of raw materials processed into products, while transportation costs change according to the amount of demand for export product and packaged cooking oil supply to domestic market.

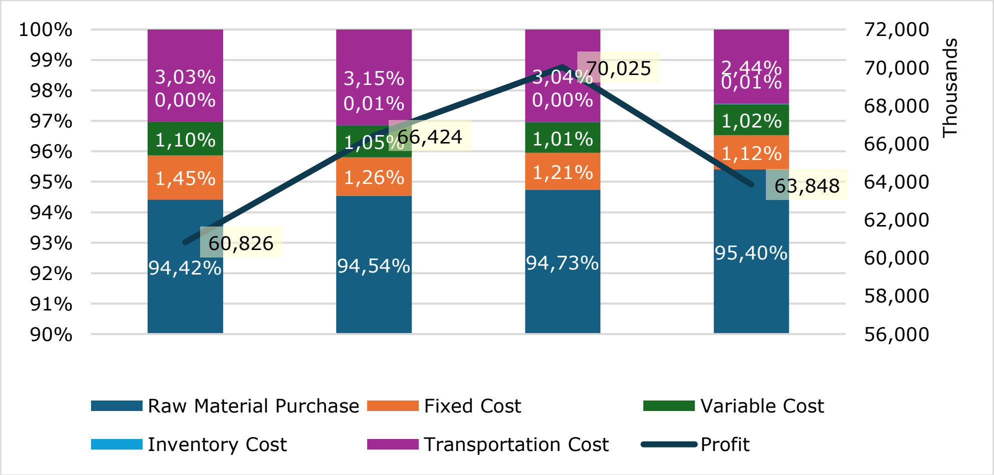

Figure 3 Cost composistion and profit from each case

Transportation costs in case 2 also increase at distribution center facility, but decrease at internal packaging plant. This indicates that the transshipment aspect based on the distance traveled has considered by model. Model results show that increasing product export prices do not affect the risk of failure in strategic decision making, but have potential to result in loss of revenue from export sales due to the influence of government policies, so that increasing selling price of palm

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oil products or global CPO prices have a negative impact on CPO export volume (Anzani et al., 2023; Prabowo et al., 2021; Yanita & Suandi, 2023). To balance this, the key role in CPO and its derivative products in this system is determination of DMO ratio value carried out by the government.

Form of supply chain network modeled in case two and three has taken into account the DMO element of 30% as a government policy that controls over export activity. Domestic demand adjusted to the export target can be met from internal packaging plant or distribution centers with full utility against largest capacity value available from set. This means that even though export prices increase, amount of quantity that can be exported will not increase because it is limited by the DMO provisions and packaging plant capacity. In this phenomenon, the DMO ratio policy set by the government can be said to have succeeded in controlling excess export quantities to maintain the fulfillment of domestic needs. In addition, the determination of the DMO policy in the form of packaged cooking oil in the form of direct consumer goods to end customers in the supply chain also controls money and goods transactions in the domestic market.

Case 4 trials DMO ratio parameter which represents a policy instrument in balancing export activities of CPO and its derivative products while meeting the needs of packaged cooking oil. The output results show that decrease in DMO ratio from 30% to 20% will reduce the overall supply chain profit by -6,177,155 USD or 8.82%.

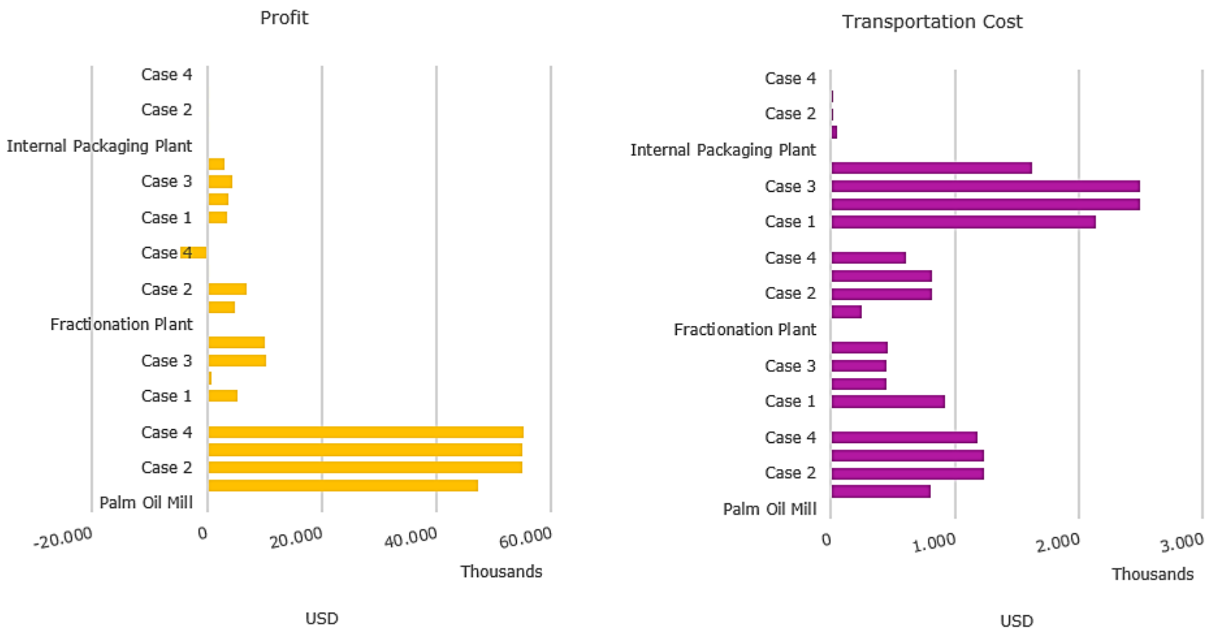

Figure 4 Profit and transportation cost in each facility and case

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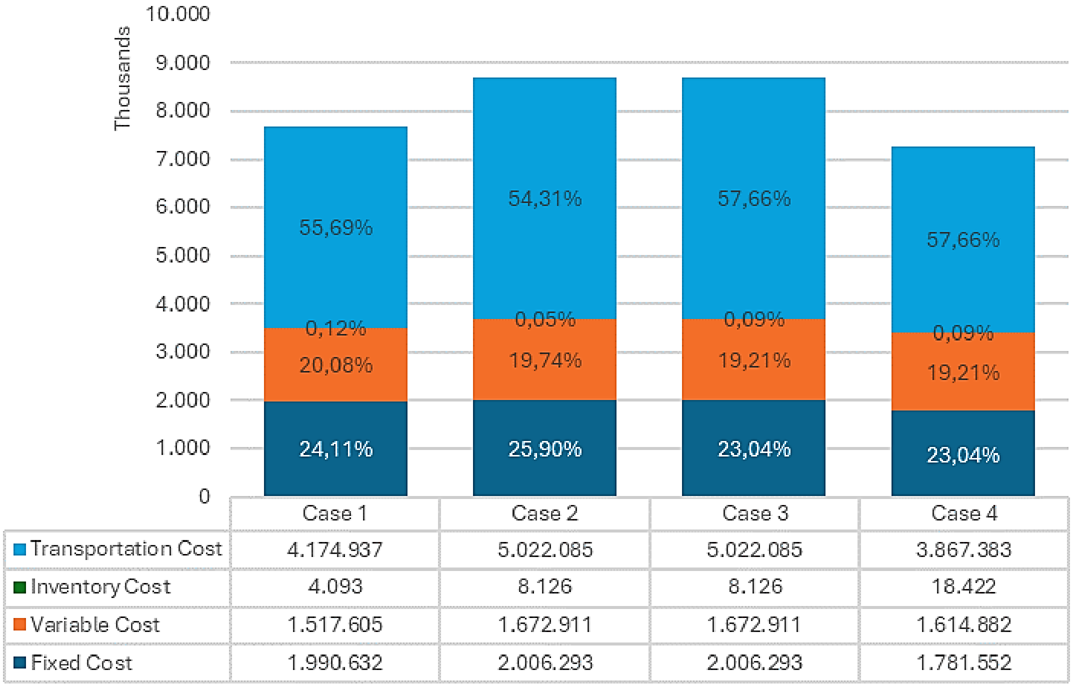
Based on the type of facility, the lowest profit is in the fractionation plant that produces RBDPOL as a raw material for packaged cooking oil. As shown in Figure 4, profit at fractionation plant is a deficit with value of -4,547,638 USD. This is mainly caused by decrease in income from sale of cooking oil without being offset by increase in export products, so the quantity of product sales will decrease.

5.3 Transportation Aspect

The comparison of cost component without raw material purchase cost presented in Figure 5, show that transportation costs are the highest cost component with value of 2,491,363 USD, obtained from cases 2 and 3. It takes an average proportion of 55.69% of the total inventory, variable, and fixed costs in all cases that have been conducted. Related to facility location, highest transportation costs come from the distribution center facility as shown in Figure 4. Geographically, the location of the packaging plant is closer to the upstream source than destination location. Packaging plant which also roles as distribution center, in accordance with its established function has a double cost burden: taking RBDPOL as raw material to the processing plant, and deliver packaged cooking oil to all market destination points as shown on Figure 6.



	Case 1	Case 2	Case 3	Case 4
🟦 Transportation Cost	4.174.937	5.022.085	5.022.085	3.867.383
🟩 Inventory Cost	4.093	8.126	8.126	18.422
🟧 Variable Cost	1.517.605	1.672.911	1.672.911	1.614.882
🟦 Fixed Cost	1.990.632	2.006.293	2.006.293	1.781.552

Figure 5 Transportation, inventory, variable, and fixed cost component Comparison

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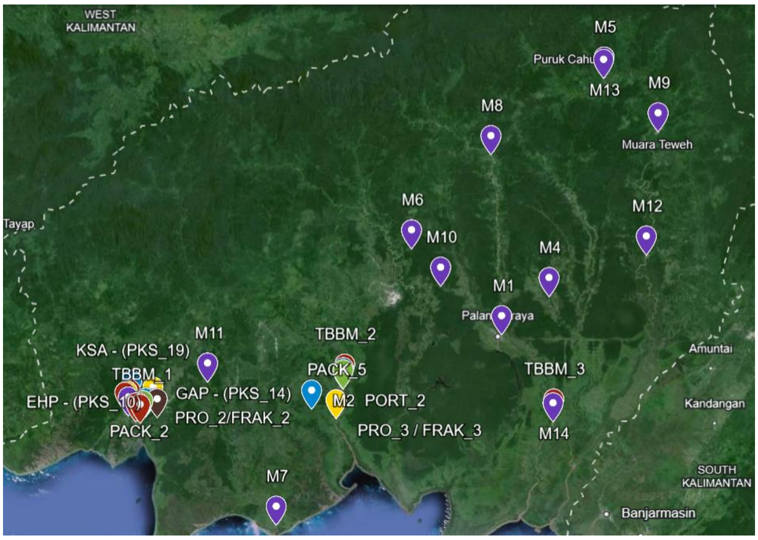

Figure 6 Model output of facility location

5.4 Scalability Assessment

The proposed Mixed Integer Linear Programming (MILP) model demonstrates notable scalability potential, primarily through its modular and flexible design. The model's multi-level approach, which accommodates multiple facility types (five palm oil mills, two refineries, five distribution centers, and two packaging plants), provides a robust framework for potential expansion. However, its current scalability is constrained by several limitations, including a static time horizon of a single month and a geographical scope limited to Central Kalimantan province. The model's ability to handle multi-product, multi-capacity, and multi-destination scenarios suggests it could be scaled vertically by extending the time frame, broadening geographical coverage, or incorporating more complex facility configurations. The researchers' approach of using percentage adjustments for distance calculations and limiting the analysis to a single product type also indicates room for technological and methodological scaling.

5.5 Replicability Analysis

The model exhibits strong replicability characteristics, primarily driven by its methodological transparency and clear optimization approach. The explicit use of Mixed Integer Linear Programming (MILP) with a well-defined objective of profit maximization provides a clear blueprint for potential replication. Key replicability components include the systematic consideration of demand variations, export product prices, and government policy impacts. However, the model's replication is challenged by its location-specific constraints, particularly the unique Indonesian Domestic Market Obligation (DMO) policy environment. The model's sensitivity to demand quantities and its ability to integrate policy constraints offer a flexible

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template that could be adapted to different supply chain contexts, albeit with careful consideration of local economic and regulatory nuances.

5.6 Policy-Sensitivity Evaluation

The MILP model demonstrates exceptional policy-sensitivity, particularly through its innovative integration of the Domestic Market Obligation (DMO) policy directly into the supply chain optimization framework. The model proves highly responsive to policy variations, showing significant changes in facility number, location, and capacity based on different policy scenarios. Its ability to connect export and domestic cooking oil networks through a constant ratio element reveals a sophisticated approach to policy constraint modeling. The research illustrates that changes in demand quantities can substantially impact strategic decisions, while product pricing primarily affects overall supply chain profitability. This policy-sensitive approach provides policymakers and industry stakeholders with a powerful tool for exploring different regulatory scenarios, understanding their potential impacts, and making informed strategic decisions.

6. Conclusion

This model shows that the priority factor of demand fulfillment, namely the existence of cooking oil demand that must be fulfilled first before export activities, will provide decision to build five packaging plants in all candidate locations to meet the DMO. Without the construction of a packaging plant, export activities will not be able to be conducted. This is also shown in the change of packaged cooking oil distribution pattern after implementation of the DMO policy. There was an addition of one chain to the distribution network, namely a sub-distributor. The emergence of a sub-distributor is the impact of packaging plant which also acts as an opener for the domestic distribution network. Study case shown that changes in export demand quantities affect facility location choices and lead to lower packaging plant capacity decision, increase in export selling prices has a positive effect on total profit without changing the configuration of facilities and their capacity, decrease in the DMO ratio from 30% to 20% resulted in a lower packaging plant capacity decision. Packaging cooking oil supply chain network design that can meet export demand, domestic cooking oil needs, and maximize the supply chain profit value obtained from the results of case test 2 with a total profit of 66,423,748 USD per month.

This research contributes significantly to public policy-based Supply Chain Network Design (SCND) by connecting policy implementation with operational planning. The study shows how government policies, particularly Indonesia's Domestic Market Obligation, can be integrated into supply chain models through a simple ratio that links export volumes to domestic supply needs. This advances SCND theory by creating a clear relationship between policy requirements and

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facility decisions. For policymakers, the model offers a practical tool to see how policy changes affect supply chain structure, capacity, and profits. By showing how policy affects distribution channels and facility investments, this research provides a method for creating policies that balance economic goals with domestic market needs. The model's approach to optimizing export profits while ensuring domestic supply represents a valuable contribution that can be used by other countries with similar challenges.

Potential expansion of this study in the future is adding a time element to the model so changes that occur in observed variables can be known within a certain time span. Second is implementing penalties or additional costs for re-opening packaging plant, also adding types of packaging other than standing pouches such as pillow packs or jerrycan to add quota multiplier parameters. Related with scope of research, adding a wider scope, especially for the Eastern Indonesian destination area, can also be done.

Declaration of Conflicting Interests

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