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Optimizing Transportation Routes and Costs in Crude Palm Oil Supply Chains Using Linear Programming: A Case Study of PT.X, OKU Regency, South Sumatera

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ABSTRACT

Transportation is one of the important driving factors that significantly affects the supply chain. One of company in OKU Regency that produce crude palm oil encounter transportation problems, particularly during the rainy season because of the inadequate road infrastructure and a lack of transportation modes. Delivery of crude palm oil amounting to 90% of total production was carried out from PT.X heads to the company that produces cooking oil. The delivery of crude palm oil to PT.Y arrived later than originally scheduled. Linear programming methods can be used to describe mathematical formulations with the objective to solve PT.X transportation problems. From the stages of collecting, processing data and testing formulations using the LINDO application, it was discovered that under ideal conditions there are 9 alternative transportation routes from origin city B to destination city TJ with the shortest time of 9 hours, the delivery of transportation mode uses 12 tanks which 9.5 tons capacity and 17 tanks which 8 tons capacity and the lowest transportation costs are Rp. 487.580. The results of the general mathematical formulation can then be used to solve transportation problems for other cases with similar conditions to PT.X. This mathematical formulation can be used for making decisions in selecting transportation routes, selecting modes and transportation costs. Changes in production factors such as capacity, number of orders, travel time, delivery distance, fuel prices, toll rates can change the decisions taken by entering their actual values in the general mathematical formulation that has been produced.

1. Introduction

The driving factors determine supply chain performance. The driving factors are facilities, supplies, transportation, resources, information and prices. Transportation activity also affects the distribution of a product. Transportation, which involves moving products from one location to another, accounts for the majority of the costs in the supply chain. We need to design and implement the right transportation system that balances responsiveness and efficiency. This balance also needs to be reached throughout a product's supply chain. This will help the competitive strategy of tracking the performance of supply chain companies in order to keep the agro-industry under control and come up with ways to make it more competitive [1]. The speed of transportation affects the costs incurred by the company. The faster the transportation time, the more expensive the costs incurred, but the more responsive to changes. The combination of modes of transportation can be done by air, land such as couriers, trucks, and trains, through water such as pipelines, ships and can also use intermodal. The main infrastructure elements are roads, ports, airports, stations and canals. In almost all countries, the government has an essential role in building and managing infrastructure [2].

Cycles or stages in the supply chain include consumer ordering, replenishment, manufacturing, and procurement. While the parties involved in the supply chain are customers, retailers, distributors, manufacturers/components and suppliers of components or raw materials. Factors that are also considered in the agricultural product distribution system are farmer knowledge and business processes [3].

PT.X is a company producing Crude Palm Oil (CPO) products in the OKU regency, South Sumatra. General Description The most extensive oil palm plantations in Indonesia are on the islands of Sumatra, Kalimantan, Sulawesi and Java. South Sumatra Province is one of the largest palm oil-producing areas. The area of plantations in South Sumatra is 1,215,476 hectares in 2021, with a total weight produced from oil palm plantations in this region reaching 14.5 million tons in 2019 and increasing to 23.3 tons in 2021. One of the areas in South Sumatra that produce plantation crops of oil palm is the Ogan Komering Ulu (OKU) district, with palm oil production of around 113,428 tons per year. In the palm oil agroindustry in the OKU regency, the parties involved in the supply chain are farmers, cooperatives/farmer groups, and palm oil mills (PKS). After completing CPO production, the company distributes CPO to derivative companies from its palm oil. The most extensive distribution of CPO products from the CPO agroindustry in the OKU regency is to the city of Lampung.

The cooking oil delivery plan in the Crude Palm Oil supply chain at PT. X involves the company owner, cooking oil company owner and other stake holders. The company owner in the supply chain is considered as a producer and the company owner is considered as a consumer who will use CPO to make cooking oil.

PT.X sends its CPO products to several consumers, in this case, a cooking oil producer, with a proportion of 90% for PT.Y and the remaining 10% for other companies with more minor business scales. CPO products are shipped from one point of origin to one point of destination. The point of origin is city B, and the destination point is city TK. The delivery route that is usually used is only two routes. Drivers usually consider route selection decisions by looking at road conditions. The problem faced by the company is that the delivery time will be slower during the rainy season due to poor infrastructure conditions. The standard delivery time is 8-9 hours with a delay tolerance time of 3 hours.

CPO delivery at PT.X use land transportation modes, namely tank trucks with a maximum capacity of 9.5 tons. To improve delivery services in fulfilling the delivery contract for a total of 500 tons which must be delivered within two weeks, the company needs to consider adding a tanker truck with a capacity of under 9.5 tons due to road conditions and maximum transport capacity requirements. Meanwhile, the available tank trucks are 12, with a capacity of 9.5 tons.

Transportation problems faced the need to find the best solution. The transportation problem is a fundamental network problem that we already know, and the goal of solving the problem is to find a similar product delivery method from the origin to the point of destination to get the minimum total cost [4]. Research with rice commodities for cultivation and distribution also uses a transportation model to minimize overall costs [5]. Other transportation research has also seen that transportation disruptions have an impact and are detrimental to the quality of transportation during product delivery [6]. This research considers a product supply chain system with a short life cycle with capacity suppliers, retailers, and various transportation routes with different disruption risks, uncertain transportation costs, and uncertain demand.

Previous research has applied several methods to solve transportation problems. An approach of multi-start Iterated Local Search (ILS) was developed to minimize distribution costs of Two-stage transportation fix cost (TSTP-FC), with the primary solution using local search procedures to improve exploration, perturbation mechanisms and neighbourhood operators to diversify the search and also present a soft computational approach to solve TSTP-FC associated with routes in optimization problems in the framework of genetic algorithms [7].

The following research proposes a different approach, an effective hybrid Genetic algorithm (GA), to solve TSTP-FC. The results are compared with existing solution approaches on 150 benchmark instances and 50 new randomly generated instances of larger size [7]. Another TSTP for soft drink products and the Mixed-Integer Linear Programming (MILP) model created is for multiple products with a fixed cost to open a DC, and a DC only serves one retailer [8]. This previous research differs from research that raises the issue of PT.X. The transportation process at PT.X does not follow two stages, and delivery do not go through the distribution centre. However, they are sent directly from the company to consumers.

The approach to be used in this research uses a mathematical approach using the Linear Programming method. Several mathematical programming model approaches have been carried out in addition to using Linear Programming, namely using Mixed Integer Programs, Stochastic Programs or Possibilistic programs, as well as heuristics such as Genetic Algorithm, Lagrangian, particle swarm optimistic and hybrid of simulated annealing and tabu search [9]. Application of the BeWhere model, a mixed integer linear programming model for energy system optimization, was used to assess the costs and benefits of optimizing the regional palm oil supply chain [10]. The aim of minimizing costs by implementing linear programming integration is found in research [11] for coffee production in Pasuruan Regency. Another application of linear programming to determine the maximum amount of production is obtained by previously forecasting the amount of production per period [12] [13] considered the model parameters uncertain.

The research aims to find the best ways to transport Crude Palm Oil (CPO). This includes finding the quickest route from the city of origin to the city of destination, figuring out how many types of land transportation are needed based on contractual obligations and production capacity, and figuring out how much the whole transportation process will cost. The study seeks to optimize transportation by selecting the shortest delivery route, choosing the appropriate land transportation mode, and minimizing overall transportation costs. Making use of transportation optimization techniques is necessary to find the best answer to every issue.

2. Method

2.1 Research framework

The research framework explains why research is carried out, the research process and what will be obtained from the research. This research is a case study research at PT.X which had CPO's transportation problems which was sent to PT.Y which is a company that processes CPO into cooking oil. This research was conducted to solve transportation problems for delivering CPO from PT.X, especially during the rainy season. The approach used in this research is a quantitative descriptive research approach because the data collected is data generated from the actual situation that occurred at PT.X.

The mathematical formulation is formed by applying the Linear Programming method and the shortest route problem. Linear Programming is applied to get optimal results from company problems arranged into a mathematical model of linear relationships. In this case study, the expected decision result is a multi-decision. The application of Linear programming can be made widely in various fields, one of which is transportation problems. With small adjustments, this mathematical method will assist in resolving issues for other businesses that are comparable to the one that PT.X experienced.

2.2 Research Stages and Data Collection Technique

This research was conducted by following several research stages starting from the detailed formulation of transportation problems faced by the company to solving the problems in ideal conditions. The stages of research that were conducted are as: (i) Detailed formulation of transportation problems, (ii) Research data collection, (iii) Formation of mathematical formulations, (iv) Formulation trials, (v) Data analysis, (vi) Determination of ideal conditions.

Data collection technique in this research were carried out in several ways:

a. Literature Review: To gather theoretical foundations related to transportation optimization. References were collected from books, previous studies, and scientific journals.
b. Field Research: To obtain real-world data on CPO transportation activities and facilities at PT.X.

The data collected from the field research is data to form a general mathematical formulation that can be used to solve transportation problems. The data are: (i) Existing and alternative delivery routes, (ii) Delivery time per route, (iii) Number of contracts, (iv) Maximum transport capacity, (v) Availability of tanker trucks, (vi) Production capacity, (vii) Distance from the factory to the delivery location, (viii) Fuel costs, (ix) Fuel consumption rates, and (x) Toll rates.

2.3 Mathematical Formulation and Model Testing

The mathematical formulation is developed using Linear Programming and tested using LINDO 6.1 software. The formulation is structured to achieve optimal transportation solutions in three key aspects: Selection of the Shortest Transportation Route and Time, Selection of Land Transportation Modes, Selection of Minimal Transportation Cost

2.4 Model Validation and Evaluation

The model is validated through:

a. **Comparison with real company data**: Ensuring model predictions align with actual transportation conditions.
b. **Scenario testing**: Simulating different weather conditions and demand fluctuations.
c. **Sensitivity analysis**: Examining the impact of changes in fuel costs, toll rates, and delivery constraints on the final cost and route efficiency.

3. Results

The collected data, both existing data that occurs in the company and data generated from the researcher's exploration process, are used to create an initial mathematical formulation as described in sub-chapter 2.2 above.

The mathematical formulation that has been formed is tested using the LINDO 6.1 software. After the trial, an analysis is carried out to determine whether the mathematical formulation that has been formed has been successful. The formulation that can run well is then used to solve the transportation problems of PT.X so that an ideal condition is obtained and answers the research objectives of getting the shortest transportation route, getting the shortest transportation time, getting the most ideal number of transportation modes and getting the most minimal transportation costs.

3.1 Selection of the shortest transportation route and shortest delivery time

The data set required to obtain the shortest transportation route and shortest delivery time are:

a. The delivery route from the starting city to the destination city (Existing route and alternative route). From figure 1, it is known that city B is the city of CPO origin and city TK is the destination city for CPO drivement. There are nine alternatives CPO delivering routes from city B to city TK.

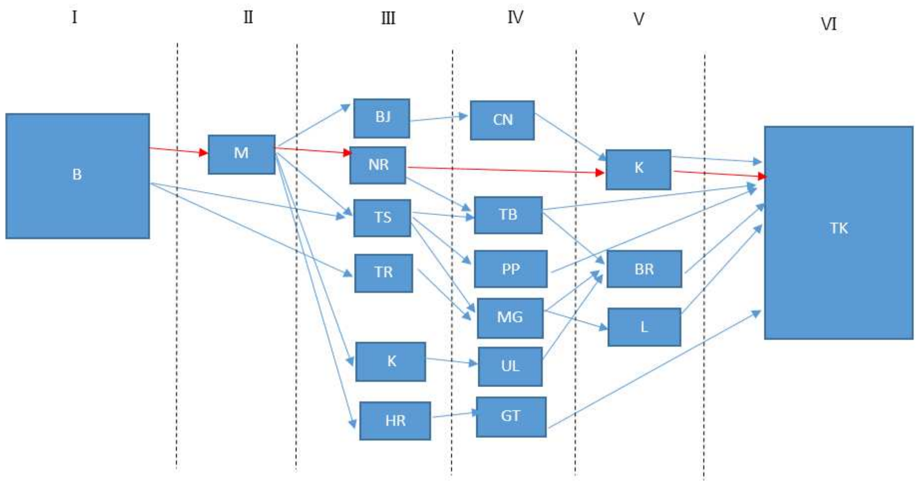

Figure 1. Route from city B to city TK

b. Delivery time per route

The CPO delivery time from each city is used as input data to obtain the shortest total delivery time. CPO delivery time from each city can be seen in Table 1

Table 1 Distribution Time per route

	Time (hour)					
Route	1	2	3	4	5	6
1	B	M	BJ	CN	K	TK
		1.5	2	1.5	1.5	3.5
2	B	M	NR	K	TK	
		1.5	3	1	3.5	
3	B	M	TS	PP (tol)	TK	
		1.5	3	1	6	
4	B	TS	MG	BR	TK	
		4.3	1.7	3.5	1	
5	B	TR	MG	L	TK	
		4.6	5.4	3.7	0.5	
6	B	TS	TB	BR	TK	
		4.3	5.7	2	1	
7	B	M	KB	UL	BR	TK
		1.5	4.1	1.4	1.6	0.8
8	B	M	NR	TB	TK	
		1.5	3	2.5	2.3	
9	B	M	HR	GT	TK	
		1.5	5.2	2.1	0.6	

Delivery route data, alternative routes and delivery time per route are used to form a mathematical formulation using the Linear Programming method with the aim of minimizing the delivery distance from starting city to the destination city [14]. The result of the mathematical formulation are as follows:

Objective function:

Minimize

$$Z = \sum_{i=1}^{n} \sum_{j=2}^{n} t_{i,j} \tag{1}$$

Subject to :

$$\sum_{i=1}^{n} \sum_{j=2}^{n} t_{i,j} \leq T_i \tag{2}$$

$$\sum_{i=1}^{n}\sum_{j=2}^{n} t_{i,j} + ET \leq T_{hi} \quad (3)$$

Parameters :

$t_{i,j}$ = distance from city i to city j
ET = extra time delivery for rainy season
i = route 1,2,…n

Decision variables :
T_i = maximum time set by the company for route i
$T_{h,i}$ = maximum time set by the company in the rainy season for route i

The formulation formed is used to obtain ideal conditions and solve PT.X transportation problems. The ideal result are total time from city B to TK was calculated for the nine alternative routes, divided into six sections and the shortest time result is 9 hours, located on route 2, the B-M-NR-K-TJ route.

3.2 Selection number of land transportation modes

The data set required to obtain the number of land transportation modes are:

a. Order contract PT. Y
   The number of contract orders from PT. Y is 500 tons with a maximum delivery period of 2 weeks
b. Maximum transport capacity and availability of existing tank trucks
   The maximum transport capacity of the tank trucks is 9.5 tons with the number of tanks available with a capacity of 9.5 tons, which are 12 tanks.
c. Production capacity per month in 202X
   Production capacity is divided into 3 parts, namely low, medium and high production capacity. Where low capacity of PT.X occurs in March to July, medium production capacity occurs in January, February, August, November and December while high capacity occurs in September and October. Production capacity data is assumed to be based on secondary data from company per year and holding company annual report per year

Table 2 Production capacity

Month	Production Capacity (ton)
Januari	2200
Februari	2000
Maret	1000
April	1200
Mei	1200
Juni	1500
Juli	1000
Agustus	2200
September	2500
Oktober	2500
November	2200
Desember	2200
	21700

The linear programming method is used to make a mathematical formula that tries to find the best number of land transportation modes based on order contracts, maximum transport capacity, the number of existing tank trucks, and production capacity [15]. The results of the mathematical formulation are as follows:

Objective Function:

Maximize $Z = \sum_{w=1}^{n} \sum_{m=1}^{n} M_{w,m}$ (4)

Subject to:

$\sum_{m=1}^{n} KA_m \sum_{w=1}^{n} \sum_{m=1}^{n} M_{w.m} \geq \sum_{w=1}^{n} S_w$ (5)

$\sum_{w=1}^{n} S_w \leq \sum_{w=1}^{n} KP_w$ (6)

$M_{w,m} \geq 1$ (7)

$KA_m \geq 1$ (8)

Parameters:
$\mathrm{KA_m} = \text{transport capacity mode m}$
$\mathrm{S_w} = \text{supply in week w}$

Decision Variables:
$\mathrm{KP_w}$=production capacity per week w
$\mathrm{M_{w,m}} = \text{modes week w with mode m}$

From the mathematical formulation that has been tried, it was found that to deliver CPO in accordance with the agreed number of delivery contracts and production capacity, the ideal condition is achieved if the number of land transportation modes with a capacity of 9.5 tons are 12 tanks and the number of 8 tons are 17 tanks.

3.3 Selection of minimal transportation cost

The data set required to obtain minimal transportation cost are:

a. The distance from city B to city TK

Table 3 Distribution distance per route

Route	1	2	3	4	5	6
1	B	M	BJ	CN	K	TK
		33.3	72	42	36	110.2
2	B	M	NR	K	TJ	
		33.3	93	29	110.2	
3	B	M	TS	PP (tol)	TK	
		33.3	94	30	178	
4	B	TS	MG	BR	TK	
		129	51	104	26	
5	B	TR	MG	L	TK	
		138	161	112	14	
6	B	TS	TB	BR	TK	
		129	171	52.5	24	
7	B	M	KB	UL	BR	TK
		33.3	122	41.2	47	22
8	B	M	NR	TB	TK	
		33.3	88.2	73.3	66.4	
9	B	M	HR	GT	TK	
		33.3	156	61	18	

b. Fuel costs: The cost of the fuel used is Rp.6800/liter

c. Assuming fuel usage: The use of fuel used is 1:5

d. Miscellaneous expense: Included in other costs is the toll fee of IDR 126,500

Distribution distance per route, fuel cost, fuel usage and toll fee are used to form a mathematic formulation using the Linear Programming method with the aim of minimizing transportation cost [16]. The result of the mathematical formulation are as follows:

Objective Function:

Minimize $Z = \sum_{i=1}^{n} \sum_{i=1}^{n} C_{i,j} \ t_{i,j}$ (9)

Subject to:

$C_{i,j} = \left(\frac{1}{PB}\right) HB + BT_{i,j}$ (10)

$C_{i,j} \geq 0$ (11)

$BT_{i,j} \geq 0$ (12)

Parameters:

$t_{i,j}$ = distance from city i to city j

HB = fuel cost

$BT_{i,j}$ = toll fee from city i to city j

Decision Variables:

$C_{i,i}$ = cost from city i to city j

From the mathematical formulation that has been tried, it is obtained that the minimum transportation cost is Rp.487.580. The transportation costs are obtained by entering the shortest transportation distance, fuel costs, fuel usage and toll fee.

4. Discussion

There are several potentials that can be developed for futher research. By applying the linear programming method, researchers can formulate research objectives mathematically. Then, the formulation results can be used further in companies with similar industries or companies with insignificant changes in the limiting function.

The first potential for futher research is research by considering several changes to some limiting function values in the mathematical formulation so that the formulation is more detailed and comprehensive. The second potential for futher research is research by developing alternative methods that can solve problems more efficiently and produce better- quality solutions

5. Conclusion

There are several results obtained from this study. The first conclusion which is the answer to the first objective is to get the route with the shortest distance and the shortest transportation time that can be taken by the CPO delivery company to the cooking oil processing company. The second conclusion is to get the ideal number of transportation modes for transporting the CPO and the last conclusion is to get the most minimal transportation costs. In the case study at PT.X, it was found that there are 9 alternative transportation routes from origin city B to destination city TJ with the shortest time of 9 hours, the delivery of transportation mode uses 12 tanks which 9.5 tons capacity and 17 tanks which 8 tons capacity and the lowest transportation costs are Rp. 487.580.

The main contributions of this research are (i) Of the nine alternative routes that can be taken from city B to TK, one alternative route has the shortest delivery time. The selection of the shortest time considers the maximum delivery time and additional delivery time during the rainy season. (ii) The number of modes of land transportation is obtained by using tank trucks already available at the company with additional capacity tank trucks below. This mode of transportation considers the maximum modal capacity that can go through transportation routes, the maximum transportation capacity, and the amount of CPO demand and supply per period. (iii) Minimum transportation costs are obtained by calculating and comparing the distance travelled for all alternative routes from city B to Tk, fuel costs, fuel usage and toll fees for alternative routes via toll roads.

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