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Optimizing Distribution Costs Using Linear Programming in Refinery Sugar Manufacturer

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This research was conducted at a private producer in Indonesia involved in the manufacturing of refined sugar commodity products. The company presently operates three factories situated in three cities across three distinct provinces. The objective of this study is to minimize the transportation costs incurred from shipping tonnage sugar from manufacturers to customers' warehouses. This study concludes that contemporary commodities companies might utilize linear programming to enhance their operations, particularly in logistics and distribution processes. Further, a new distribution pattern involving multiple warehouses and distribution centres, or customer warehouses, was proposed to the management team, resulting in more efficient distribution costs compared to previous expenditures. The analysis concludes that the minimum transportation cost for sugar dispatching is IDR 7,755,670,000. The warehouse at Cilegon has been designated to distribute the product to Jambi, South Sulawesi, DKI Jakarta, and Bogor. The warehouse in Surabaya was designated to transport sugar to Bandung, Pekalongan, Semarang, and Sidoarjo. A warehouse in Makassar was assigned to deliver sugar to Bogor, Bandung, Palangkaraya and Banjarmasin in Indonesia. The research suggests that management can employ a linear programming approach to minimize transportation costs by optimizing the sugar distribution pattern from each warehouse to the customer. This study suggests that management can use a linear programming approach and combine this method with a transportation model to minimize transportation costs. Management team, particularly the logistics department, can utilize two phases of solution analysis which is the initial and optimal solution.
Keywords: Distribution centers, food processing, linear programming, shipment, transportation cost.

INTRODUCTION

Indonesia is one of the largest sugar-consuming countries in the world, with a consumption value of up to 7.2 million tons in 2022 (Kompas Research Center). This number increased significantly compared to the previous year (increased by 50.2%). Currently, there are only some sugar manufacturers in Indonesia. Effectiveness and efficiency of work processes are absolutely necessary to maintain the competitiveness of sugar factories. One potential enhancement is the optimization of the sugar distribution route from the warehouse or depot to the customers, which includes factories and warehouses (Andry *et al.*, 2023). Companies can surpass their competitors by emphasizing their distribution process, which is a critical component of supply chain management (Azmi *et al.*, 2017). Globalization forces companies to cooperate with each other to form a supply chain cycle, since companies cannot operate and thrive independently (Tardyonic *et al.*, 2015). If a firm can achieve efficacy in its supply chain management, it will be pivotal to its business success (Bowersox *et al.*, 2013; Tannady *et al.*, 2023). Simon *et al.* (2014) stated that the prevailing competition exists between the supply chain management of specific firms and that of others.

Distribution is one of the key players and important elements of the success of supply chain management (Mwakyeja and Kimario, 2024). Improper management of the distribution process by the organization will lead to an ineffective and inefficient distribution system (Sertyesilisik, 2022), Improper management of the distribution process by the organization will lead to an ineffective and inefficient distribution system (Sertyesilisik, 2022). Ineffective distribution has several parameters such as delays in sending products and picking up products. Both factors have implications for manufacturing and customer service levels (Chandani *et al.*, 2022). Inefficient distribution will be identified based on logistics costs (Chen *et al.*, 2023). Various variables contribute to excessive distribution costs, including fleet

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expenses, labor costs, fuel expenditures, port fees, and inventory management systems (Geo *et al.,* 2022) Management must exhibit seriousness and focus to establish a vertical plan encompassing strategic, tactical, and operational levels (Hidayat and Tannady, 2023). Numerous studies have demonstrated that effective distribution management influences the efficacy of supply chain management and, consequently, affects business performance (Mishra *et al.,* 2023). This research was conducted at a private producer in Indonesia specializing in the manufacture of refined sugar commodities. The company presently operates three factories situated in three cities across three distinct provinces. The monthly supply capacity of these three depots is 27,950 tons. The three warehouses are responsible for supplying sugar to twelve industries and customer warehouses. No explicit regulations govern the distribution flow from the warehouse to the market. Every shipping line possesses a distinct transportation cost per ton of product. This research will develop a mathematical model employing a linear programming approach to map sugar distribution. Figure 1 illustrates the delivery path.

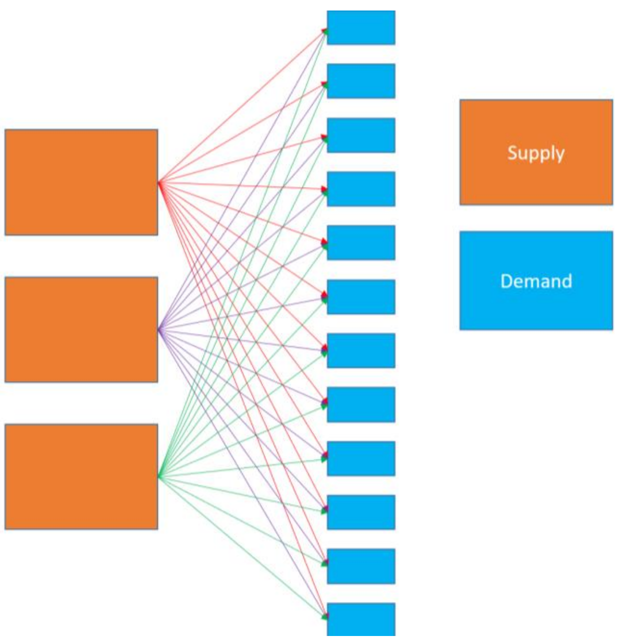

Figure 1. Illustration of transportation networks.

Figure 2 illustrates a map of Indonesia, indicating the locations of warehouses for both manufacturers and customers. Manufacturer's warehouses are located in three provinces: West Java, East Java, and South Sulawesi, whereas customer warehouses are divided over eight provinces: Jambi, South Sulawesi, Jakarta, West Java, Central Java, East Java, Central Borneo, and South Borneo.
This study employs an optimization approach utilizing linear programming techniques. Linear programming is a mathematical method for addressing difficulties arising from constrained resources (Anne *et al.,* 2020; Sarbjit, 2018; Uddin *et al.,* 2022). Numerous prior research has demonstrated that linear programming can assist organizations in resolving diverse optimization challenges. Solaja *et al.* (2019) employed linear programming to assist the organization in resolving its production planning issue. Adebiyi *et al.* (2014) addressed a production issue at a paint industry by the application of linear programming. Fagoyinbo and Ajibode (2014) employed linear programming to optimize personnel management, particularly in reducing training costs. This study aims to offer a solution for the company's management team through a suggestion for the distribution pattern of refinery sugar from all producers' warehouses to all consumers' warehouses, utilizing the transportation model approach and linear programming method.

Figure 2. Location of warehouses for manufacturer and customer.

MATERIALS AND METHODS

Interviews were conducted with marketing managers and supply chain managers concerning company warehouse locations, customer warehouse locations, production policies, logistics costs per ton from each manufacturer's warehouse to the customer's warehouse, the monthly consumer's demand and monthly production capacity of the manufacturer. This study aims to reduce distribution and logistics costs from three sugar warehouses to twelve market locations by utilizing the distribution routes from each warehouse to each market, incorporating the capacity of each warehouse and the demand from each client as constraints.
The research was conducted from August to November 2023.
Sarbjit (2018) outlines several steps in the Linear Programming analysis method: defining the problem's aim (maximize or minimize), identifying all relevant variables, formulating the objective function, establishing the constraints, and solving the formulation.

Following are formulations of linear programming:
Objective Function (max or min)
$Z = c_1x_1 + c_2x_2 + \dots\dots\dots + c_nx_n$
Constraints Function
$a_{11}x_1 + a_{12}x_2 + \dots\dots\dots + a_{1n}x_n \ (\leq, =, \geq) b_1$
$a_{21}x_1 + a_{22}x_2 + \dots\dots\dots + a_{2n}x_n \ (\leq, =, \geq) b_1$
$a_{31}x_1 + a_{32}x_2 + \dots\dots\dots + a_{3n}x_n \ (\leq, =, \geq) b_1$
.
.
.
.
$a_{m1}x_1 + a_{m2}x_2 + \dots\dots\dots + a_{mn}x_n \ (\leq, =, \geq) b_1$

RESULTS AND DISCUSSION

This section begins by making a list of the location of each warehouse, both the manufacturers and customers' warehouses. Tables 1 and 2 show the location and province of each warehouse. Code F within the table indicates the manufacturer's warehouse and C is the code for customer's warehouse.

Table 1. Location of manufacturer's warehouse.

No.	Code	Location	Province
1	P1	Cilegon	West Java
2	P2	Surabaya	East Java
3	P3	Makassar	South Sulawesi

Source: Firm's Secondary Data

Table 2. Location of customers' warehouse.

No.	Code	Location	Province
1	C1	Jambi	Jambi
2	C2	Palembang	South Sulawesi
3	C3	Jakarta Barat	Jakarta
4	C4	Bogor	West Java
5	C5	Bandung	West Java
6	C6	Pekalongan	Central Java
7	C7	Semarang	Central Java
8	C8	Sidoarjo	East Java
9	C9	Palangkaraya	Central Borneo
10	C10	Banjarmasin	South Borneo

Source: Firm's Secondary Data

Warehouse locations for manufacturers are located in the cities of Cilegon, Surabaya and Makassar. Warehouses P1 and P2 are located in the island of Java while warehouses P3 is located in the island of Sulawesi. Customer's warehouses are located in the cities of Jambi, Palembang, Jakarta Barat, Bogor, Bandung, Pekalongan, Semarang, Sidoarjo, Palangkaraya and Banjarmasin. Warehouses C1 and C2 are located in the island of Sumatera, warehouses C3, C4, C5, C6, C7 and C8 are located in the island of Java, warehouses C9 and C10 are located in the island of Kalimantan.

Table 3. Cost per tons (IDR).

Customer's Warehouse	Producer's Warehouse		
	P1	P2	P3
C1	461.50	1023.75	1558.70
C2	285.35	846.95	1382.55
C3	60.45	512.20	1041.95
C4	83.20	526.50	962.10
C5	161.20	503.75	940.00
C6	296.40	282.75	819.00
C7	349.70	226.20	761.80
C8	570.05	20.15	551.20
C9	967.20	499.20	773.50
C10	1092.65	624.65	690.95

Source: Firm's Secondary Data

The transportation costs in table 3 are the logistics costs for each ton sent from P1, P2 and P3 to each customer's warehouse (C1-C10). As the delivery distance increases, transportation expenses will rise correspondingly. The most expensive transportation cost ships from P3 to C1 (Makassar → Jambi). The cheapest transportation costs ships from P2 to C8 (Surabaya → Sidoarjo).

Table 4. Customers' demand.

No.	Code	Total demand /month (tons)
1	C1	2.100
2	C2	1.750
3	C3	6.100
4	C4	5.400
5	C5	4.800
6	C6	1.650
7	C7	1.800
8	C8	2.400
9	C9	7.000
10	C10	1.250

Source: Firm's Secondary Data

Table 5. Factories' capacities.

No.	Code	Total Capacity/Month (Tons)
1	P1	12.475
2	P2	6.250
3	P3	9.225

Source: Firm's Secondary Data

The transportation issue for this organization is a balanced transportation problem, as the total demand from each customer closely aligns with the total capacity of each production, which is 27,950 tons. The producer's warehouse situated at P1 (Cilegon) has the largest capacity, totaling 12,475 tons. The highest demand originates from clients in C3 (DKI Jakarta), totaling 6,100 tons.
The next step is to determine all variables of the research, whether the objective function is maximizing or minimizing, the constraint functions, both the constraints which owned

by producers in the form of production capacity and constraints from the customer side, namely the number of demands. The study used 30 variables, namely the amount of tonnage for each route that connecting the producer's warehouses and the customer's warehouses. Following are the variables to be identified in the research.

Variables:

From i to j

F1 to C1-10: X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}

F2 to C1-10: X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}, X_{17}, X_{18}, X_{19}, X_{20}

F3 to C1-10: X_{21}, X_{22}, X_{23}, X_{24}, X_{25}, X_{26}, X_{27}, X_{28}, X_{29}, X_{30}

Following is the formula for the objective function to minimize transportation cost.

Objective Function (Minimize):

Z_{min} = 461.500 X_1 + 285.350 X_2 + 60.450 X_3 + 83.200 X_4 + 161.200 X_5 + 296.400 X_6 + 349.700 X_7 + 570.050 X_8 + 967.200 X_9 + 1.092.650 X_{10} + 1.023.750 X_{11} + 846. 950 X_{12} + 512.200 X_{13} + 526.500 X_{14} + 503.750 X_{15} + 282.750 X_{16} + 226.200 X_{17} + 20.150 X_{18} + 499.200 X_{19} + 624.650 X_{20} + 1.558.700 X_{21} + 1.382.550 X_{22} + 1.041.950 X_{23} + 962.100 X_{24} + 940.000 X_{25} + 819.000 X_{26} + 761.800 X_{27} + 551.200 X_{28} + 773.500 X_{29} + 690.950 X_{30}

Each variable represents tons distributed from manufacturer to customer. X_1 means number of tons distributed from P1 to C1, X_2 means number of tons distributed from P1 to C2, etc. X_{11} represents tons distributed from P2 to C1, X_{12} is tons distributed from P2 to C2, etc. X_{21} represents the amount of sugar distributed from P3 to C1, X_{22} represents the amount of sugar distributed from P3 to C2, etc.

Constraints:

Limitation of Capacity

$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} \leq$ 12.475 (Capacity of Factory in P1)

$X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + X_{16} + X_{17} + X_{18} + X_{19} + X_{20} \leq$ 6.250 (Capacity of Factory in P2)

$X_{21} + X_{22} + X_{23} + X_{24} + X_{25} + X_{26} + X_{27} + X_{28} + X_{29} + X_{30} \leq$ 9.225 (Capacity of Factory in P3)

Limitation of Demand

$X_1 + X_{11} + X_{21}$ = 2.100 (Number of demands in C1)

$X_2 + X_{12} + X_{22}$ = 1.750 (Number of demands in C2)

$X_3 + X_{13} + X_{23}$ = 6.100 (Number of demands in C3)

$X_4 + X_{14} + X_{24}$ = 5.400 (Number of demands in C4)

$X_5 + X_{15} + X_{25}$ = 4.800 (Number of demands in C5)

$X_6 + X_{16} + X_{26}$ = 1.650 (Number of demands in C6)

$X_7 + X_{17} + X_{27}$ = 1.800 (Number of demands in C7)

$X_8 + X_{18} + X_{28}$ = 2.400 (Number of demands in C8)

$X_9 + X_{19} + X_{29}$ = 700 (Number of demands in C9)

$X_{10} + X_{20} + X_{30}$ = 1.250 (Number of demands in C10)

The constraint function is the constraint on the limitation amount of capacity in the producer's warehouses and limitation on the number of customer demand (Nwabueze *et al.,* 2022). The function of limitation of capacity consists of three formulas and involves 10 routes for each one manufacturer's warehouse. Meanwhile, the function of the limitation of demand consists of 10 formulas and involves three routes for each customer's warehouse.

Table 6. Allocation of tons' sugar.

Customer's Warehouse	Producer's Warehouse			Demand
	P1	P2	P3	
C1	2100	-	-	2100
C2	1750	-	-	1750
C3	6100	-	-	6100
C4	2525	-	2875	5400
C5	-	400	4400	4800
C6	-	1650	-	1650
C7	-	1800	-	1800
C8	-	2400	-	2400
C9	-	-	700	700
C10	-	-	1250	1250
Capacity	12475	6250	9225	27950

Source: Data Processing

The results of data processing using all the formulas show a proposed distribution pattern that can be given to the company, in agreement with Maheshwari *et al*. (2023). Transportation costs will be more efficient if the warehouse in Cilegon distributes 2100 tonnes to customers in Jambi, 1750 tonnes to Sulawesi Selatan, 6100 tonnes to DKI Jakarta and 2525 tonnes to Bogor. Warehouse in Surabaya distributes 400 tonnes to Bandung, 1650 tonnes to Pekalongan, 1800 tonnes to Semarang and 2400 tonnes to Sidoarjo. Warehouse in Makassar distributes 2875 tonnes of sugar to Bogor, 4400 tonnes to Bandung, 700 tonnes to Palangkaraya and 1250 tonnes to Banjarmasin. This distribution pattern will result transportation cost of IDR 7.755.670.000.

***Conclusion*:** The analysis concludes that the minimum transportation cost for sugar dispatching is IDR 7,755,670,000. The warehouse at Cilegon has been designated to distribute the product to Jambi, South Sulawesi, DKI Jakarta, and Bogor. The warehouse in Surabaya was designated to transport sugar to Bandung, Pekalongan, Semarang, and Sidoarjo. Warehouse in Makassar was assigned to deliver sugar to Bogor, Bandung, Palangkaraya and Banjarmasin. The research suggests that management can employ a linear programming approach to minimize transportation costs by optimizing the sugar distribution pattern from each warehouse to the customer. Future researchers can employ other approaches to minimize sugar transportation costs or use the application of linear programming on different research objects. Future researchers may utilize other variables which not examined in this study–such as costs incurred from delays in delivery causes by bad weather, problems with modes of transportation or loading and unloading problems that occur in the shipping and receiving areas

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SDGs addressed: Decent work and economic growth, Industry, innovation and infrastructure, Zero hunger.

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