AGROINDUSTRIAL TECHNOLOGY JOURNAL
ISSN : 2599-0799 (print) ISSN : 2598-9480 (online)
Accredited SINTA 3: No.225/E/KPT/2022

An Integrated Approach to Natural Rubber Distribution Using Initial Solution and Optimization Methods

Sigit Susanto[1*]

[1]Rubber and Plastic Processing Technology Study Program, ATK Polytechnic Yogyakarta, Bantul, Yogyakarta, Indonesia, Bantul, Daerah Istimewa Yogyakarta, 55188, Indonesia
[*]Correspondence email: sigitsusanto@politeknikatk.ac.id

Article history:
Submitted: 15 August 2026
Revision: 3 October 2026
Accepted: 12 October 2026
Online: 30 November 2026
DOI :
http://doi.org/10.21111/atj.v10i2.153

ABSTRACT*: An effective distribution system is required to ensure that natural rubber is delivered from suppliers to consumers in the right quantities, at the appropriate time and efficient cost. This study aims to determine an efficient natural rubber distribution plan by integrating initial solution and optimization methods. Phase 1 of the natural rubber distribution planning involves using initial solution methods—specifically the North-West Corner (NWC) and Least Cost (LC) methods. This is followed by Phase 2, which entails optimization using the Stepping Stone method based on the results from the NWC and LC methods. Finally, the total costs are compared to identify the lowest-cost option. The analysis of natural rubber data indicates that optimization using the Least Cost (LC) and Stepping Stone methods yields the lowest distribution cost that is IDR.76,973,532., while the optimization using NWC and Stepping stone yields distribution cost of IDR.313,687,254.*

Keywords: *Distribution optimization; Natural rubber; North-West Corner (NWC); Least Cost (LC); Stepping stone*

1. INTRODUCTION

There are two approaches to the distribution of natural rubber: the initial solution and the optimization approach. The former includes the North-West Corner (NWC) and Least Cost (LC) methods. The latter includes the Stepping Stone method The NWC method is an approach for obtaining an Initial Basic Feasible Solution (IBFS) to a transportation problem by allocating shipments starting from the upper-left (north-west) corner of the transportation table. The LC method is an approach for obtaining an IBFS for a transportation problem by first allocating shipments to the cell with the lowest transportation cost. The term Stepping Stone means an intermediate step toward achieving a particular objective (Arofah & Gesthantiara, 2021).

The Stepping Stone method is used to evaluate and improve an existing transportation solution by examining each unoccupied cell as a stepping stone to determine whether reallocating shipments along a closed path can reduce the total transportation cost (Kanthi & Kristanto, 2020)

Several studies have investigated the NWC, LC, and Stepping Stone methods. One study developed a C#-based program to determine an IBFS for transportation problems using the NWC method. The study explains that the transportation problem is a branch of linear programming that aims to allocate shipments from sources to

destinations efficiently, subject to the condition that total supply and total demand are balanced, or by introducing a dummy source or destination when they are not balanced. The developed program can handle both balanced and unbalanced transportation problems and automatically generate results, thereby reducing calculation errors and the time required for manual computation. The findings indicate that the NWC method is easy to implement, rapidly produces an initial feasible solution, and serves as an effective basis for subsequent optimization, although it does not necessarily yield the optimal solution. Therefore, further optimization methods are required for improvement (Ranasinghe & Rathnayaka, 2021).

Meanwhile, another study examined the optimization of transportation costs for distributing cassava from several plantations in Bogor Regency (Jonggol, Cariu, and Sukamakmur) to a factory in Bekasi Regency, using the NWC and LC methods to determine the most efficient allocation and delivery routes. The main problem addressed in the study was the high distribution cost and the lack of an optimal allocation of shipment quantities and delivery routes. Therefore, a transportation model was employed to minimize transportation costs. Overall, the application of the NWC and LC methods was found to improve distribution efficiency by identifying the minimum transportation cost and the optimal distribution pattern (Haryadi & Hasanah, 2024).

Another study on the NWC method presented the implementation of a quantitative transportation model using the Stepping Stone method to optimize ceramic distribution costs. The initial shipment allocation generated using the NWC method was evaluated through two iterations to obtain the minimum-cost solution. The results showed that the optimal shipment allocation reduced the company's total logistics costs (Rini et al., 2024).

Meanwhile, another study on the Stepping Stone method focused on minimizing the distribution costs of imported sports shoes. A quantitative approach was first used to evaluate the conventional shipment allocation using the NWC method. Subsequently, the final optimization was performed using the Stepping Stone method, which successfully reduced the total distribution cost (Tambunan et al., 2024).

Meanwhile, another study examines the Transportation Problem (TP) as a special case of the Linear Programming Problem (LPP). Essentially, the TP focuses on transporting goods from sources to destinations at the lowest possible cost. It covers the mathematical formulation of primal-dual models and the complementary slackness conditions that aid in analyzing basic feasible solutions. There are three primary methods for obtaining an Initial Basic Feasible Solution: the Northwest Corner Rule (NWC), the Least Cost Method (LCM), and Vogel's Approximation Method (VAM). Additionally, the document explains the MODI (Modified Distribution) method for finding the optimal solution. It goes further by discussing how to handle cases of degeneracy and how to address Transportation Problems involving specific capacity constraints (Ali et al., 2025).

Meanwhile, another study focused on finding an Initial Basic Feasible Solution (IBFS) for real-world transportation problems and comparing the effectiveness of various methods in determining optimal costs. Researchers tested a new approach—the DSM Method—and compared it against methods such as ASM, the Arithmetic Mean Method (AMM), NWCR, VAM, LCM, Row-Minima, and Column-Minima. The results showed that both the ASM Method and the Arithmetic Mean Method yielded the lowest transportation cost—743. Although the Arithmetic Mean Method is relatively easy to use, the process of determining the solution proved to be more time-consuming than that of the ASM. Consequently, the researchers concluded that the ASM Method is more suitable and efficient for calculating solutions to transportation problems (Sharma & Goel, 2022).

A study was conducted with the objective of optimizing routes and

determining the minimum transportation cost distribution using the Vogel's Approximation Method (VAM) and TCOM-SUM. Both methods were further refined through the stepping-stone test to arrive at the optimal solution for the transportation problem at hand. The analysis results indicate that the optimal transportation cost obtained using the VAM is 357,546, while the TCOM-SUM yields a cost of 488,610, representing a difference of 131,064 (Lubis & Mardiningsih, 2023).

Meanwhile, another study proposes an algorithm for solving a two-criteria transportation problem, aiming to minimize both total cost and total transportation time while satisfying supply and demand constraints. The algorithm calculates an optimal solution by assigning unequal weights to the cost and time criteria—based on the decision-maker's preferences—and employs the stepping-stone method to verify optimality conditions. The analysis results indicate that increasing the priority placed on cost leads to a maximum reduction in transportation costs of 15%; however, this process also results in a 43% increase in delivery time (S. Das, 2022).

On the other hand, there are other studies that aim to compare various traditional and modern methods for obtaining an Initial Basic Feasible Solution (IBFS) to optimize resource allocation and minimize costs in transportation problems. The approaches evaluated include classical methods such as the North-West Corner Method (NWCM), the Least Cost Method (LCM), and Vogel's Approximation Method (VAM), as well as proposed modern techniques like the Modified Distribution Method (MODI), the Unique Weighted Optimization Method (UWOM), the Dynamic Cost Adjustment Heuristic (DCAH), and Advanced Iterative Refinement (AIR). The analysis results indicate that modern methods such as UWOM offer advantages in terms of uniqueness and efficiency for large-scale problems, while the AIR method provides the highest accuracy, with the smallest average optimality gap of 1.0% compared to the other methods (Martha et al., 2024).

Meanwhile, another study was conducted with the objective of determining a basic feasible solution and identifying methods to reach an optimal solution for a balanced transportation problem, by comparing the North-West Corner Method, the Least Cost Method, and Vogel's Approximation Method. The findings indicate that the North-West Corner Method provides a quick solution due to its brief computation, but it yields a poor result as it is far from optimal. In contrast, the Least Cost Method and Vogel's Approximation Method provide superior initial solutions that are close to the optimum, although Vogel's Approximation Method is computationally slower and more time-consuming. In conclusion, the transportation problem serves to determine the quantities to be shipped from various origins to various destinations, such that the total transportation cost is minimized without violating constraints related to supply availability and demand requirements (Bharathi.S & M.Ramy, 2022).

Meanwhile, this study addresses the mathematical formulation of the Transportation Problem, which is a specific structure of a Linear Programming Problem (LPP). To solve it, three alternative procedures for phase 1 are described, along with the MODI method for phase 2, to arrive at an optimal solution. Furthermore, the study also covers the Capacitated Transportation Problem, in which specific capacities are assigned to all routes within the transportation network (Mallia et al., 2021).

Meanwhile, another study presents a synthesis of supply chain optimization concepts using mathematical modeling, applying the Simplex transportation algorithm to minimize total logistics shipping costs. In a case study involving a company with 3 warehouses and 4 customers, the Northwest Corner method or the Minimum Unit Cost method was employed to determine an initial feasible solution. This initial solution was subsequently optimized using the Stepping Stone method, resulting in

a minimum cost of 39,500 monetary units—a saving of 16,000 monetary units compared to the initial solution (Varga et al., 2023).

Meanwhile, another study aimed to optimize the distribution costs for 3 kg gas cylinders at PT. Gemilang Putra Sejati by employing the North West Corner (NWC), Least Cost, and Vogel Approximation Method (VAM), followed by testing with the Stepping Stone method. The research results indicated initial distribution costs of IDR 41,760 using NWC, IDR 34,400 using the Least Cost method, and IDR 33,990 using VAM. Following optimization via the Stepping Stone method, the distribution cost decreased to IDR 30,090; therefore, the use of VAM followed by the Stepping Stone method is recommended to enhance distribution efficiency (Dimasuharto & Subagyo, 2021).

Additionally, a study conducted by Riandari and Sihotang (2025) compared the North West Corner (NWC) method, the Modified Distribution Method (MODI), and the Stepping Stone method for optimizing distribution costs, utilizing data simulation and Python programming. The research results indicate that an initial cost of 540 units could be reduced to 425 units through preliminary optimization, and further to 410 units after three iterations, resulting in savings of approximately 24%. The MODI method proved more efficient in terms of calculation, while the Stepping Stone method facilitated the tracking of cost changes via closed paths to arrive at an optimal solution (Riandari & Sihotang, 2025).

Meanwhile, another study proposes a new and efficient method called the Least-looping stepping-stone based ASM (LS-ASM) for solving both crisp transportation problems (crisp TPs) and triangular intuitionistic fuzzy transportation problems (TIFTPs). Unlike the traditional stepping-stone method, LS-ASM processes only a select few non-basic cells under specific conditions, thereby successfully minimizing computational load. Testing across various case studies demonstrates that LS-ASM outperforms comparative algorithms—such as the MODI method and the original ASM—by providing optimal solutions while requiring less computational effort (K. N. Das et al., 2021).

On the other hand, there is a study that aims to find an optimal solution for fuzzy transportation problems by applying a magnitude method for defuzzification, constructing an Entire Contingency Cost Table (ECCT), and utilizing standard deviation for optimal allocation. Based on numerical testing, the proposed method has been shown to yield lower minimum transportation costs—specifically 302.87 in Example 1 and 71.75 in Example 2—when compared to conventional methods such as the North West Corner, Matrix Minima, and Vogel's Approximation methods. In conclusion, this new approach provides a more optimal solution with a straightforward computational process and reduced time complexity; furthermore, it can be applied to various other types of problems, such as assignment and transshipment problems (Sikkannan & Shanmugavel, 2021).

Meanwhile, another study aimed to examine the practical application of a transportation model at Otebu Investment Limited in Idah, Kogi State. The primary method employed by the company was Vogel's Approximation Method (VAM), with other transportation methods also illustrated to justify the selection of this particular approach. The research findings indicate that the effective implementation of a transportation model helps minimize transportation costs while simultaneously boosting the company's revenue (Samson, 2024).

Although the Initial Basic Feasible Solution (IBFS) methods such as Northwest Corner (NWC) and Least Cost (LC) have proven to be effective and quick in generating initial solutions for commodity distribution that is both in balanced and unbalanced conditions using computing systems (such as C#-based programs) that is these methods have fundamental limitations. The main gap lies in the inability of the IBFS method to

guaranty optimal cost efficiency because its allocation has not been tested against closed paths. On the other hand, the use of optimization methods such as Stepping Stone independently cannot proceed without an accurate IBFS as the initial foundation. Therefore, there is a gap in integrating or comparing the effectiveness of the transition from the initial NWC/LC solution to the Stepping Stone optimization phase, specifically in the case of natural rubber distribution, in order to achieve maximum distribution cost efficiency.

The efficiency of transportation allocation in the distribution of natural rubber is a crucial aspect that directly affects the total operational costs. The conventional approach using IBFS methods, such as Northwest Corner (NWC) and Least Cost (LC), indeed offers ease of implementation and speed in generating initial operational solutions computationally. However, this approach does not consider the evaluation of unoccupied cells, often resulting in sub-optimality that triggers waste in the distribution budget. To achieve true financial efficiency, the initial solution must be re-optimized using the Stepping Stone method through the relocation of shipments along the closed path. Therefore, this research focuses on addressing the efficiency uncertainty in the IBFS method by applying an optimization algorithm to significantly reduce the total transportation cost in natural rubber distribution. In other word, this research gap is integration and comparison of NWC + Stepping Stone and LC + Stepping Stone for natural rubber distribution. So, the research objective aims to compare two integrated transportation approaches, NWC + Stepping Stone and LC + Stepping Stone, for minimizing the total distribution cost of natural rubber.

2. MATERIALS AND METHODS

This study follows the classical transportation problem-solving framework, beginning with problem formulation and ending with the optimization process. The research methodology consists of the following steps:

1. Problem Formulation: A mathematical model of the transportation problem is formulated by defining the supply, demand, and transportation cost parameters between locations (Vanshika, 2025).

Decision variables:

x_{ij} = amount of natural rubber shipped from source i to destination j (kg) with $i = 1,2,\dots,m$,

$j = 1,2,\dots,n$

$x_{ij} \geq 0$,

Example:

x_{11} = amount of natural rubber from source S1 to destination D1 (kg)

x_{12} = amount of natural rubber from source S1 to destination D2 (kg)

x_{21} = amount of natural rubber from source S2 to destination D1 (kg)

Transportation cost parameters:

c_{ij} = transportation cost (IDR per kg) of natural rubber from source i to destination j

S_i = amount of supply of natural rubber at source i (kg)

D_j = amount of demand of natural rubber at destination j (kg)

Table 1. Transportation Problem Formulation

Source/ Destination	D1	D2	…	Dn	Supply
S1	C11	C12	…	C1n	S1
S2	C21	C22	…	C2n	S2
…	…	…	…	…	…
Sm	Cm1	Cm2	…	cmn	Sm
Demand	D1	D2	…	Dn	

Objective Function:

$$\min Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}.x_{ij} \qquad (1)$$

Supply Constraint:

$$\sum_{j=1}^{n} x_{ij} = S_i \quad (2)$$

Demand Constraint:

$$\sum_{i=1}^{m} x_{ij} = D_j \quad (3)$$

Non-negativity Constraints:

$$X_{ij} \geq 0 \quad (4)$$

2. Initial Solution Using the NWC Method: Obtain an initial basic feasible solution using the **NWC** method, in which allocations are made starting from the upper-left corner of the transportation table (Ranasinghe & Rathnayaka, 2021; Aliu et al., 2022; Chandra, 2016).
   Total supply before adding the dummy source. The actual sources are S1=14,408, S2=48,274, S3=43,238. TotalSupply=14,408+48,274+43,238=105,920. The destination demands are, D1=31,377, D2=237,694, D3=163,446. TotalDemand=31,377+237,694+163,446=432,517. Before adding the dummy source:105,920<432,517. The shortage =432,517-105,920=326,597. Thus, the original transportation problem is unbalanced because Total Supply<Total Demand. A dummy source with a supply of 326,597 units is therefore introduced. The dummy source is not an actual natural rubber supplier. It is an artificial source used to mathematicallny balance the transportation problem. The dummy source represents the portion of demand that cannot be supplied by the actual sources. Its transportation costs are set to zero. Thus, the dummy row can be seen at Table 2.

   The zero transportation cost does not mean that physically transporting natural rubber from the dummy source costs zero. Rather, it indicates that the dummy source is not a real shipment. It is simply a balancing mechanism.
3. Optimization Using the Stepping Stone Method: The initial solution obtained from the NWC method is optimized using the Stepping Stone method. This procedure evaluates the closed path associated with each non-basic cell and calculates the resulting cost changes until the optimal solution is achieved (Tambunan et al., 2024).

The stepping-Stone method is an iterative algorithm used in linear programming to find an optimal solution to transportation problems. The process of evaluating and improving the solution follows the systematic steps below:

1. Evaluation of Non-Basic Cells (Closed Loop)**:** Each non-basic cell (an empty cell with no allocation) is evaluated individually by constructing a closed loop. The loop moves horizontally and vertically, starting from the non-basic cell being evaluated and turning only at basic cells (cells containing allocations) before returning to the initial non-basic cell.

2. Calculation of Cost Change (Opportunity Cost): Along the closed loop, plus \((+)\) and minus \((-)\) signs are assigned alternately to the cell costs, starting with a plus \((+)\) sign at the non-basic cell being evaluated. The algebraic sum of these costs produces the improvement index or *opportunity cost* for that cell, indicating the change in total cost per unit if the allocation is shifted to that cell.

3. Reallocation: If a non-basic cell has a negative improvement index, indicating that reallocating shipments to that cell would reduce the total cost, a certain quantity of the commodity is reallocated to that cell. The quantity reallocated is determined by the minimum allocation among the cells marked with a minus \((-)\) sign along the closed loop. This reallocation process is repeated as long as an improvement opportunity remains.

<u>Optimality Criterion</u>

The Stepping-Stone procedure is terminated when the following optimality criterion is satisfied: Optimality Criterion: The transportation solution is considered optimal, and the procedure is terminated if and only if

all improvement indices (*opportunity costs*) for all non-basic cells are non-negative (greater than or equal to zero, i.e., \(\geq 0\)). When this condition holds, no empty cell can reduce the total transportation cost if we allocate to it, indicating that the minimum feasible transportation cost has been obtained.

4. Initial Solution Using the LC Method: Obtain an initial basic feasible solution using the LC method by allocating the maximum possible quantity to the cell with the lowest unit transportation cost (Atikah et al., 2024).
   Allocation Rule
   Once a cell (i,j) with the lowest transportation cost has been selected, the quantity allocated to that cell is determined as:
   Allocation = min(Si,Dj)
   where:
   (Si) = remaining supply capacity at source (i)
   (Dj) = remaining demand at destination (j)

   After the allocation is made:
   Reduce the supply and demand by the allocated quantity.
   Eliminate row (i) if its remaining supply becomes 0, or eliminate column (j) if its remaining demand becomes 0.

Tie-Breaking Procedure

If two or more cells have the same lowest unit transportation cost, select a cell according to the following priority hierarchy to facilitate the solution process and minimize the number of subsequent iterations.

Priority 1: Maximum Allocation
Select the cell that allows the largest quantity of units to be allocated :
(max(min(Si,Dj))).
This criterion is prioritized because it directly exhausts the largest available supply or demand, thereby accelerating the elimination of a row or column from the matrix.

Priority 2: Simultaneous Row and Column Elimination
If the maximum possible allocation is the same, select the cell for which the remaining supply and demand are exactly equal (Si=Dj). This allocation eliminates one row and one column simultaneously, substantially reducing the size of the remaining transportation matrix.

Priority 3: Matrix Position (Arbitrary/Deterministic Rule)
If all the criteria above result in a tie, select the cell located in the upper-leftmost position, based first on the smallest row index (i), followed by the smallest column index (j). This rule is arbitrary but provides a standardized procedure, particularly for computer-based implementation, so that the algorithm produces consistent results.

5. Optimization Using the Stepping Stone Method: The initial solution obtained from the LC method is further optimized using the Stepping Stone method. This procedure evaluates the closed path associated with each non-basic cell and calculates the resulting cost changes until the optimal solution is achieved.

   The performance of each integrated approach is evaluated based on the final total transportation cost. Specifically, the study compares the total transportation costs obtained from the NWC + Stepping Stone and LC + Stepping Stone combinations ('Aisyah & Syaichu, 2024; Obele & Nwagor, 2021). The complete research method is illustrated in **Figure 1**.

2.1. Figure and Table

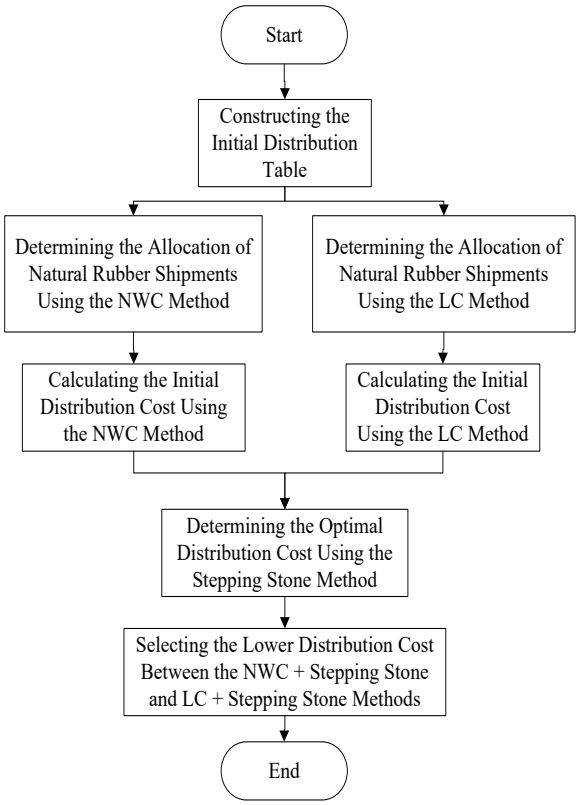


Figure 1. Research Method

Table 2. Initial Transportation Matrix

Sources	D1	D2	D3	Supply
S1	969	762	684	**14408**
S2	714	348	243	**48274**
S3	1416	1281	1143	**43238**
Dummy	0	0	0	**326597**
Demand	**31377**	**237694**	**163446**	**432517**

Table 3. NWC Results

Sources		D1	D2	D3	Supply
S1		14408	0	0	**14408**
S2		16969	0	31305	**48274**
S3		0	148791	88903	**43238**
Dummy		0	88903	43238	**326596**
Demand		**31377**	**237694**	**163446**	**432517**

Distribution cost using the NWC method= IDR.969/kg x 14408kg + IDR. 714/kg x 16969kg + IDR. 1281/kg x 148791kg + IDR. 243/kg x 31305kg + IDR. 1143/kg x 99803kg = IDR. 325,901,733

Table 4. Distribution Results Using the North-West Corner (NWC) and Stepping Stone Methods

Sources	D1	D2	D3	Supply
S1	0	14408	0	**14408**
S2	0	48274	0	**48274**
S3	0	103078	134616	**43238**
Dummy	31377	71934	28830	**326596**
Demand	**31377**	**237694**	**163446**	**432517**

Distribution Costs Using the NWC and Stepping Stone Methods = IDR. 762/kg x 14408kg + IDR. 348/kg x 48274kg + IDR. 1281/kg x 103078kg + IDR. 1143/kg x 134616kg = IDR. 313,687,254

Tabel 5. Distribution Result Using the LC Method

Sources	D1	D2	D3	Supply
S1	0	0	14408	**14408**
S2	0	0	48274	**48274**
S3	0	43238	0	**43238**
Dummy	31377	194456	100764	**326596**
Demand	**31377**	**237694**	**163446**	**432517**

Distribution cost using the LC method = IDR. 1281/kg x 43238kg + IDR. 684/kg x 14408kg + IDR. 243/kg x 48274kg = IDR.76,973,532

Table 6. Distribution Results Using the LC and Stepping Stone Methods

Sources	D1	D2	D3	Supply
S1	0	0	14408	**14408**
S2	0	0	48274	**48274**
S3	0	43238	0	**43238**
Dummy	31377	194456	100764	**326596**
Demand	**31377**	**237694**	**163446**	**432517**

Distribution cost using LC+Stepping stone methods= IDR. 1281/kg x 43238kg + IDR. 684/kg x 14408kg + IDR. 243/kg x 48274kg = IDR.76,973,532

3. RESULTS AND DISCUSSION

3.1 Initial transportation condition

So, the results in Table 2 show that the distribution problem focuses on three supply sources—S1, S2, and S3—and three destinations—D1, D2, and D3. There's quite a gap here: the total actual supply is 105,920 kg, while demand shoots up to 432,517 kg. That's way out of balance, so the model adds a dummy source of 326,596 kg to even things out. This imbalance isn't just a technicality—it's crucial for optimization results. The dummy source acts as a mathematical fix when supply falls short of demand. It doesn't show where actual goods come from, but highlights how much demand goes unmet by the real sources. Looking at the initial cost matrix, each supply-to-destination pair has its own transport cost. The cheapest route is S2 to D3 at IDR.243, then S2 to D2 at IDR.348, and S1 to D3 at IDR.684. These cost differences really matter—they help shape how distribution gets allocated to minimize the total transport expense.

3.2 The results of North-West Corner method

The North-West Corner (NWC) method generates an initial solution based on cell positions in the transportation matrix, without considering transportation costs at the initial allocation stage. Based on Table 3, the NWC allocation distributes 14,408 kg from S1 to D1, 16,969 kg from S2 to D1, and 31,305 kg from S2 to D3, while the allocations from S3 to D2 and D3 correspond to the available capacity.

Because NWC does not consider transportation costs when determining allocations, its initial solution does not necessarily produce the minimum distribution cost. Based on the values presented in Table 3, the recalculated total NWC distribution cost is IDR 338,360,433.

These results indicate that NWC is better regarded as an initial feasible solution than an optimal solution. This is consistent with the nature of transportation problems, where an initial solution must be evaluated and improved using an optimization method such as the Stepping-Stone method.

3.3 Improvement Using the Stepping-Stone Method

Table 4 shows that applying the Stepping-Stone method to the NWC solution produces a different distribution pattern. The resulting allocations are 14,408 kg from S1 to D3, 48,274 kg from S2 to D2, 103,078 kg from S3 to D2, and 134,616 kg from S3 to D3, with the remaining demand fulfilled through the dummy destination. The total distribution cost after optimization is IDR 313,687,254. Compared with the NWC cost calculated from the values in Table 3, this represents a reduction of IDR 24,673,179, or approximately 7.29%.

The reduction indicates that the Stepping-Stone method can evaluate alternative allocations through closed loops and redirect shipments toward more economical route combinations. Thus, combining NWC with Stepping Stone produces a more cost-efficient solution than using the initial NWC solution alone.

The finding also demonstrates that forming an initial feasible solution is not sufficient in a transportation problem. An optimality test is necessary because a feasible allocation does not necessarily yield the minimum transportation cost.

3.4 Results of the Least Cost Method

Unlike NWC, the Least Cost (LC) method uses the lowest transportation cost as the primary basis for determining the allocation. Table 5 shows that the actual allocations concentrate on routes with relatively low unit transportation costs: S2–D3 at 48,274 kg, S1–D3 at 14,408 kg, and

S3–D3 at 43,238 kg. This pattern indicates that when transportation cost is prioritized, available supply is directed to destination D3 because it has the lowest transportation cost from each actual source. Meanwhile, the remaining demand at D1, D2, and D3 is fulfilled through the dummy destination.

Based on the calculation, the total distribution cost using the LC method is IDR 76,973,532. This value is substantially lower than the costs obtained using NWC and NWC followed by the Stepping Stone method. However, this large difference is primarily attributable to the transportation problem's structure, where total supply is substantially lower than total demand. Consequently, a large portion of the demand is assigned to the dummy source at zero transportation cost.

Therefore, the LC result requires careful interpretation. The substantially lower cost does not necessarily indicate greater actual operational efficiency because a large proportion of the demand is fulfilled by the dummy source. In this model, the dummy source is a mathematical device used to balance supply and demand and should not be interpreted directly as a physical shipment with zero transportation cost.

3.5 Comparison of LC and Stepping-Stone Results

Table 6 shows that applying the Stepping-Stone method to the LC solution does not change either the allocation pattern or the total transportation cost. This indicates that the LC solution already satisfies the optimality criterion under the Stepping-Stone evaluation. Therefore, given the cost structure of this transportation problem, the LC solution has a mathematically lower cost than both the NWC solution and the NWC solution improved through Stepping Stone.

Note: The NWC cost was recalculated based on the allocation values presented in Table 3. Compared with NWC, the LC method reduces the mathematical cost by IDR 261,386,901, or approximately 77.25%. Compared with the NWC + Stepping-Stone solution, the LC cost is IDR 236,713,722 lower, or approximately 75.46%.

However, these differences should not be interpreted directly as operational cost savings of 77.25% under actual distribution conditions. The large dummy allocation indicates that 326,596 kg of demand is not covered by the actual sources included in the model. The more important managerial implication is therefore not simply the selection of the method with the lowest mathematical cost, but the adequacy of actual supply capacity.

If the dummy represents demand that must be fulfilled through external sources, the actual distribution cost should include the procurement or transportation costs associated with those external sources. If the dummy cost is set to zero solely to balance the transportation model, the value of IDR 76,973,532 should be interpreted as the transportation cost associated with the actual sources included in the model, rather than the total actual distribution cost.

A summary of the transport cost comparison can be seen in the Table 7.

Table 7. Transportation cost comparison

No	Transportation Method	Cost (IDR)
1	NWC initial solution	325,901,733
2	NWC+Stepping stone	313,687,254
3	LC initial solution	76,973,532
4	LC+Stepping stone	76,973,532

Several studies have investigated distribution methods. One study presented and evaluated three new corner rules—the North-East Corner Rule (NECR), South-West Corner Rule (SWCR), and South-East Corner Rule (SECR)—for obtaining an initial basic feasible solution to transportation problems. These methods were compared with existing approaches, including the NWCR, the LCM, and VAM, through a series of numerical case studies. The findings showed that the NECR and SWCR methods produced lower transportation costs than the NWCR and SECR methods and even compared

favorably with VAM, which is generally regarded as one of the most effective methods for minimizing transportation costs. Nevertheless, the proposed methods did not consistently produce optimal solutions when compared with VAM. The authors recommended the proposed algorithms for business organizations seeking to minimize transportation costs and improve profitability, as they are easy to apply to both balanced and unbalanced transportation problems within limited time constraints (Aliu et al., 2022).

In addition, another study aimed to determine the minimum distribution cost and the optimal shipment routes for transporting cassava from plantations in Bogor Regency to three cassava chip factories in Bekasi Regency. It addresses the problem of high transportation costs. The study employed transportation methods, specifically the NWC and LC methods. The NWC method allocates the maximum possible quantity starting from the upper-left corner of the transportation table until all supplies have been exhausted, whereas the LC method allocates products to the cells with the lowest transportation costs in order to obtain an optimal solution. The results showed that the LC method produced the minimum distribution cost of IDR 5,410,000.00. The optimal distribution plan consisted of shipping 90 tons from Cariu to Muktijaya, 100 tons from Sukamakmur to Cijengkol, 10 tons from Cariu to Ciledug, 140 tons from Jonggol to Ciledug, and 20 tons from Sukamakmur to Ciledug. In addition, the Nearest Neighbor method was applied to determine optimal delivery routes, yielding the routes Jonggol–Muktijaya–Cijengkol–Ciledug, Cariu–Muktijaya–Cijengkol–Ciledug, and Sukamakmur–Muktijaya–Cijengkol–Ciledug (Atikah et al., 2024).

In addition to the two studies discussed above, another study aimed to optimize the distribution cost of rice from Rice Distributor X in Karawang Regency to its agents and, subsequently, to local markets, using the NWC method. This transportation method was selected because of its simplicity in generating an initial solution, although the resulting solution is not necessarily optimal. The study analyzed rice shipment data from July 2019 to determine the most cost-efficient distribution plan. The results showed that the North-West Corner (NWC) method produced an optimal transportation cost of IDR 1,180,000. Although the NWC method is primarily an initial solution method, the study concluded that its application enabled the distributor to reduce transportation costs and minimize financial losses (Dwiyanti et al., 2024).

Meanwhile, another study aimed to determine the minimum-cost distribution schedule for Guinness Malt products from two factories to nine major dealers in Ghana. To achieve this objective, the study employed two linear programming approaches: the NWC and LC methods. These methods were selected for their simplicity and ability to generate good, feasible solutions without requiring complex computations. The findings showed that the LC method produced a distribution schedule with a significantly lower total transportation cost than the NWC method. Therefore, the study recommended adopting the distribution schedule generated by the LC method to minimize the transportation costs of distributing products from the two factories (Obele & Nwagor, 2021).

Meanwhile, another study reviewed the application of transportation models to optimize product distribution chain management, particularly to reduce transportation costs and improve operational efficiency. The study employed the LC and the NWC method to generate initial feasible solutions, which were subsequently refined using the Stepping Stone method. The findings demonstrated that these linear programming methods could produce a minimum-cost distribution schedule. For NOWAS Oil and Gas, the proposed approach reduced the total distribution cost by ₦35 million compared with the initial cost. The study highlights the importance of carefully

analyzing supply and demand constraints to achieve cost savings and ensure optimal resource utilization in the distribution process (Ndubuisi, 2021).

4. CONCLUSIONS AND RECOMMENDATIONS

The North-West Corner method produces an initial solution, but the resulting allocation is not optimal. The allocation process at this stage does not consider transportation costs, which limits its cost efficiency. Based on the calculations in Table 3, the total transportation cost using NWC is IDR 338,360,433. After optimization using the Stepping-Stone method, the cost decreases to IDR 313,687,254, representing a reduction of approximately 7.29%. In contrast, the Least Cost method produces a substantially lower transportation cost of IDR 76,973,532. Applying the Stepping-Stone method does not change the LC allocation or its total cost, indicating that the LC solution is already optimal under the transportation model used in this study. Mathematically, therefore, the Least Cost method produces the lowest transportation cost among the evaluated solutions, both before and after Stepping-Stone optimization.

The NWC+Stepping stone cost is IDR.313,687,254. The LC+Stepping stone cost is IDR.76,973,532. Compared to the NWC + Stepping Stone solution, the LC cost is lower by IDR 236,713,722, or approximately 75.46%.

The findings provide a potential reference for improving transportation-cost efficiency in natural rubber distribution under similar supply and demand conditions. Recommendations for Future Research are comparison with VAM as another initial solution method, validation using the MODI method**,** analysis using different supply–demand scenarios, incorporation of transportation time, product quality deterioration, or capacity constraints, that is relevant to the natural rubber distribution context.

ACKNOWLEDGMENTS

Special thanks are extended to the leadership of Politeknik ATK Yogyakarta based on decree of decision of the director of Politeknik ATK Yogyakarta number 89 of 2026, as well as all colleagues and the entire Politeknik ATK Yogyakarta community, for their assistance in conducting this research.

REFERENCES

Ali, R., Dalimunthe, U., Lestiani, M. E., & Waskito, S. K. (2025). *Optimizing Vaccine Distribution Costs Using Transportation Mod- els : North West Corner and MODI Approaches in the Healthcare Supply Chain of PT Silkargo Indonesia*. *8*(1), 63–69.

Aliu, T. O., Aderinto, Y. O., & Issa, K. (2022). Corner Rules Method of Solving Transportation Problem. *Earthline Journal of Mathematical Sciences*, *10*(2), 305–316. https://doi.org/10.34198/ejms.10222.305316

Arofah, I., & Gesthantiara, N. N. (2021). Optimasi Biaya Distribusi Barang dengan Menggunakan Model Transportasi. *JMT : Jurnal Matematika Dan Terapan*, *3*(1), 1–9. https://doi.org/10.21009/jmt.3.1.1

Atikah, Tiara, & Perdana, S. (2024). *Analisis Biaya Transportasi dalam Pendistribusian Singkong Menggunakan Metode Northwest Corner dan Least Cost*. *6*(2). https://doi.org/10.32877/ef.v6i2

Bharathi.S, D., & M.Ramy. (2022). Comparison of Transportation Problem in Operation Research. *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, *10*(February), 1472–1479. https://doi.org/https://doi.org/10.22214/ijraset.2022.40310

Das, K. N., Das, R., & Acharjya, D. P. (2021). Least - looping stepping - stone

- based ASM approach for transportation and triangular intuitionistic fuzzy transportation problems. *Complex & Intelligent Systems*, *7*(6), 2885–2894. https://doi.org/10.1007/s40747-021-00472-0

Das, S. (2022). Analysing impact of strategies adopted by decision makers on performance parameters of bi-criteria transportation problem. *Int. J. Advanced Operations Management*, *14*(1). https://doi.org/10.1504/IJAOM.2022.10047222

Dimasuharto, N., & Subagyo, A. M. (2021). Optimization of distribution cost of 3 kg gas cylinder at pt gemilang putra sejati using the north west corner, least cost, and vogel approximation method. *International Journal of Economics, Business and Accounting Research (IJEBAR)*, *5*(2), 541–550. https://doi.org/https://doi.org/10.29040/ijebar.v5i2.2428

Dwiyanti, D., Irmayani, D., & Sihombing, V. (2024). Optimal Biaya Pengiriman Beras Menggunakan Model Transportasi Motode North Westh Corner (NWC). *Informatic Media Journal (JUMIN)*, *5*(2), 209–213. http://ejournal.sisfokomtek.org/index.php/jumin%0AOptimal

Haryadi, D., & Hasanah, U. (2024). Comparative Analysis of Transportation Methods in Order to Minimize Distribution Costs. *Almana : Jurnal Manajemen Dan Bisnis*, *8*(3), 574–580. https://doi.org/10.36555/almana.v8i3.2719

Kanthi, Y. A., & Kristanto, B. K. (2020). Implementasi Metode North West Corner Dan Stepping Stone Implementation of North-West Corner Method and Stepping Stone Method for Shipping Goods To the Bimasakti Gallery. *Jurnal Teknologi Informasi Dan Ilmu Komputer (JTIIK)*, *7*(4), 845–852. https://doi.org/10.25126/jtiik.202071625

Lubis, L. A., & Mardiningsih. (2023). Comparison of completion of VAM , TCOM-SUM Transportation problems with Stepping Stone to Determine optimal solutions. *Journal of Physics: Conference Series*, *2421*(0122005), 1–6. https://doi.org/10.1088/1742-6596/2421/1/012005

Mallia, B., Das, M., & Das, C. (2021). Fundamentals of Transportation Problem. *International Journal of Engineering and Advanced Technology*, *8958*(5), 90–103. https://doi.org/10.35940/ijeat.E2654.0610521

Martha, S., Devi, U. M., Rachana, M., Martha, P., Nuthana, M., & Martha, P. (2024). Comparative Study of Existing Initial Basic Feasible Solutions in Transportation Problems. *International Journal for Multidisciplinary Research (IJFMR)*, *6*(6), 1–5.

Ndubuisi, D. P. O. (2021). Application of Transportation Model for Optimal Product Distribution Chain Management. *International Journal of Management & Entrepreneurship Research*, *3*(3), 107–117. https://doi.org/10.51594/ijmer.v3i3.218

Obele, R. E., & Nwagor, P. (2021). *Determining The Minimum Cost of Products Distribution, Using North-West Corner and Least Cost Models*. *3*(1), 76–84.

Ranasinghe, R. M., & Rathnayaka, R. K. M. T. (2021). North West Corner Rule based programming development to find the initial basic feasible solution of transportation problem. *International Conference on Advanced Research in Computing (ICARC-2021)*, 140–144.

Riandari, F., & Sihotang, H. T. (2025). Distribution cost optimization: Comparison of NWC, MODI, and Stepping Stone methods in transportation problems. *International Journal of Basic and Applied Science*, *14*(2), 85–96. https://doi.org/10.35335/ijobas.v14i2.688

Rini, R. S., Vidada, I. A., Istiatik, D. I., Rani, R., & Saridawati, S. (2024). Minimize the distribution cost of tortillas at Corner Kebab using the Stepping Stone method. *Jurnal Orientasi Bisnis Dan Entrepreneurship (JOBS)*, *5*(1), 50–60. https://doi.org/10.33476/jobs.v5i1.4453

Samson, A. (2024). Transportation Model : Review of Its Practical Application in Kogi State , Nigeria. *International Journal of Applied and Scientific Research (IJASR)*, *2*(4), 409–424. https://doi.org/DOI: https://doi.org/10.59890/ijasr.v2i4.1695

Sharma, S. K., & Goel, K. (2022). Analysis of IBFS for Transportation Problem by Using Various Methods. *Matheatics and Statistics*, *10*(4), 741–746. https://doi.org/10.13189/ms.2022.100404

Sikkannan, K. P., & Shanmugavel, V. (2021). Sorting Out Fuzzy Transportation Problems via ECCT and Standard Deviation. *International Journal of Operations Research and Information Systems*, *12*(2), 1–14. https://doi.org/10.4018/IJORIS.202104 01.oa1

Tambunan, A. M., Siswoko, A. P. P., Friansiah, M. A. D., & Paduloh. (2024). Meningkatkan efisiensi biaya sepatu olahraga menggunakan model logistic stepping stone. *Edu Research Indonesian Institute For Corporate Learning And Studies (IICLS)*, *5*(1), 70–80.

Vanshika. (2025). The transportation problem. *Data Science and IOT Management System*, *4*(1), 24–27.

Varga, I. E., Emil, G., & Mures, T. (2023). Mathematical models used in the optimizations of supply chains. *Acta Marisiensis. SeriaTechnologica*, *20*(2), 27–31. https://doi.org/10.2478/amset-2023-0005