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Unbalanced Transportation Problem For Crude Palm Kernel Oil (CPKO) Distribution Cost Optimization Using ASM Modification Method

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Abstract
In the global agricultural sector, Indonesia is the largest producer of palm oil within the agricultural sector. Palm fruit is then processed into palm oil. This research optimizes the distribution cost of crude palm kernel oil (CPKO) at Agrojaya Perdana by addressing transportation imbalances. The study uses a Modified ASM method, which adds a dummy column to handle excess production capacity, followed by row and column reduction to identify optimal allocations. The initial solution from the Modified ASM method is then further optimized using the Stepping Stone method. The results show a significant cost reduction of Rp 15,132,000.00 (approximately 2.251%) compared to the initial distribution cost of Rp 672,336,000.00, demonstrating the effectiveness of the combined Modified ASM and Stepping Stone methods in resolving transportation imbalances and optimizing distribution costs for PT. Agrojaya Perdana.

Keywords: ASM Modification, Optimization, Stepping Stone, Distribution

1. Introduction

In the global agricultural sector, Indonesia is the largest producer of palm oil, a significant agricultural sector. The oil palm plant originates from Nigeria, West Africa. The palm fruit is processed into palm oil, a crucial commodity in global trade. Palm oil is produced from fresh fruit bunches (FFB) into crude palm kernel oil (PKO) (Nugraha, 2020). Palm kernel oil, often known as Crude Palm Kernel Oil (CPKO), is derived from processed palm kernels. These can be used as raw materials for oleochemicals with numerous benefits, such as medium-chain triglycerides/oil.

Transportation problems exist in the distribution of Crude Palm Kernel Oil (CPKO). In today's world, transportation issues are a common challenge across various industries, including CPKO distribution. This imbalance occurs when the amount of production capacity does not match the demand at various delivery destinations. Generally, transportation with limited supply to several destinations with specific demands at minimum transportation costs. The transportation model is used in goods distribution. It helps to streamline goods distribution, maximize allocation from source to destination, and reduce total transportation costs (Affandi, 2019). Over time, new methods have emerged to optimize transportation costs without the need to find an intermediate feasible solution, including the Zero Neighboring Method, Zero Suffix Method, Zero Point Method, Exponential Approach Method, ASM Method, and others (Handayani & Ahmad, 2023).

PT. Agrojaya Perdana, a leading Indonesian Crude Palm Kernel Oil (CPKO) producer with a large workforce, faces the challenge of managing optimal distribution costs. This is particularly due to the imbalance between transportation capacity and CPKO demand at various locations. Therefore, a mathematical method the Modified ASM Method is used to solve PT. Agrojaya Perdana transportation problems, aiming to optimize CPKO distribution costs and avoid waste by aligning transportation capacity with CPKO demand. The ASM method, a transportation problem method introduced by Abdul Quddoos, Dr. Shakeel Javaid, and Prof. Mohd Masood Khalid (hence the acronym ASM), focuses on zero-valued reduction results. It proceeds by assigning indices to zeros and allocating based on the smallest index. This optimization technique aims to minimize transportation costs while considering transportation capacity and demand constraints at each destination. Therefore, a Modified ASM method is needed for unbalanced transportation problems.

The Modified ASM algorithm involves adding a dummy row/column with zero costs, significantly affecting reduction results. Additional algorithms are thus needed to optimize the zeros appearing in the dummy row/column (Fawa'idl, Pradana, & Rahmalia, 2022). Therefore, optimizing distribution costs using the Modified ASM and Stepping Stone methods is crucial. Unbalanced distribution problems can lead to significantly increased costs and reduced service quality for customers. This research aims to provide a simple solution that PT Agrojaya Perdana can implement to overcome the problems of distributing CPKO from the factory to each company.

2. Methods

The general transportation problem is shown in the following diagram

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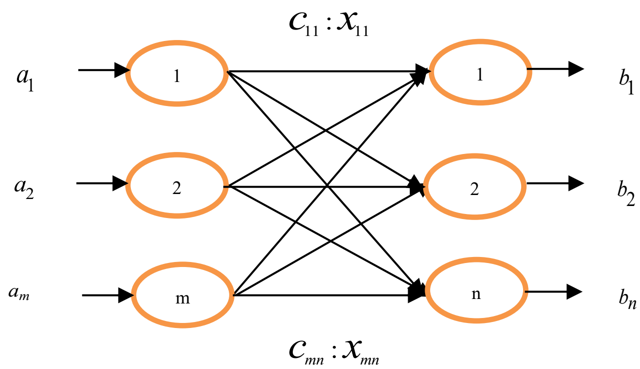
Figure 1
Common Transportation Problems



The model diagram above shows m sources to n destinations. The arrows indicate the routes connecting m to n, satisfying supply and demand.

Table 1
Transportation Problem

Source	Objective				Dummy	Supply
	D_1	D_2	...	D_n		a_n
S_1	X_{11} C_{11}	X_{12} C_{12}	... ...	X_{1n} C_{1n}	0	a_1
S_2	X_{21} C_{21}	X_{22} C_{22}	... ...	X_{2n} C_{2n}	0	a_2
...	... ...	... ...	... ...	... ...	0	...
S_m	X_{m1} C_{m1}	X_{m2} C_{m2}	... ...	X_{mn} C_{mn}	0	a_1
Demand b_j	b_1	b_2	...	b_n		$\sum_{i=1}^{m} b_j > \sum_{j=1}^{n} a_i$

2.1 Metode Modifikasi ASM

The steps of the modified ASM method are as follows:

1. Create a transportation table
2. Observe wheter the transportation problem is a balanced or unbalanced. Add a *dummy* row with an initial cost of 0 to absorb the excess. $\Sigma b_j - \Sigma a_i$.
3. Reduce the transportation table using row reduction, if a *dummy* row was added, continue with column reduction.
4. Perform row reduction by subtracting each row entry from the smallest cost in that row.
5. Add or assign index e. The index e for each sel-ij with a value $0, e$ is the sum of the numbers 0 in the-i row and- j column, excluding the 0 chosen in the sel-ij.
6. Allocation is done by selecting number 0 with the smallest index e and allocation the largest possible amount, considering production capacity and demand. If there are multiple cells with the same smallest index e, then the sum of the $c_{ij} = c_{ij} - u_i - v_j$ on i-th and k j-th column for each of these sel-ij is calculated. The largest possible amount is then allocated to the cell with the largest sum. If there is still a tie, the sel-ij with the same smallest index e and the smallest average of production capacity and demand is chosen.
7. For subsequent calculations, a new transportation table is created, ignoring rows or columns where demand or supply has been met, it is then cheked whether the new transportation table has at least one value 0 in each row and column. If not, return to step (5).
8. Steps (6) end (7) are repeated until all supply and demand are met.
9. This result in a minimum cost solution or an initial feasible solution. This method is denoted as Minimum $Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}$.

2.2. Metode Stepping Stone

The steps of the stepping stone method are as follows

1. Select an empty cell to improve. Starting from it, trace aclosed path until it returns to an empty cell. This path can move vertically or horizontally through used cells, and it can skip over any cells, regardless of whether they are empty or occupied.
2. To calculate, start by placing a (+) sign in the unused cell. Then, alternately place (+) and (-) signs along the closed path you've just traced.
3. For each cell marked with a (+), calculate by summing the unit costs.
4. Subtract the unit costs of all cells marked with a (-) (Zulkarnain, Lubis, & Cipta, 2024).

3. Result and Discussion

The data collected represents Crude Palm Kernel Oil (CPKO) sales from November 2024 to April 2025. This includes CPKO inventory data from each site for six months, CPKO demand data at each destination for six months, and transportation costs totaling Rp 672,336,000.00. PT Agrojaya Perdana uses several sites to distribute CPKO and meet the demands of various factories (customers). This is shown in the following table (which is missing from this text).

Table 2.

Production Capacity Data

No	Factory	Storage Capacity (ton)
1	Site A	3.000
2	Site B	4.000
	Quantity	7.000

The demand data from each site to each consumer company is shown below:

Table 3.

Demand Data

No	Company	Demand (ton)
1	PT Soci Mas	400
2	PT Pacific Medan Industri	400
3	PT Multimas Nabati Asahan	100
4	PT Unilever Oleochemical Indonesia	1.432
5	PT Musim Mas	2,800
6	PT Domas Agrointi Prima	1600
	Quantity	6.732

Transportation cost data from each site to each destination is shown below:

Table 4.

Distribution Cost Data

From/to	PT Soci Mas	PT Pacific Medan Industri	PT Multimas Nabati Asahan	PT Unilever Oleochemical Indonesia	PT Musim Mas	PT Domas Agrointi Prima
Site A	58.000	58.000	148.000	148.000	58.000	148.000
Site B	55.000	55.000	145.000	145.000	55.000	145.000

Table 5.
Transportation Table

Objective Source	D_1	D_2	D_3	D_4	D_5	D_6	Supply
Site A (S_1)	58000	58000	148000	148000	58000	148000	3000
Site B (S_2)	55000	55000	144000	144000	55000	144000	4000
Demand	400	400	100	1432	2800	1600	7000 6732

Description

D_1 : PT Soci Mas
D_2 : PT Pacific Medan Industri
D_3 : PT Multimas Nabati Asahan
D_4 : PT Unilever Oleochemical Indonesia
D_5 : PT Musim Mas
D_6 : PT Domas Agrointi Prima

Based on the table above, it can be formulated into a mathematical form shown in the following equation.

$$Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \qquad Z = \sum_{i=1}^{2} \sum_{j=1}^{6} c_{ij} x_{ij}$$

Therefore,

$$X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + X_{16} = 3000$$
$$X_{21} + X_{22} + X_{23} + X_{24} + X_{25} + X_{26} = 4000$$
$$X_{11} + X_{21} = 400$$
$$X_{12} + X_{22} = 400$$
$$X_{13} + X_{23} = 100$$
$$X_{14} + X_{24} = 1432$$
$$X_{15} + X_{25} = 2800$$
$$X_{16} + X_{26} = 1600$$

Given the objective function derived from all shipping costs, it can be presented as follows:

$$Z = 58000X_{11} + 58000X_{12} + 148000X_{13} + 148000X_{14} + 58000X_{15} + 148000X_{16}$$
$$+ 55000X_{21} + 55000X_{22} 144000X_{23} + 144000X_{24} + 55000X_{25} + 144000X_{26}$$

After obtaining the objective function as described above, then determine the constraint function shown as follows:

$$\sum_{j=1}^{6} X_{ij} \geq a_i$$

The above shows the constraint function where supply is greater than demand.
Description:

X_{ij} = The amount of oil from plant i to company j

C_{ij} = The transportation cost per ton of oil from plant i to company j

a_i = The amount of oil from plant i

b_j = The amount of oil from company j

3.1 Initial Solution Using the Modified ASM Method

Create a transportation table, then add a dummy column with an initial cost of 0 to absorb excess production capacity. This can be seen in:

Table 6.
Dummy Column

Objective Source	D_1	D_2	D_3	D_4	D_5	D_6	Dummy	Supply
Site A (S_1)	58000	58000	148000	148000	58000	148000	0	3000
Site B (S_2)	55000	55000	144000	144000	55000	144000	0	4000
Demand	400	400	100	1432	2800	1600	268	7000

After adding the dummy column, the transportation table is reduced by reducing each column by its smallest cost.

Table 7.
Reducted Column Results

Objective Source	D_1	D_2	D_3	D_4	D_5	D_6	Dummy	Supply
Site A (S_1)	3000	3000	4000	4000	3000	4000	0	3000
Site B (S_2)	0	0	0	0	0	0	0	4000
Demand	400	400	100	1432	2800	1600	268	7000

Next, the dummy is filled with the largest reduced column value. From the column reduction, the largest reduced value obtained is 4000, so the dummy value is replaced with 4000.

Table 8.
Adding of a Dummy Value

Objective Source	D_1	D_2	D_3	D_4	D_5	D_6	Dummy	Supply
Site A (S_1)	3000	3000	4000	4000	3000	4000	4000	3000
Site B (S_2)	0	0	0	0	0	0	4000	4000
Demand	400	400	100	1432	2800	1600	268	7000

Next, row reduction is performed by subtracting each row entry by its smallest cost.

Table 9.
Reducted Row Result

Objective Source	D_1	D_2	D_3	D_4	D_5	D_6	Dummy	Supply
Site A (S_1)	0	0	1000	1000	0	1000	1000	3000
Site B (S_2)	0	0	0	0	0	0	4000	4000
Demand	400	400	100	1432	2800	1600	268	7000

Column reduction is performed again to ensure at least one 0 value in the dummy column by subtracting each column entry by its smallest cost.

Table 10.
Reducted Column Result

Objective Source	D_1	D_2	D_3	D_4	D_5	D_6	Dummy	Supply
Site A (S_1)	0	0	1000	1000	0	1000	0	3000
Site B (S_2)	0	0	0	0	0	0	3000	4000
Demand	400	400	100	1432	2800	1600	268	7000

Next, index e is assigned to each sel i-j with a value of 0, where index e is the number of 0 in each row i and column j.

Table 11.
Index Assignment

Objective Source	D_1	D_2	D_3	D_4	D_5	D_6	Dummy	Supply

Site A (S_1)	0^4	0^4	1000	1000	0^4	1000	0^3	3000
Site B (S_2)	0^6	0^6	0^5	0^5	0^6	0^5	3000	4000
Demand	400	400	100	1432	2800	1600	268	7000

Next, allocation is performed by selecting the 0 with the smallest index and allocating the cell with the largest possible amount, considering the supply and demand until the supply and demand are met.

Table 12.
Allocation to the Smallest Index

Objective Source	D_1	D_2	D_3	D_4	D_5	D_6	Dummy	Supply
Site A (S_1)	0^4	0^4	1000	1000	0^4	1000	0^3 [268]	3000
Site B (S_2)	0^6	0^6	0^5	0^5	0^6	0^5	3000	4000
Demand	400	400	100	1432	2800	1600	0	7000

Allocation is performed for the next smallest index.

Table 13.
Allocation to the Smallest Index

Objective Source	D_1	D_2	D_3	D_4	D_5	D_6	Dummy	Supply
Site A (S_1)	0^4 [400]	0^4 [400]	1000	1000	0^4 [1932]	1000	0^3 [268]	3000
Site B (S_2)	0^6	0^6	0^5	0^5	0^6	0^5	3000	4000
Demand	0	0	100	1432	868	1600	268	7000

Allocation is performed for the next smallest index.

Table 14.
Allocation to the Smallest Index

Objective Source	D_1	D_2	D_3	D_4	D_5	D_6	Dummy	Supply
Site A (S_1)	0^4 [400]	0^4 [400]	1000	1000	0^4 [1932]	1000	0^3 [268]	0
Site B (S_2)	0^6	0^6	0^5 [100]	0^5 [1432]	0^6 [868]	0^5 [1600]	3000	0
Demand	0	0	0	0	0	0	0	0

Therefore, all supply and demand for Crude Palm Kernel Oil (CPKO) from each PT Agrojaya Perdana site to each demand location are met. The next step is to re-enter the initial transportation costs previously determined.

Table 15.
Allocation

Objective Source	D_1	D_2	D_3	D_4	D_5	D_6	Dummy	Supply
Site A (S_1)	400 58000	400 58000	148000	148000	1932 58000	148000	268 0^{3}	0
Site B (S_2)	55000	55000	100 144000	1432 144000	868 55000	1600 144000	3000	0
Demand	0	0	0	0	0	0	0	0

Using the equation above, the next step is to calculate the total transportation cost:

$$\text{Minimum z} = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij} = C_{11}X_{11} + \ldots + C_{mn}X_{mn}$$

$$\text{Minimum Z} = (C_{11}X_{11}) + (C_{12}X_{12}) + (C_{15}X_{15}) + (C_{17}X_{17}) + (C_{23}X_{23}) + (C_{24}X_{24}) + (C_{25}X_{25}) + (C_{26}X_{26})$$

$$\text{Minimum Z} = (58.000 \text{ x } 400) + (58.000 \text{ x } 400) + (58.000 \text{ x } 1932) + (0 \text{ x } 268) + (144.000 \text{ x } 100) + (144.000 \text{ x } 1432) + (55.000 \text{ x } 868) + (144.000 \text{ x } 1600)$$

$$\text{Minimum Z} = 23.200.000 + 23.200.000 + 112.056.000 + 0 + 14.400.000 + 206.208.000 + 47.740.000 + 230.400.000$$

$$\text{Minimum Z} = 657.204.000$$

The result of applying the ASM method to address the transportation imbalance problem using the modified ASM method is Rp. 657,204,000. This represents a decrease of Rp. 15,132,000 or 2.251%.

3.2 Optimal Stepping Stone Solution

The search for the optimal solution using the stepping stone method is done by continuing the initial solution of the Modified ASM method. There are 6 empty cells.

Table 16.
Stepping Stone Method Solution

Objective Source		D_1	D_2	D_3	D_4	D_5	D_6	Dummy	Supply
Site A		58000	58000	148000	148000	58000	148000	0	3000

(S_1)		400	400 (−)	X	x	1932 (+)	X	268	
Site B (S_2)		55000 X	55000 x (+)	144000 100	144000 1432	55000 868 (−)	144000 1600	 X	4000
Demand		400	400	100	1432	2800	1600	268	7000

Then, find another empty cell and then find the cells passed through, or the stepping stones, which are the closed loops that can be traversed using the Stepping Stone method.

Table 17.

Stepping Stone Method Solution

Objective Source	D_1	D_2	D_3	D_4	D_5	D_6	Dummy	Supply
Site A (S_1)	58000 400 (−)	58000 X	148000 X	148000 x	58000 2332 (+)	148000 X	0 268	3000
Site B (S_2)	55000 X (+)	55000 400	144000 100	144000 1432	55000 468 (−)	144000 1600	 X	4000
Demand	400	400	100	1432	2800	1600	268	7000

The application of the above produces the following table:

Table 18.

Stepping Stone Method Solution

Objective Source	D_1	D_2	D_3	D_4	D_5	D_6	Dummy	Supply
Site A (S_1)	58000 X	58000 X	148000 X	148000 X	58000 2732	148000 X	0 268	3000
Site B (S_2)	55000 400	55000 400	144000 100	144000 1432	55000 68	144000 1600	 X	4000
Demand	400	400	100	1432	2800	1600	268	7000

After applying the Stepping Stone method, the next step is to calculate the total distribution cost after applying the method using the following formula:

$$\text{Minimum Z} = (C_{15}X_{15}) + (C_{17}X_{17}) + (C_{21}X_{21}) + (C_{22}X_{22}) + (C_{23}X_{23}) + (C_{24}X_{24}) + (C_{25}X_{25}) + (C_{26}X_{26})$$

$$\text{Minimum Z} = (2732 \text{ x } 58.000) + (268 \text{ x } 0) + (400 \text{ x } 55.000) + (400 \text{ x } 55.000) + (100 \text{ x } 144.000) + (1432 \text{ x } 144.000) + (68 \text{ x } 55.000) + (1600 \text{ x } 144000)$$

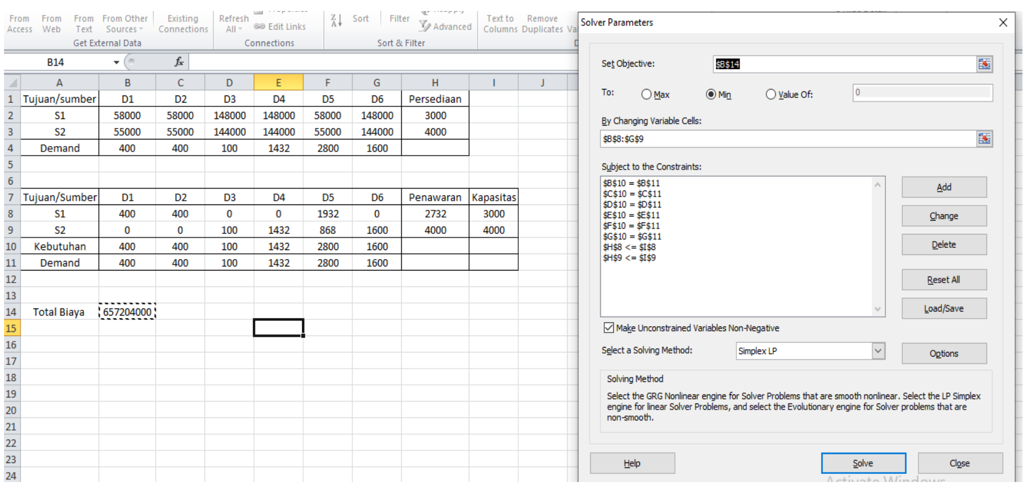
$$\text{Minimum Z} = 158.456.000 + 0 + 22.000.000 + 22.000.000 + 14.400.000 + 206.208.000 + 3.740.000 + 230.400.000$$

$$\text{Minimum Z} = 657.204.000$$

The optimal result of the stepping stone method in addressing the transportation imbalance problem using the modified ASM method is Rp. 657,204,000. This represents a decrease of Rp. 15,132,000 or 2.251%. After calculation using the Excel Solver application, the same result was obtained, namely Rp 657,204,000.00, which can be displayed as follows:

Figure 2.

Excel Solver Result



4. Conclusion

The data obtained from PT Agrojaya Perdana for 6 months, totaling the cost of shipping goods from both sites from November 2024 to April 2025, is Rp 672,336,000.00. The results of the calculations using the Modified ASM and Stepping Stone methods yielded Rp 657,204,000.00, meaning a reduction in distribution costs of Rp 15,132,000.00 or 2.251%. Therefore, the Modified

ASM and Stepping Stone methods are very effective in addressing the transportation imbalance problem faced by PT Agrojaya Perdana.

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