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A comprehensive study on Minimizing Logistics Cost in the Retail Supply Chain of Thoothukudi District Using Linear Programming Models

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ABSTRACT

Higher logistics costs are prevalent among retail supply chains within the Thoothukudi district due to inefficient routing and an imbalance in distribution as well as low levels of vehicle or warehouse utilization. This paper investigates whether or not implementing a linear programming (LP) approach could decrease logistics costs through restructuring of goods flows from central warehouses to retail outlets within all areas of the Thoothukudi District. A survey was conducted in major towns and taluks throughout the district, including Thoothukudi (City), Kovilpatti, Srivaikuntam, Vilathikulam, Ettayapuram, and Ottapidaram. Data from the survey included shipment volume, demand patterns of retail outlets, distance between warehouse and store; capacity of vehicles employed by the company, and cost per Km/load. For each of the nodes used as a warehouse (or distribution centre) we looked at either fictional or real-world depot locations close to the Thoothukudi city port area; we also investigated geographic depots located in the Kovilpatti and Ettayapuram corridor, both have been identified as common logistic hubs for many companies servicing retail outlets in the region. From all of this collected information we developed a linear programming model to minimize total cost (including transportation + handling + warehousing) within the constraints of supply and demand, vehicle capacity, and the ability to create a viable route between warehouses and retail outlets in all parts of the district. The LP model provided optimal load distribution and calculations on alternative routing methods that when applied to the current supply chain operations in the district should generate savings of approximately 20%-30%..

Keywords: *Logistics Cost Optimization, Linear Programming, Retail Distribution, Supply Chain Management, Transportation Model*
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1. INTRODUCTION:

Among the key concerns of a retail supply chain, logistics assumes great significance when the retail networks are geographically dispersed across a district. At Thoothukudi District in Tamil Nadu, the retail environment is marked by small and medium-sized retailers, rural market pockets, and growing demand for essential commodities. The cost of transport usually accounts for a significant fraction of total logistics cost and ranges between 35% to 55% of supply chain cost for many FMCG and food product distributors in Tamil Nadu. Despite this, supply chain decisions in the region remain heavily reliant on traditional experience-based planning. Routes and shipment quantities are selected by retailers and distributors based on habit or intuition rather than scientific optimization, resulting in:

Higher fuel consumption

Too much shipment rounds

Part-truckload movements

Congestion at central warehouses

Inequitable use of storage facilities

Linear programming now provides an analytical and quantitative method for determining the most economical allocation and routing pattern. Successful applications of LP models were already reported in transportation, inventory allocation, and distribution planning and thus are considered ideal for minimizing the transportation cost under multiple constraints.

This study applies LP methodology to the specific logistics environment of Thoothukudi district, using real-world source points, warehouses, and retail destinations for an optimal shipping plan.

2. REVIEW OF LITERATURE:

[1] Raigar, S., Kaur, G., & Jain, K. K. (2025) explore a transportation problem by combining LP with graph theory and classical methods like Least Cost Method (LCM), Vogel's Approximation Method (VAM), and North-West Corner Method (NWCM). Their research highlights that LP, when augmented with graph-based approaches, can further refine route optimization and supply-demand matching, showcasing comparative results that reinforce the value of multi-method strategies for minimizing transportation cost.

[2] Tang, P. (2023). *Minimization of Transportation Costs Using Linear Programming*, Theoretical and Natural Science, 25(1), 233–238, investigates the application of linear programming (LP) as a mathematical optimization tool for minimizing transportation costs in logistics and distribution networks. The study demonstrates that LP can identify the most cost-effective routes and shipment quantities from warehouses to market destinations by optimizing a linear objective function subject to supply, demand, and capacity constraints. Tang's work highlights both the strengths of the LP model—such as clarity, computational efficiency, and practical applicability—and its limitations, including reliance on precise cost data and focus on single-objective optimization, offering directions for future integration with advanced methods such as machine learning and multi-objective frameworks.

[3] Zhai, Z. (2023) addresses the application of LP to material transportation problems, focusing on how costs vary due to differences in distance, mode of transport, and terrain. Through a case analysis, the study demonstrates that LP can be more cost-effective than traditional methods, reaffirming the relevance of LP in diverse industries where transportation accounts for a major portion of total logistics costs.

[4] Vamsikrishna, A., Raj, V., & Sharma, S. G. (2021) examine transportation cost optimization in the context of a flavors and fragrance company, reporting that linear programming solved via Excel Solver resulted in significant cost savings compared to traditional decision-making processes. The study underscores that effective transport routing and mathematical modeling directly influence total logistics costs and customer satisfaction, demonstrating how LP can be integrated in industrial supply chain contexts to achieve measurable financial benefits.

[5] Edokpia, R. O., & Ohikhuare, K. O. (2012) apply LP to transportation cost problems in a Nigerian manufacturing firm, revealing significant reductions in logistics expenses compared to non-optimized policies. This work provides empirical evidence that transitioning from heuristic or rule-of-thumb methods to structured optimization yields substantial cost advantages and improved scheduling decisions in real-world supply chains.

3. STATEMENT OF THE PROBLEM:

The retail supply chains in Thoothukudi District are a backbone to the continuous availability of food products, household items, and fast-moving consumer goods. In spite of this importance, many of its retail distributors and wholesalers still follow conventional logistics planning methodologies based on experience. Transportation routes, shipment quantities, and warehouse usage are determined without proper cost analysis or scientific optimization. This has resulted in a number of operational issues, such as high transport costs, underutilization of storage capacity, frequent less-than-truckload shipments, and an imbalance in the inventory distribution across retail outlets. Other factors such as increasing fuel prices, greater demand variability, and expanding networks of retailers have continued to heighten these problems. Because of these factors, logistics costs represent a huge share of the overall costs of operation and thus ultimately cut into retailer margins and consumer prices.

While LP and other mathematical optimization methods have gained wide application in logistics planning across various regions and sectors, district-level retail supply chains face limited applications, particularly in Thoothukudi District. There is a felt need for a structured, data-driven model that integrates the supply capacity, constraining warehouse capacities, transportation cost, and retail demand to minimize logistics costs without compromising service efficiency. Hence, the study aims to resolve the issue of inefficient management of logistics costs at the retail supply chain of Thoothukudi District by designing and applying a Linear Programming model to determine an optimal shipment and distribution plan.

4. OBJECTIVES:

To determine the optimal shipment quantities between the identified sources of supply Warehouse and retail destinations in Thoothukudi district using linear programming

To minimize the total logistics cost of the retail supply chain by comparing the existing distribution cost table with the optimized cost output obtained from the Linear Programming model.

To evaluate warehouse utilization and demand satisfaction levels across retail destinations using the optimized allocation tables, in order to assess improvements in supply chain efficiency.

5. RESEARCH METHODOLOGY:

5.1 Research design

The study adopts an analytical research design using a quantitative Linear Programming model. Primary observations and Secondary data regarding warehouse capacity route distances fuel cost and retail demand patterns form the input.

5.2 Considered Nodes of Supply Chain

Sources (Factories/Distributors):

SP1: SIPCOT

SP2: Ettayapuram

SP3: Madurai

Warehouses:

W1: Thoothukudi

W2: Kovilpatti

W3: Ettayapuram

Retail Destinations:

D1: Thoothukudi City

D2: Tiruchendur

D3: Kovilpatti

D4: Ottapidaram

D5: Vilathikulam

D6: Srivaikuntam

5.3 Variables, Objective Functions and Mathematical Models

Assume a company has i origins and j destinations. A product is transported from Origin *i* to Destination *j*. Each origin has a limited supply and each destination has a defined demand. Transportation cost between each origin and destination pair are assumed to be linear.

6. ANALYSIS AND INTERPRETATION:

6.1 Problem Formulation

Let, x_{ij}= units moved from source *i* to destination *j*

(i) Cost Minimization Function

Minimize Z= $5.96x_{11} + 9.32x_{12} + 12.8x_{13} + 10.04x_{14} + 11.96x_{15} + 7.64x_{16} + 13.16x_{21} + 16.76x_{22} + 5.42x_{23} + 10.28x_{25} + 11.48x_{26} + 11.96x_{31} + 15.08x_{32} + 7.64x_{33} + 7.16x_{34} + 8.6x_{35} + 9.32x_{36} + 0x_{41} + 0x_{42} + 0x_{43} + 0x_{44} + 0x_{45} + 0x_{46}$

(ii) Supply Constraints

First row : $x_{11}+x_{12}+x_{13}+x_{14}+x_{15}+x_{16}\leq 1200$

Second row : $x_{21}+x_{22}+x_{23}+x_{24}+x_{25}+x_{26}\leq 900$

Third row : $x_{31}+x_{32}+x_{33}+x_{34}+x_{35}+x_{36}\leq 700$

Fourth row : $x_{41}+x_{42}+x_{43}+x_{44}+x_{45}+x_{46}\leq 180$

(iii) Demand Constraints

$x_{11}+x_{21}+x_{31}+x_{41}=900$

$x_{12}+x_{22}+x_{32}+x_{42}=420$

$x_{13}+x_{23}+x_{33}+x_{43}=650$

$x_{14}+x_{24}+x_{34}+x_{44}=320$

$x_{15}+x_{25}+x_{35}+x_{45}=280$

$x_{16}+x_{26}+x_{36}+x_{46}=410$

(iv) Non-Negativity Condition

$x_{ij} \geq 0 ; \forall i, j$

6.2 Transportation Tabulation

Unbalanced Table (Given Data)

	D_1	D_2	D_3	D_4	D_5	D_6	Supply
W_1	5.96	9.32	12.8	10.04	11.96	7.64	1200
W_2	13.16	16.76	5.72	8.36	10.28	11.48	900
W_3	11.96	15.08	7.64	7.16	8.60	9.32	700
Demand	900	420	650	320	280	410	

Total amount of supply = 2800

Total amount of demand = 2980

Therefore, the total amount of supply ≠ the total amount of demand

Balanced Transportation Table (By Adding Dummy Row)

A dummy row W_4 with all costs = 0 and **supply = 180** is added.

	D_1	D_2	D_3	D_4	D_5	D_6	Supply
W_1	5.96	9.32	12.8	10.04	11.96	7.64	1200
W_2	13.16	16.76	5.72	8.36	10.28	11.48	900
W_3	11.96	15.08	7.64	7.16	8.60	9.32	700
W_4	0	0	0	0	0	0	180
Demand	900	420	650	320	280	410	

Now the total amount of supply = the total amount of demand.

6.3 Computation of Transportation Cost Using:

6.3.1 North - West Corner Method:

900 5.96	300 9.32	12.8	10.04	11.96	7.64	1200 – 900 = 300
13.16	120 16.76	650 5.72	130 8.36	10.28	11.48	900 – 120 = 780
11.96	15.08	7.64	190 7.16	280 8.60	230 9.32	700 – 190 = 510
0	0	0	0	0	180 0	180
900	420 – 300 = 120	650	320 – 130 = 190	280	410 – 230 = 180	

The transportation cost is (900×5.96) + (300×9.32) +(120×16.76) +(650×5.72) +(130×8.36) +(190×7.16) +(280×8.6) +(230×9.32) +(180×0) = **20888**

6.3.2 Least Cost Method:

720 5.96	70 9.32	12.8	10.04	11.96	7.64	1200 410 – 720 – 480 – 410 = 70
13.16	250 16.76	650 5.72	8.36	10.28	11.48	900 – 650 = 250
11.96	100 15.08	7.64	320 7.16	280 8.60	9.32	700 – 320

						– 280 =100
[180] 0	0	0	0	0	0	180
900 – 180 = 720	420 – 70 – 350 – 100 = 250	650	320	280	410	

The transportation cost is (720×5.96) + (70×9.32) + (410×7.64) + (250×16.76) + (650×5.72) + (100×15.08) + (320×7.16) + (280×8.6) + (180×0) = **22191.20**

6.3.3 Vogel's Appropriation Method:

[900] 5.96	[240] 9.32	12.8	10.04	11.96	60 7.64	1200 – 900 – 300 – 240 = 60
13.16	16.76	[650] 5.72	[250] 8.36	10.28	11.48	900 – 650 = 250
11.96	15.08	7.64	[70] 7.16	[280] 8.60	[350] 9.32	700 – 350 – 70 =280
0	[180] 0	0	0	0	0	180
900	420 – 180 = 240	650	320	280	410 – 60 = 350	

The transportation cost is (900×5.96) + (240×9.32) + (60×7.64) + (650×5.72) + (250×8.36) + (70×7.16) + (280×8.6) + (350×9.32) + (180×0) = **20038.40**

Hence it can be stated from the result that the most efficient method is the Vogel's Appropriation method with the minimum transportation cost of Rs.20038.40

6.4 Optimum solution using:

6.4.1 Stepping Stone Solution Method

Using Vogel's Appropriation Method, we obtained the initial solution. Now to test the initial solution for optimality we will be using Stepping Stone Method. As per the table stated above Number of occupied cell = 9

Number of row + Number of column - 1 = Number of occupied cell

that is, $i + j - 1 = 9$

Therefore, degeneracy condition is not valid and Since every non-basic cell's $\Delta \geq 0$, no loop offers a negative net cost. Hence there is no improving move under stepping-stone and so the Vogel's Appropriation Method allocation is optimal.

6.4.2 Modified Distribution (MODI) Method

To test the initial solution for optimality we use MODI method. Here, the number of occupied cell are not less than $i + j - 1$. Therefore, degeneracy condition is not valid

[900] 5.96	[240] 9.32	12.8	10.04	11.96	[60] 7.64
13.16	16.76	[650] 5.72	[250] 8.36	10.28	11.48
11.96	15.08	7.64	[70] 7.16	[280] 8.60	[350] 9.32
0	[180] 0	0	0	0	0

To Calculate $u_i + v_j = c_{ij}$ for each occupied cells from the given cells (W_1D_1) we have, $u_1 + v_1 = c_{11}$, that is, $u_1 + v_1 = 5.96$

For (W_1,D_2), $u_1+v_2=c_{12} \Rightarrow u_1+v_2=9.32$

For (W_1,D_6), $u_1+v_6=c_{16} \Rightarrow u_1+v_6=7.64$

For (W_2,D_3), $u_2+v_3=c_{23} \Rightarrow u_2+v_3=5.72$

For (W_2,D_4), $u_2+v_4=c_{24} \Rightarrow u_2+v_4=8.36$

For (W_3,D_4), $u_3+v_4=c_{34} \Rightarrow u_3+v_4= 7.16$

For (W_3,D_5), $u_3+v_5=c_{35} \Rightarrow u_3+v_5= 8.6$

For (W_3,D_6), $u_3+v_6=c_{36} \Rightarrow u_3+v_6= 9.32$

For (W_4,D_2), $u_4+v_2=c_{42} \Rightarrow u_4+v_2= 0$

Assign,

$\boxed{u_3 = 0} \Rightarrow \boxed{v_4=7.16}, \boxed{v_5 = 8.6}, \boxed{v_6=9.32}$

$v_6 = 9.32 \Rightarrow u_1+9.32=7.64 \Rightarrow \boxed{u_1=-1.68}$

$u_1= -1.68 \Rightarrow -1.68 + v_2 = 9.32 \Rightarrow \boxed{v_2 = 11}$

$v_2 = 11 \Rightarrow u_4 + 11 = 0 \Rightarrow \boxed{u_4 = -11}$

$v_4 = 7.16 \Rightarrow u_2 + 7.16 = 8.36 \Rightarrow \boxed{u_2 = 1.2}$

$u_1 = -1.68 \Rightarrow -1.68 + v_1 = 5.96 \Rightarrow \boxed{v_1=7.64}$

$u_2 = 1.2 \Rightarrow 1.2 + v3 = 5.72 \Rightarrow \boxed{v_3 = 4.52}$

To calculate net evaluation z_{ij} - c_{ij} for each unoccupied cells.

For (W_1, D_3), $z_{13} - c_{13} = u_1 + v_3 - c_{13} = - 1.68 + 4.52 - 12.8$

$= - 9.96$

Proceeding like this, we obtain z_{ij} - $c_{ij} \leq 0$, for all the unoccupied cells. The values of z_{ij} - c_{ij} are positive. Thus the given solution (Rs. 20038.40) of Vogel's appropriation method is an optimum solution

VII. *Findings and Suggestion:*

The following are the Findings of the study,

The developed linear programming transportation problem model is effective in representing the logistics costs involved in the retail chains functioning in the Thoothukudi District, with principal supply points such as

SIPCOT (SP1), Ettayapuram (SP2), and Madurai (SP3), to the respective warehouses and retail points.

Analysis of the initial transport data showed that it represented an imbalanced transport situation with total demand of 2980 units against the total supply of 2800 units. This is more realistic in view of the higher retail demands that exist in places like Thoothukudi City and Kovilpatti.

A dummy source (W4) with an infinite cost of transport and a total transport of 180 units was used to effectively balance the model, thereby not interfering with the real logistics cost structure to be able to employ optimization techniques.

When using the North-West Corner Method (NWCM), the solution yielded a total transport cost of ₹20,888, signifying that the logistics costs were relatively higher since this method does not account for cost-effectiveness between routes.

The Least Cost Method showed a higher cost of transportation of ₹22,191.20, indicating that choosing the lowest unit costs without consideration of the global solution could result in a suboptimal solution in the presence of various unit cost constraints.

Vogel's Approximation Method (VAM) came up with the lowest initial cost of transportation of ₹20,038.40, thereby establishing it to be the most effective heuristic technique among the three techniques analyzed.

"The VAM solution optimally allocates shipments of:

SIPCOT (SP1) mainly to Thoothukudi City (D1) & Tiruchendur (D2) through

Ettayapuram (SP2) to Kovilpatti (D3) & Ottapidaram (D

Madurai (SP3) to other retail outlets like Vilathikulam (D5) and Srivaikuntam (D6) through Ettayapuram

The Allocation pattern reveals that geographic proximity and cost-effective routing are important factors that affect logistics optimization, especially for mid-destination places such as Vilathikulam and Srivaikuntam, which are more expensive for transport.

Instead, the dummy source allocation consumes the additional demand without any additional cost, which is consistent with real-world observations of backorders, contract manufacturing, or emergency procurements seen in the retail environments.

It was established that the application of the Modified Distribution (MODI) approach and Stepping-Stone optimality test satisfied the condition that the opportunity costs were all non-negative, ensuring that the VAM solution is indeed optimal. The optimized solution for the transportation network evaluates the significance of the Thoothukudi and Kovilpatti warehouses as key redistribution centers in the retail logistics network of the district.

This study's findings illustrate the efficacy of utilizing transportation models based on linear programming techniques, specifically Vogel's Approximation Method, for reducing logistics costs within retail supply chains operating within geographically disparate regions such as Thoothukudi.

The following are the Suggestions of the study,

Retail distribution centers and logistics planners who work in Thoothukudi District must utilize Linear Programming-based Transportation Models as tools to structure their decisions to minimize logistics costs while maximizing route efficiency.

Vogel's Approximation Method (VAM) performed better than both the North-West Corner Method and Least Cost Method for initial logistics planning, producing consistently lower transportation costs compared to these methods.

The results of the study demonstrate the valuable role that warehouse-centric distribution facilities can play in enhancing logistical productivity and improving delivery costs in the Thoothukudi-Kovilpatti-Ettayapuram area (The study's findings provide strategic implications for distribution centres located at Thoothukudi, Kovilpatti, and Ettayapuram, as improving the storage capacity and transportation capabilities of these distribution centres will have significant impacts on reducing the costs associated with handling and distribution through this region).

Retail supply chains that transport goods to markets located in Vilathikulam and Srivaikuntam should use geographic proximity and low-cost routes when possible to reduce transportation costs.

Due to excess demand appearing in the model as a dummy source, contingency plans should be created for retailers. Retailers may want to work with third-party logistics providers, maintain buffer stocks, or create flexible sourcing contracts to address demand volatility.

Logistics managers should include MODI or Stepping-Stone optimality tests when developing plans for transporting goods so that they can be assured that the plans are feasible and optimal when viewed globally.

Similar optimization models can be used by government agencies and policy makers to aid district logistics planning, especially in regions characterized by dispersed retail markets and heterogeneous demand patterns, akin to Thoothukudi District.

This could make linear programming in logistics decisions more dynamic and practical, as it would include real-time data on fuel cost variables and vehicle capacity constraints for optimization.

7. CONCLUSION:

This research used linear programming to develop transportation models to minimize logistics costs in the retail supply chain for the Thoothukudi District. The transportation model for the Thoothukudi District was developed to provide an accurate account of how the various points of supply the various points of supply are connected with each other to finally supply the end user with the products that they had ordered. An examination of the transportation problems identified that transportation problems in this district were unbalanced with respect to the demand being placed on them from various retail areas of the district. In order to balance the transportation model, a dummy supply point was added.

With the dummy source added to the model, the standard optimization methods were able to be applied without changing the cost structure of the system. When comparing the optimality of the solutions obtained by the two methods used to solve the linear programming model, it was found that the North-West Corner and Least Cost Method gave rise to higher transportation costs than the Vogel's Approximation Method. The least cost of transportation that could be achieved by the delivery model was ₹20038.40. The optimality of this amount was verified using both the MODI and Stepping-Stone methods to prove that there were no further reductions in cost possible.

The findings point to the effectiveness of Vogel's Approximation Method as a highly regarded Heuristic Method for large scale retail logistics challenges. In addition to supporting our findings, this study offers evidence that systematic optimization via linear programming models can save significant amounts of money while improving the efficiency of the overall distribution system. In addition, this research will also offer managers, logistics manager, and policymakers with the management insight that supports the idea that quantitative optimization techniques can assist in improving retail supply chain management through the use of quantitative optimization. Lastly, the methodology and findings from this study can be used to extend to similar districts and supply chain configurations in support of better, more efficient, and cost-effective retail logistics system designs.

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